MODULE 1. INTRODUCTION TO SCIENCE OF DISASTER

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INTRODUCTION

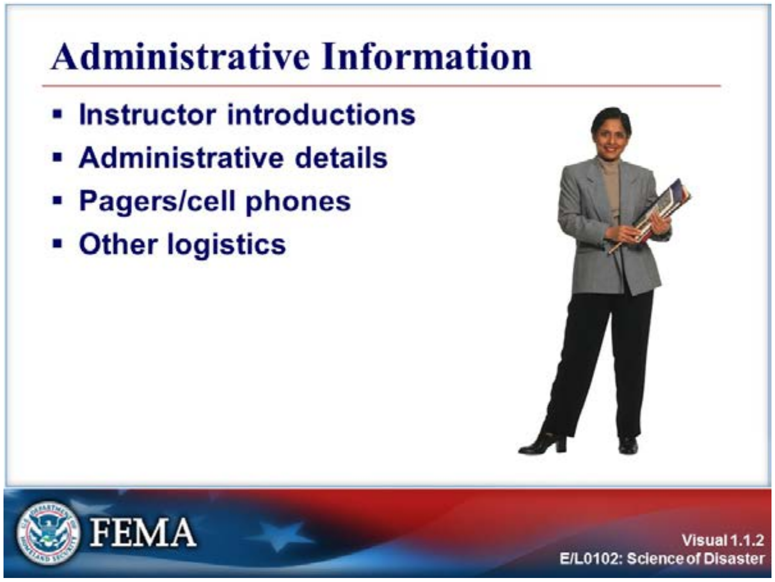
Visual 1.1.1

Key Points

Welcome to E/L0102, Science of Disaster.

INTRODUCTION

Visual 1.1.2

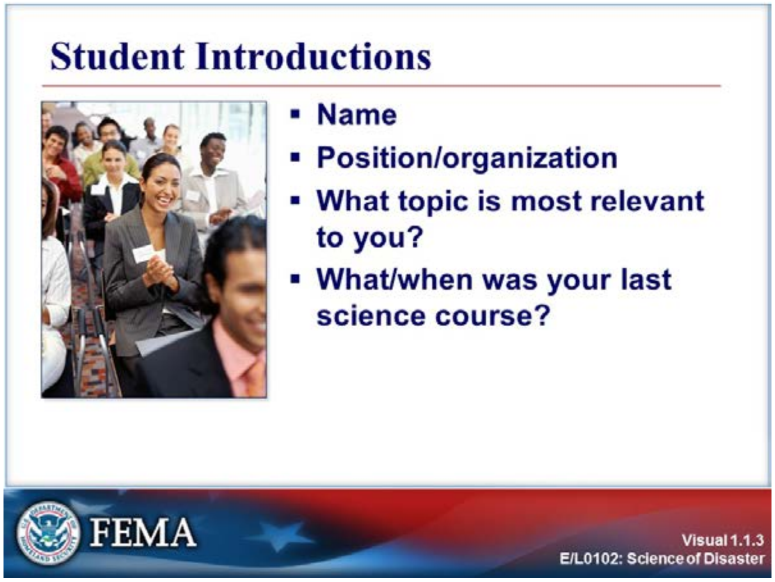


Key Points

Please remember to silence your mobile devices.

INTRODUCTION

Visual 1.1.3

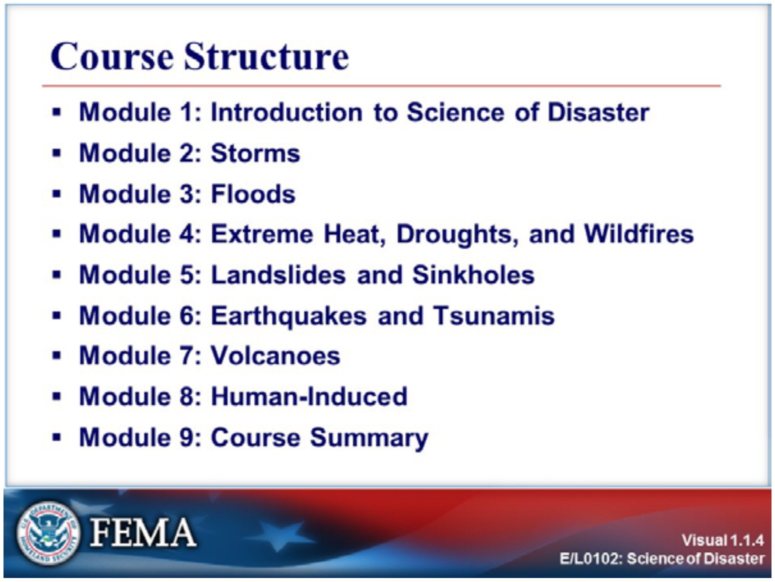


Key Points

You will be given an opportunity to introduce yourself. Please include the information listed on the visual.

COURSE STRUCTURE

Visual 1.1.4



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Course Structure

- Module 1: Introduction to Science of Disaster
- Module 2: Storms
- Module 3: Floods
- Module 4: Extreme Heat, Droughts, and Wildfires
- Module 5: Landslides and Sinkholes
- Module 6: Earthquakes and Tsunamis
- Module 7: Volcanoes
- Module 8: Human-Induced
- Module 9: Course Summary

Key Points

This course will introduce you to scientific concepts and principles in several key areas related to natural and human-caused disasters. It is not possible to cover each and every hazard that might occur. Instead, the course will focus on common and emerging threats that provide a basis for understanding the science of disaster.

COURSE STRUCTURE

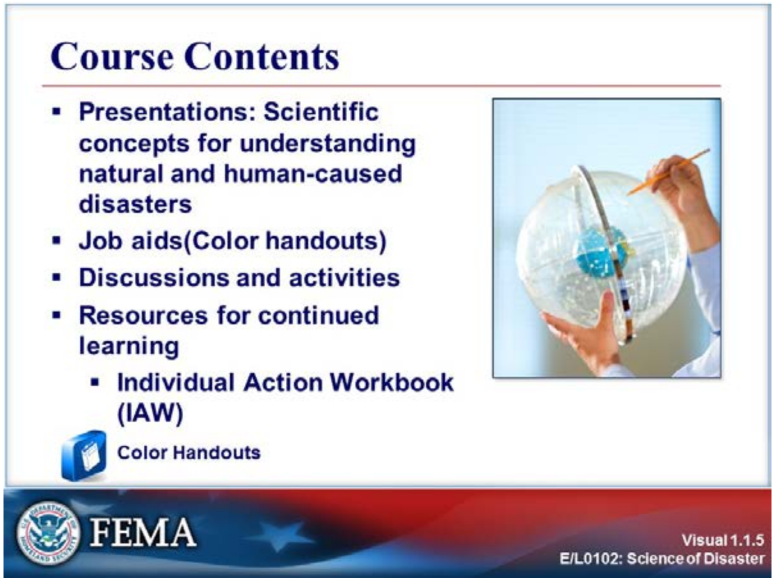
Visual 1.1.4 (Continued)

The course is organized as follows:

- **Module 1: Introduction to Science of Disaster**
- **Module 2: Storms**
  - Unit 1: Atmospheric Science Overview
  - Unit 2: Hurricanes
  - Unit 3: Convective Storms
  - Unit 4: Other Hazardous Weather
- **Module 3: Floods**
- **Module 4: Extreme Heat, Droughts, and Wildfires**
- **Module 5: Landslides and Sinkholes**
- **Module 6: Earthquakes and Tsunamis**
  - Unit 1: Earthquakes
  - Unit 2: Tsunamis
- **Module 7: Volcanoes**
- **Module 8: Human-Induced**
  - Unit 1: Science of Human-Induced Disasters
  - Unit 2: Chemical
  - Unit 3: Biological
  - Unit 4: Explosives
  - Unit 5: Radiation
- **Module 9: Course Summary**

COURSE STRUCTURE

Visual 1.1.5



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Course Contents

- Presentations: Scientific concepts for understanding natural and human-caused disasters
- Job aids (Color handouts)
- Discussions and activities
- Resources for continued learning
    - Individual Action Workbook (IAW)

Color Handouts

Key Points

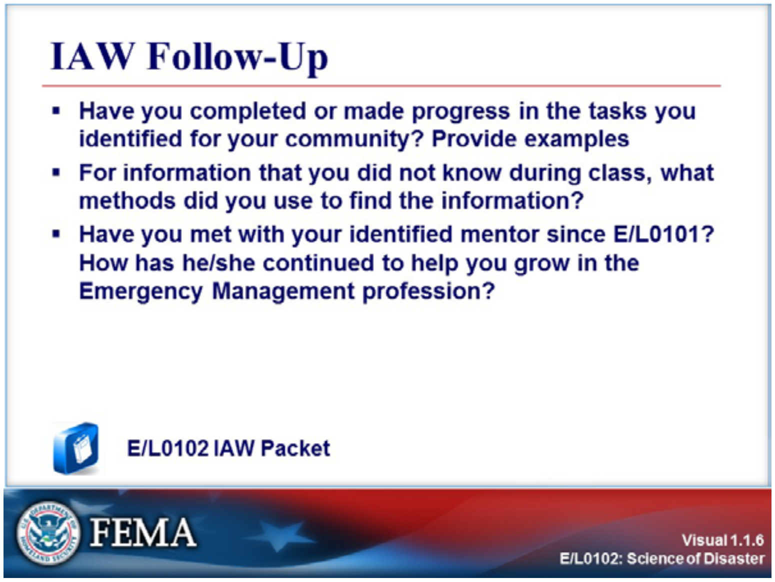
The presentations in this course will provide basic scientific information related to natural and human-caused disasters. Presentations will be supplemented with detailed job aids, provided in the Student Manual.

There will be opportunities to apply these concepts in large-group discussions and table-group activities.

Finally, each unit will identify resources from which you can continue learning about the topic. There is a wide array of resources available to help you learn more about scientific principles underlying disaster hazards and threats, including web-based resources, training, and local experts.

IAW FOLLOW-UP

Visual 1.1.6



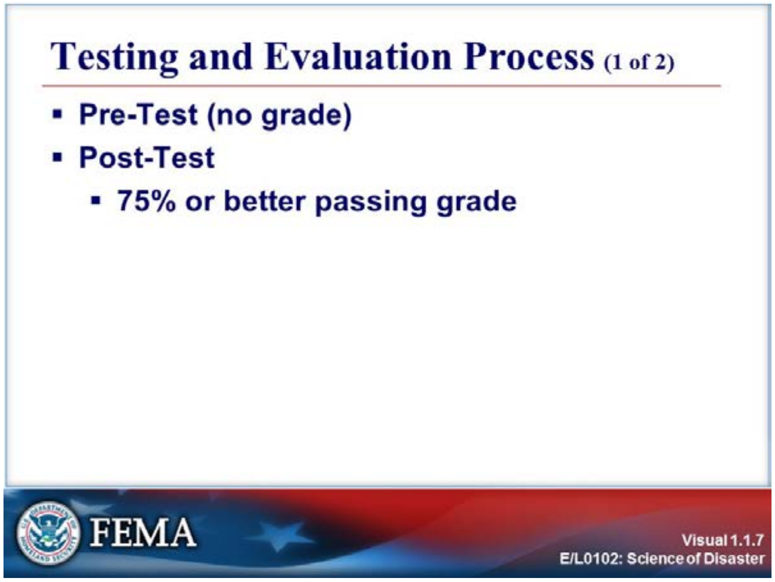
Key Points

Based on the topics, issues, activities, and priorities you identified in the E/L0101 Foundations in Emergency Management and course, discuss the following:

1. Have you completed or made progress in the tasks you identified for your community? Provide examples.
2. For information that you did not know during class, what methods did you use to find the information?
3. Have you met with your identified mentor since E/L0101? How has he/she continued to help you grow in the Emergency Management profession?

TESTING AND EVALUATION PROCESS

Visual 1.1.7



Key Points

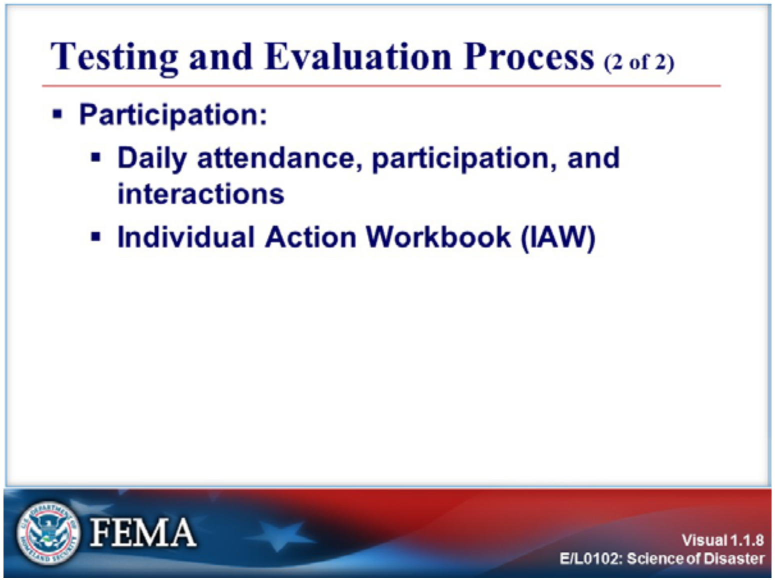
The course will contain several graded and ungraded testing and evaluation opportunities.

There will be a total of two tests—a pre-test and a post-test. The Pre-Test will not count towards the score to pass the class.

You are required to score a minimum of 75% on the Post Test.

TESTING AND EVALUATION PROCESS

Visual 1.1.8



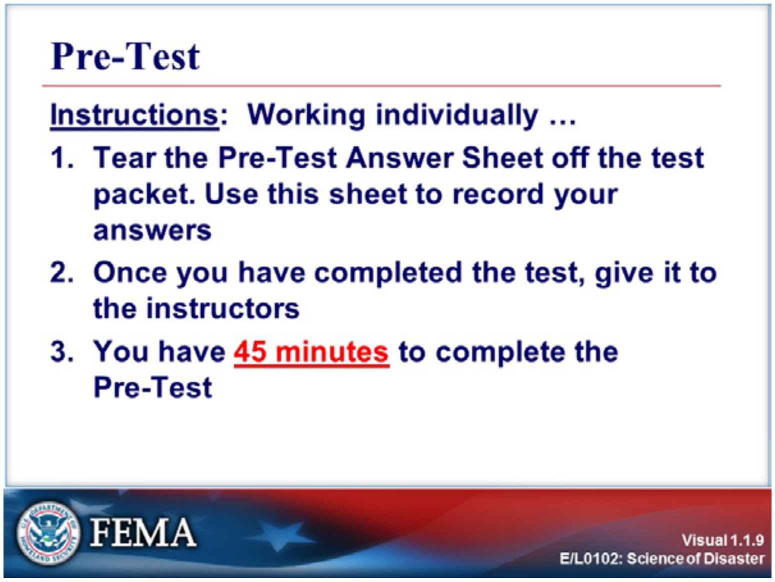
Key Points

In addition to the required minimum scores on the two Post-Tests, you will also be required to be an active participant in the class. Instructors will be observing your:

- Daily attendance and interactions in the class
- Completion of IAW activities

PRE-TEST

Visual 1.1.9



Key Points

Instructions: Working individually…

1. Tear the Pre-Test Answer Sheet off of the test packet. Use this sheet to record your answers.
2. Once you have completed the test, turn it into the instructors.
3. You have 45 minutes to complete the Pre-Test.

INTRODUCTION

Visual 1.1.10

Key Points

The goal of this course is to enhance understanding of how scientific principles can be used before, during, and after a disaster.

We will explore various types of natural and human-caused threats and hazards and consider the science behind:

- How they occur
- Why they occur
- Where they occur
- What we can predict about their occurrence

We will also consider what Emergency Managers can do with the types of warning and predictions provided by scientists.

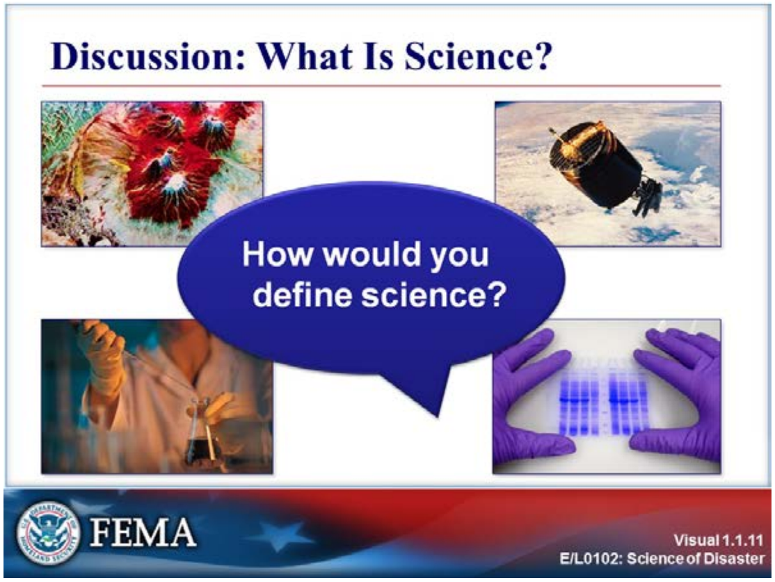
TIME PLAN

A suggested time plan for this module is shown below.

Topic	Time
Introduction	60 minutes
Benefits and Limitations of Science	20 minutes
Course Structure	5 minutes
Unit Summary	5 minutes
Total Time	**1 hour 30 minutes**

SCIENCE

Visual 1.1.11

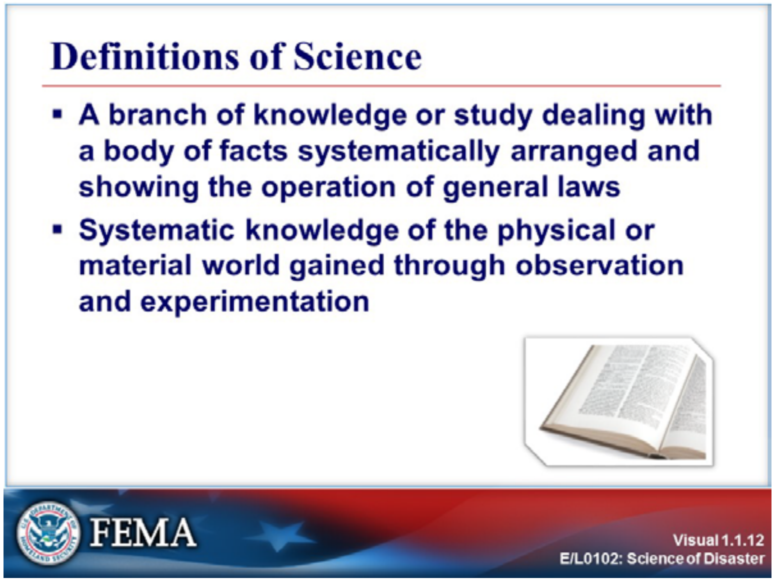


Key Points

<u>Discussion Question</u>: How would you define science?

SCIENCE

Visual 1.1.12



Key Points

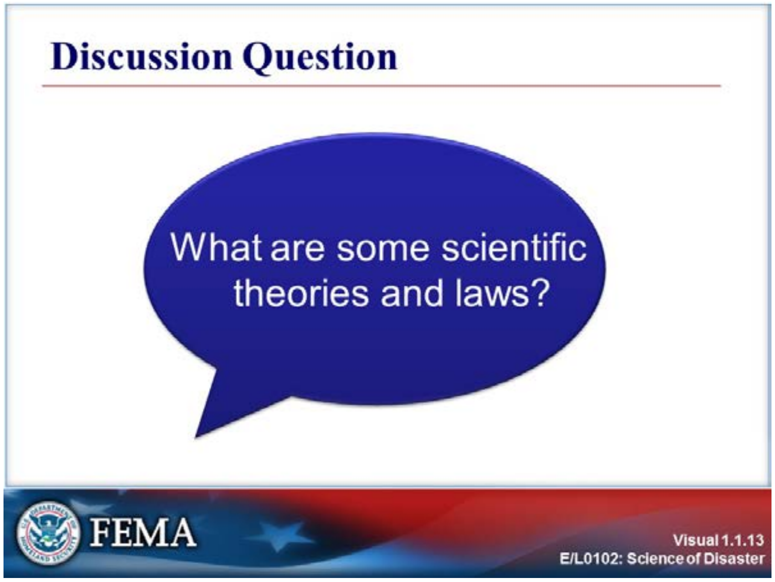
There are many definitions of science. For example, science can be described in the following ways:

- Science is a branch of knowledge or study dealing with a body of facts systematically arranged and showing the operation of general laws.
- Science is systematic knowledge of the physical or material world gained through observation and experimentation.

Note that what both definitions have in common is "knowledge." Science is a systematic process that builds and organizes knowledge in the form of testable, repeatable explanations and predictions about the universe.

DISCUSSION QUESTION

Visual 1.1.13



Key Points

<u>Discussion Question</u>: What are some scientific theories and laws?

It is important that people recognize that theories DO NOT become law once they are “proven true.” Laws and theories are two entirely different concepts.

Laws describe **how** an object behaves in a given circumstance and under specific conditions. Laws do not explain **why** something happens. For example, Kepler’s Laws of Planetary Motion describe how the planets revolve around the Sun, but give absolutely no explanation of why they revolve around the Sun they way they do. Laws are specific and can often be described with a mathematical equation. They describe one type of thing rather than a broad range of observations.

DISCUSSION QUESTION

Visual 1.1.13 (Continued)

Conversely, theories try to explain why something occurs as it does. Plate tectonics explains why mountains form where they do, why volcanoes occur where they do, and why earthquakes occur along localized zones. Theories involve a mechanism or process that explains a wide range of observations.

Theories NEVER become laws. Theories, like laws, are the best that we have. Theories that last are well documented with a wide range of confirming evidence that supports the process or mechanism. For example, the process of evolution was recognized in various ways long before Darwin hypothesized the mechanism by which it occurred. Darwin's ideas of natural selection explained the observations in the fossil record, and the observations in animal husbandry, and the observations of biodiversity. DNA studies provide further confirming evidence in support of evolutionary theory.

Kepler's Laws of Planetary Motion (Johannes Kepler, early 1600s):

1) The path of the planets about the Sun is elliptical in shape, with the center of the Sun being located at one focus of the ellipse. Also known as the Law of Ellipses.
2) An imaginary line drawn from the center of the Sun to the center of the planet will sweep out equal areas in equal intervals of time. Also known as The Law of Equal Areas.
3) The ratio of the squares of the orbital periods of any two planets is equal to the ratio of the cubes of their average distances from the Sun. Also known as the Law of Harmonies. Unlike the previous two laws, this law compares motions of the planets.

Newton's Law of Universal Gravitation (1687):

All objects attract each other with a force of gravitational attraction dependent upon the masses of the two objects and inversely proportional to the square of the distance that separates them.

$$F_{grav} \propto \frac{m_1 \times m_2}{d^2}$$

Newton's Laws of Motion

1) Law of Inertia: An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.
2) The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

$$F = m \times a$$

3) For every action there is an equal and opposite reaction.

Laws of Thermodynamics

1) First Law: Energy cannot be created or destroyed in an isolated system. Also known as the Law of Conservation of Energy.

$$\Delta E = q + w$$

2) Second Law – Entropy of any isolated system always increases.
3) Third Law – Entropy of a system approaches a constant value as the temperature approaches absolute zero.

DISCUSSION QUESTION

Visual 1.1.13 (Continued)

Gas Laws

1) Boyle's Law: $V \propto \frac{1}{P}$ The volume of a gas is inversely proportional to the pressure applied on the gas.
2) Charles's Law: $V \propto T$ The volume of a gas held at a constant pressure is directly proportional to the Kelvin temperature.
3) Gay-Lussac Law: $P \propto T$ The pressure of a given amount of gas held at a constant volume is directly proportional to the Kelvin temperature.
4) Ideal Gas Law: $PV = nRT$, where *P* is the pressure of the gas, *V* is the volume of the gas, *n* is the amount of the substance of the gas (in moles), *R* is the ideal, or universal, gas constant, and *T* is the temperature.

BENEFITS AND LIMITATIONS OF SCIENCE

Visual 1.1.14

Key Points

Scientific information and scientific methods can play an important role in preparedness. Being informed and taking full advantage of scientific analysis and prediction helps communities build and sustain core capabilities that enable us to:

- Prevent
- Protect against
- Mitigate the effects of
- Respond to, and
- Recover from disasters

Prevent and Protect Against: While it is difficult to prevent natural disasters, science has enabled the formation of warning systems (e.g., for flood, severe weather, tsunami) that help prevent loss of life through evacuation strategies.

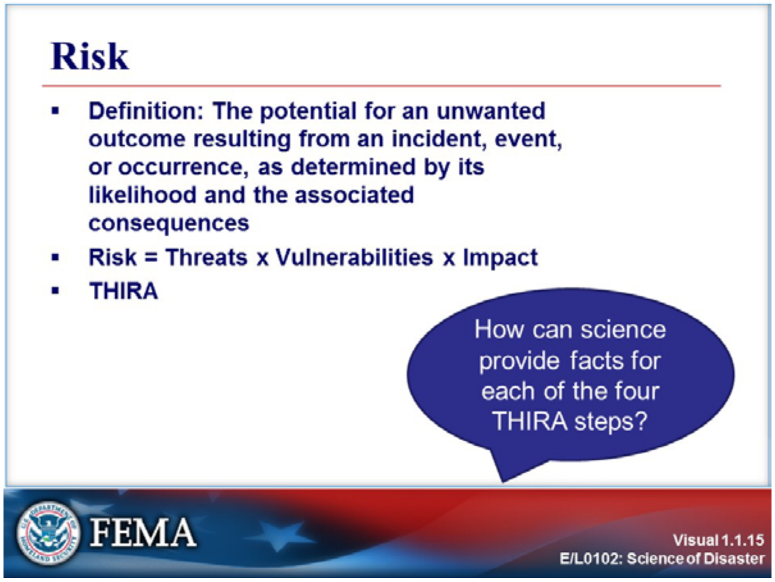
Mitigate the effects of: Science allows us to address risk by creating and enforcing building codes, defining flood plains, installing artificial and natural barriers to water hazards.

Respond to: Science has helped first responders to identify the location of victims (e.g., SR530 mudslide), identify where to send first responders after an earthquake, determine when to blow levees to protect downstream communities (e.g., 2011 Mississippi River flood).

Recover from: Scientists learn from every natural disaster more that helps us to understand better the triggers of disaster (e.g., mudslides and forest fires), the conditions that exacerbate disaster (e.g., extreme drought), and the conditions that lead to disaster (e.g., severe weather, hurricanes, tornadoes).

RISK

Visual 1.1.15



Alt Text for Visual 1.1.15
Risk

- Definition: The potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences
- Risk = Threats x Vulnerabilities x Impact
- THIRA

How can science provide facts for each of the four THIRA steps?

Key Points

This is a nonmathematical construct sometimes used to describe risk with:

- Threats: the frequency of potentially adverse incidents, events, or occurrences
- Vulnerability: the likelihood of success of a particular threat
- Impact: the consequences experienced by the target from the threat

Emergency Managers address risk with the Threat and Hazard Identification and Risk Assessment (THIRA) four-step process:

1. Identify Threats and Hazards of Concern
   a. Based on a combination of experience, forecasting, subject matter expertise, and other available resources, identify a list of the threats and hazards of primary concern to the community.
2. Give the Threats and Hazards Context
   a. Describe the threats and hazards of concern, showing how they may affect the community.

RISK

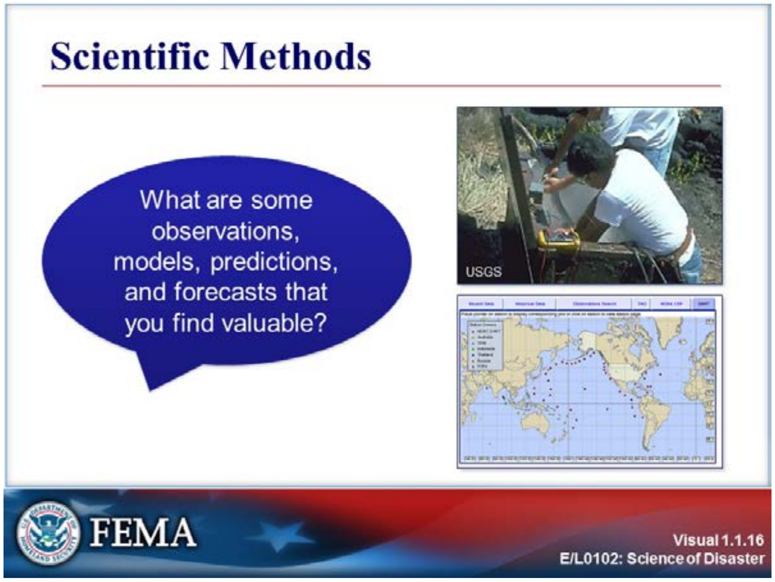
Visual 1.1.15 (Continued)

3. Establish Capability Targets
    a. Assess each threat and hazard in context to develop a specific capability target for each core capability identified in the National Preparedness Goal. The capability target defines success for the capability.
4. Apply the Results
    a. For each core capability, estimate the resources required to achieve the capability targets through the use of community assets and mutual aid, while also considering preparedness activities, including mitigation opportunities.

Discussion Question: How can science provide facts for each of the four THIRA steps?

BENEFITS AND LIMITATIONS OF SCIENCE

Visual 1.1.16



Key Points

<u>Discussion Question:</u> What are some observations, models, predictions, and forecasts that you find valuable?

Scientists use many methods, instruments, and technologies to observe, measure, and predict hazards and disasters. These activities are fundamental to understanding hazards and helping to make society safer. Some of the scientific methods used include:

- **Scientific observations:** The collection of data through seismometers, satellites, samples, estimations, measurements, and numerous other technologies is essential to understanding past and current disasters and predicting future disasters.
  - **Examples:** USGS Lidar Maps for landslide information; USGS Hydrology for streamflow and flood conditions; USGS Volcano and Earthquake monitoring and alerts

- **Scientific models:** Scientists create models to make sense of their measurements and observations, to extend them to areas where no observations exist, and to make forecasts about the future.
  - **Examples:** USGS & NWS Flood Prediction Models; USGS ShakeMaps

- **Hazard predictions:** A prediction is a specific, testable statement that identifies a particular outcome at a certain time. To be able to make a prediction, scientists need enough data and sufficient understanding of the natural process to recognize patterns and figure out what will happen next. As you will see, in the vast majority of situations it is not realistic for scientists to issue predictions per se. In most cases, scientists instead issue forecasts.
  - **Examples:** National Weather Service (NWS) Severe Weather

BENEFITS AND LIMITATIONS OF SCIENCE

Visual 1.1.16 (Continued)

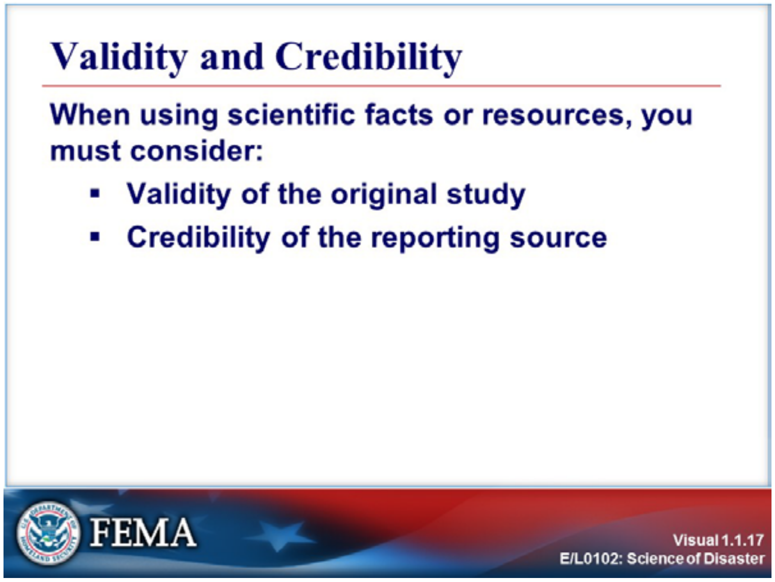
- **Forecasts:** Scientists routinely issue forecasts regarding potentially hazardous events—forecasts that may cover short or long timeframes. A forecast is a definitive statement or statistical estimate of the likelihood of occurrence of a future event or conditions for a specific area. Unlike predictions, forecasts involve uncertainty about each of the components of a prediction—location, size, and timing—and typically communicate some degree of uncertainty about whether the event will happen at all.
    - **Examples:** USGS Volcano Alert, USGS Post-Fire Debris Flow Hazard, USGS Earthquake Hazard Forecasts, NWS Hurricane Tracker

- **Advisements and Warnings:** Short-term forecasts may take the form of advisements or warnings. The style, frequency, and terminology of these warnings differ from hazard to hazard, as do the levels of uncertainty.

We will see how each of these methods is applied to a particular hazard or disaster as we continue through the course. You will find that while there are great difficulties involved in all of these methods (particularly in forecasting and prediction), the methods contribute enormously to understanding and preparing for disasters.

BENEFITS AND LIMITATIONS OF SCIENCE

Visual 1.1.17



Key Points

Not all sources (models, maps, etc.) are equal, so as Emergency Managers you must be mindful of the validity and credibility of a source/resource when gathering scientific information. The popular press and public view is that to be "fair," an article must report both sides. This is a fallacy for scientific writing, which only passes on facts that meet a statistical level of validity. It is important to realize that in fact-based reporting, both sides are not always valid.

Validity:

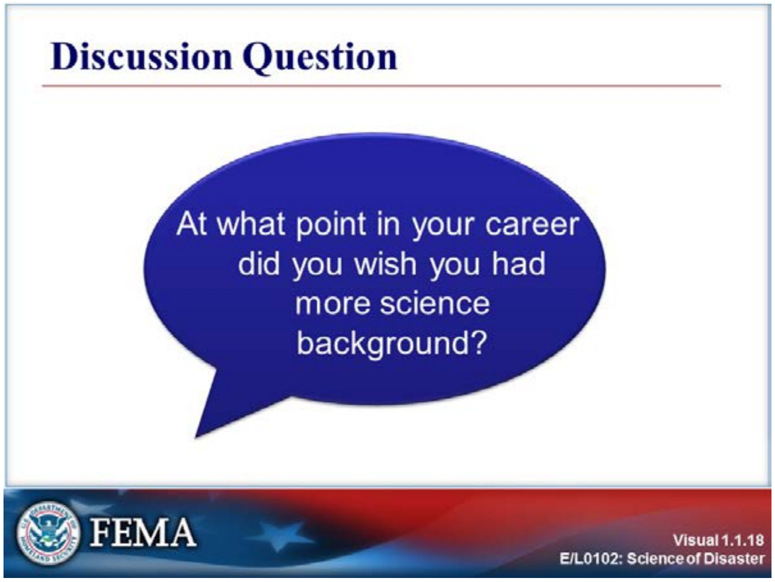
- Who paid for/sponsored the study?
- Was the study large enough to pass statistical muster?
- Was it designed well?
- Did it last long enough?
- Were there any other possible explanations for the conclusions of the study, or reasons to doubt the findings?
- Do the conclusions fit with other scientific evidence? If not, why?
- Do you have the full picture?
- Have the findings been checked by other experts (i.e., peer-reviewed)?
- What are the implications of the research? Any potential problems or applications?

Credibility:

- Type: What kind of content is this?
- Source: Who and what are the sources cited and why should I believe them?
- Evidence: What's the evidence and how was it vetted?
- Interpretation: Is the main point of the piece proven by the evidence?
- Completeness: What's missing?
- Knowledge: Am I learning every day what I need?

BENEFITS AND LIMITATIONS OF SCIENCE

Visual 1.1.18

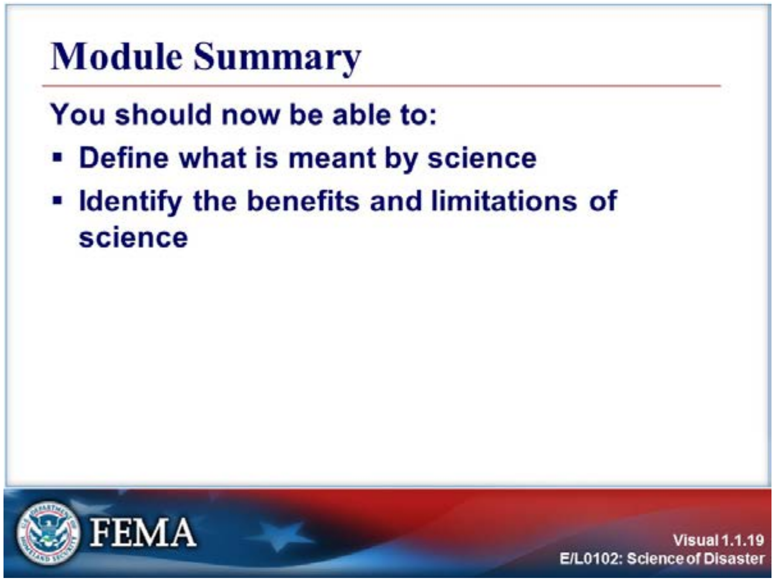


Key Points

Discussion Question: **At what point in your career did you wish you had more science background?**

MODULE SUMMARY

Visual 1.1.19



Key Points

Do you have any questions about the material covered in this module?

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MODULE 2. STORMS

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UNIT 1. ATMOSPHERIC SCIENCE OVERVIEW

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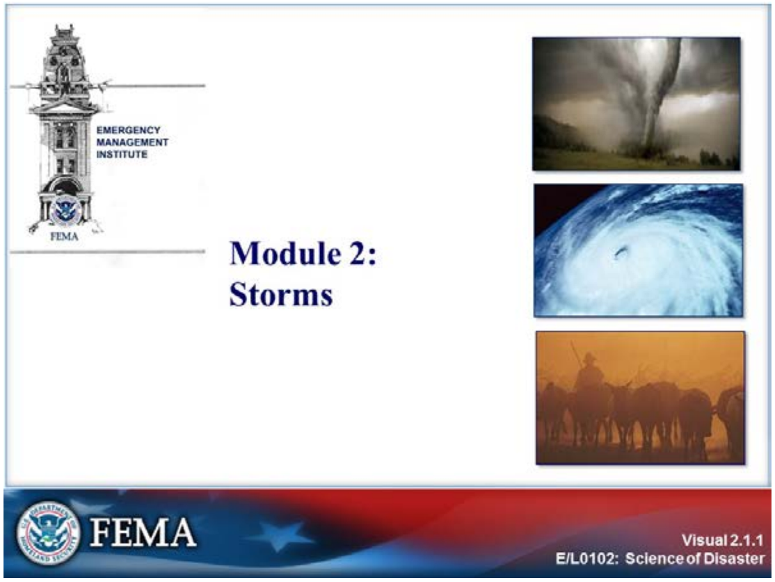
INTRODUCTION

Visual 2.1.1

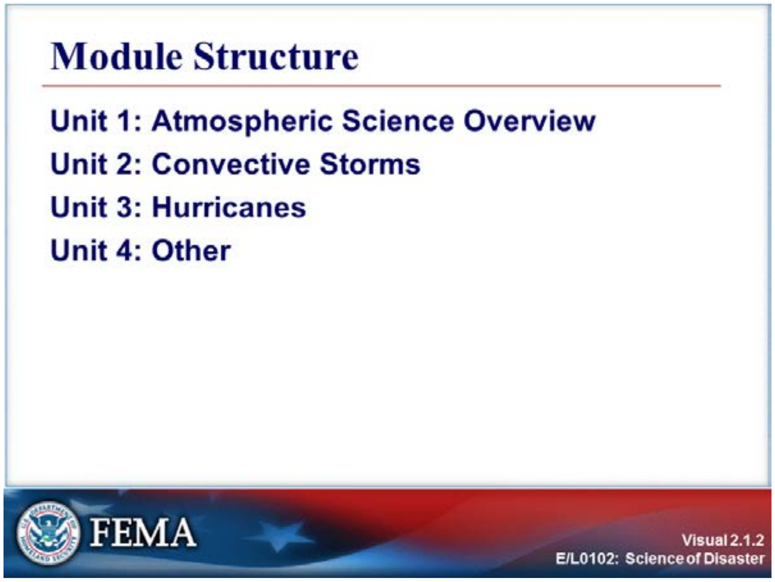


Key Points

Welcome to Module 2, Storms.

INTRODUCTION

Visual 2.1.2



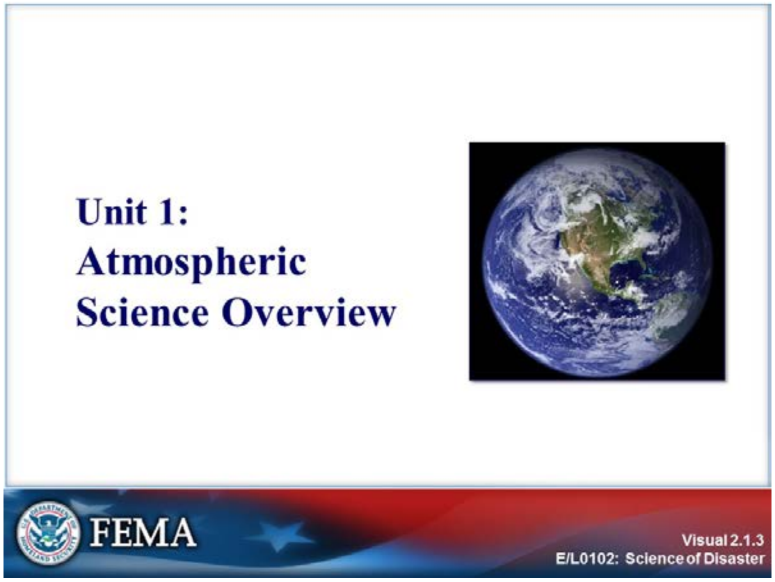
Key Points

This module consists of the following units:

Unit	Time
Unit 1: Atmospheric Science Overview • Activity 2.1 – Back-to-Back La Niñas (Visual 2.1.28) • Activity 2.2 – In Your Community (Visual 2.1.33)	1 hour 25 minutes
Unit 2: Convective Storms • Activity 2.3 – 2011 Joplin, MO Case Study (Visual 2.2.25)	1 hour 35 minutes
Unit 3: Tropical Cyclones • Activity 2.4 – New D-FIRM Maps (Visual 2.3.28)	1 hour 35 minutes
Unit 4: Other Hazardous Weather • Activity 2.5 – The Perfect Storm Case Study (Visual 2.4.13) • Activity 2.6 – Module 2 IAW (Visual 2.4.25)	1 hour 40 minutes
Total Module Time:	**6 hours 15 minutes**

INTRODUCTION

Visual 2.1.3



Key Points

This unit will present basic information about climatological concepts and factors that influence weather and climate.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Scales of Weather	10 minutes
Factors Affecting Weather	15 minutes
Climate Factors • Activity 2.1 – Back-to-Back La Niñas	30 minutes
Climate Change • Activity 2.2 – In Your Community	20 minutes
Unit Summary	5 minutes
Total Time	**1 hour 25 minutes**

INTRODUCTION

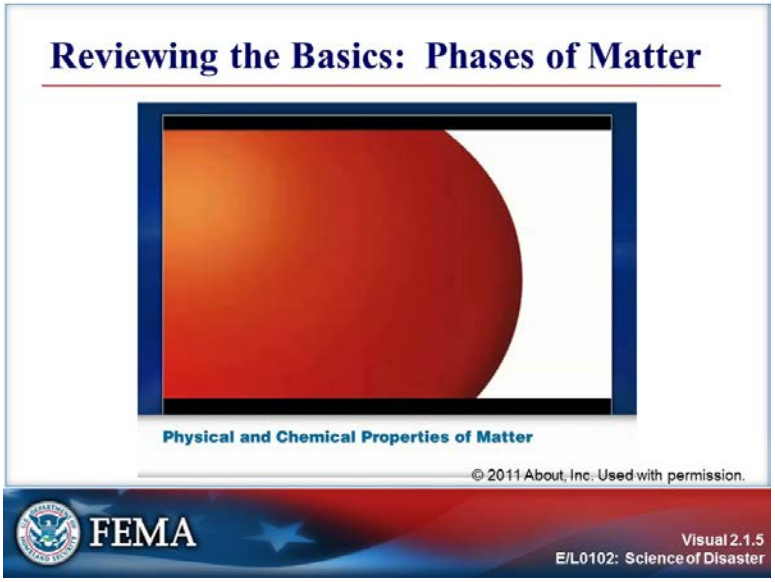
Visual 2.1.4

Key Points

Review the unit objectives as listed on the visual.

INTRODUCTION

Visual 2.1.5



Key Points

Video © 2011 About, Inc. Used with permission.

Introduction: Matter can exist in different phases (also called states): solid, liquid, or gas. Most substances can transition between these phases based on the amount of heat the material absorbs (or loses). This video will discuss the phases of matter and how they can change.

Video Transcript:

Phases of Matter

The phases of matter are:

- Solid—which has a definite shape and volume
- Liquid—which has a definite volume, but it can change shape
- Gas—the shape and volume of a gas can change

Phase Changes of Matter

There are several ways in which phases of matter can change from one to another:

- Melting—melting occurs when a substance changes from a solid to a liquid
- Boiling—boiling is when a substance changes from a liquid to a gas
- Condensing—condensation is when a gas changes to a liquid
- Freezing—freezing is when a liquid changes to a solid

INTRODUCTION

Visual 2.1.5 (Continued)

Classes of Changes in Matter

The changes that take place in substances may be categorized in two classes:

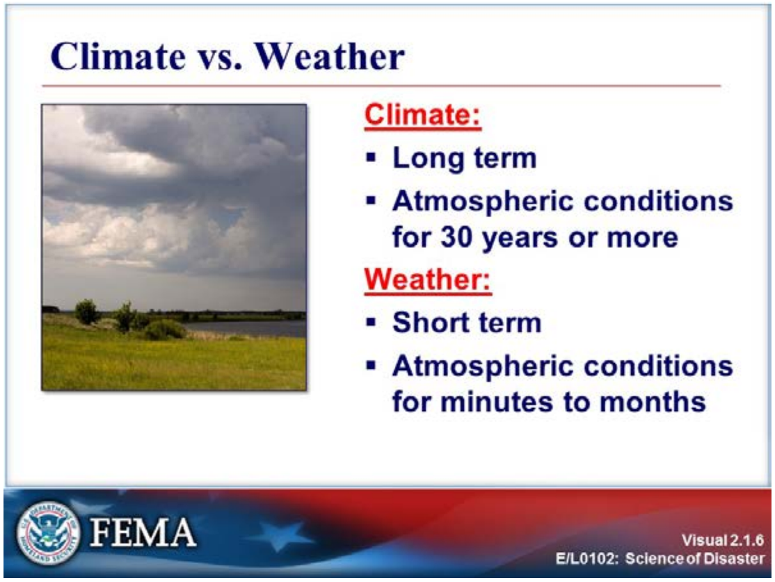
- Physical Change—a new substance is not produced and just the physical properties are changed (for example, phase changes, or crushing a can).
- Chemical Change—a new substance is produced with different chemical properties (for example, burning, rusting, and photosynthesis).

Solutions

Sometimes, when two or more substances are combined, it results in a solution. Making a solution can produce either a physical or chemical change. When there's a physical change in a solution, the original substances can be separated from one another. If a chemical change takes place while creating a solution, the original substances cannot be separated from one another.

INTRODUCTION

Visual 2.1.6



Key Points

The difference between climate and weather is, essentially, one of time.

Climate: describes long-term (i.e., 30 years or more) trends and patterns of weather.

Climatology is the study of the sum total of the meteorological elements that characterize the average and extreme condition of the atmosphere over a long period of time at any one place or region of the Earth's surface. It can be the collective state of the atmosphere at a given place or over a given area within a specified period of time.

Understanding climatology provides the basis for future climate expectations and enables planning by assisting in long-term prediction.

Weather describes the conditions of the atmosphere over a much shorter period of time (i.e., minutes to months).

Meteorology is the science dealing with the atmosphere and its phenomena, which sounds quite similar to climatology. The distinction is that climatology is primarily concerned with average, not actual, weather conditions.

INTRODUCTION

Visual 2.1.6 (continued)

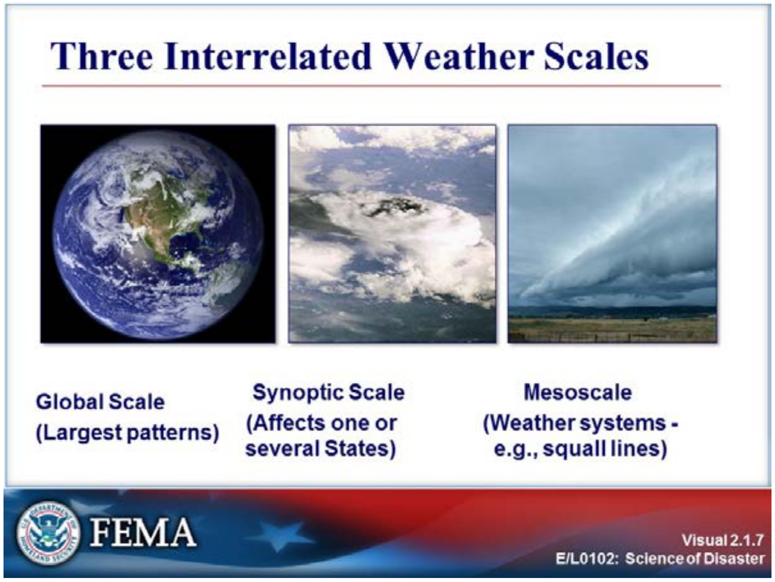
Forecast accuracy has increased significantly over the past 30 years due to advances in multiple areas, including:

- Scientific understanding of weather processes
- Instruments (such as satellites and radar) for observing the atmosphere
- Computer model sophistication – for example, as a result of scientific advances, the 3-to-4-day forecasts are now as accurate as the 2-day forecast was in 1985, The average tornado warning lead times have increased from 5 minutes to 13 minutes.
- Training for forecasters

Familiarity with the science of weather can improve decision-making in areas related to hazardous weather. The major limitation is that the science behind weather does not provide all of the answers. Weather is a complicated combination of factors, and conditions can change quickly.

SCALES OF WEATHER

Visual 2.1.7



Key Points

One of the complications involved with studying the science of weather is that there are three different scales over which weather develops and interacts. Understanding these scales is a necessary preliminary to understanding climate.

- **Global Scale:** The largest weather features occur on the global scale. At this scale, forecasters are thinking about large patterns of winds, temperature, and pressure.

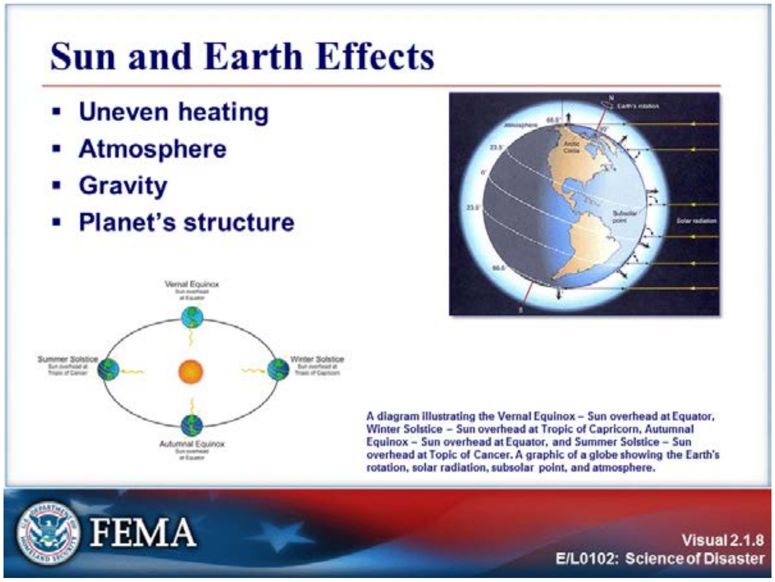
- **Synoptic Scale:** Weather patterns that affect one or several states are called synoptic scale events. Examples of these events include circulations around high- and low-pressure areas, large snowstorms, large-scale droughts, and hurricanes.

- **Mesoscale:** Weather systems smaller than synoptic-scale systems but larger than storm-scale systems. Horizontal dimensions generally range from around 50 miles to several hundred miles. Examples include squall lines and organized clusters of thunderstorms.

All three scales are interrelated, so a mesoscale event will have its roots in global and synoptic patterns. Likewise, a global or synoptic scale event will have a variety of consequences on the mesoscale.

FACTORS AFFECTING WEATHER

Visual 2.1.8



Alt Text for Visual 2.1.8
Sun and Earth Effects

- Uneven heating
- Atmosphere
- Gravity
- Planet's structure

A diagram illustrating the Vernal Equinox – Sun overhead at Equator, Winter Solstice – Sun overhead at Tropic of Capricorn, Autumnal Equinox – Sun overhead at Equator, and Summer Solstice – Sun overhead at Topic of Cancer. A graphic of a globe showing the Earth's rotation, solar radiation, subsolar point, and atmosphere.

Key Points

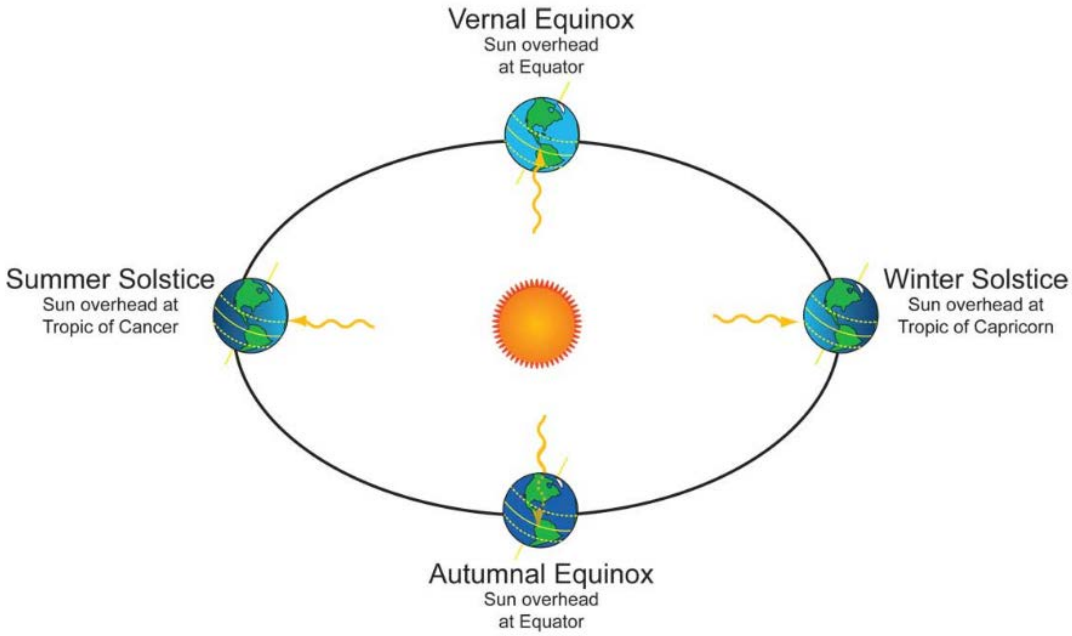
On a global scale, weather is influenced by effects of the Sun and Earth.

- **Uneven heating:** The weather on our planet largely results from the Sun heating areas of the planet unequally. This unequal distribution occurs because of:
  - **Tilt, rotation, and orbit:** The Earth's axis is tilted 23.5 degrees. The Earth rotates on its axis every 24 hours, creating day and night. It revolves around the Sun on an elliptical path, creating our seasons as it completes its yearly journey.

    As the Earth moves around the Sun, the concentration of sunlight shifts to be either more or less concentrated in the northern hemisphere depending on where the earth is relative to the Sun.

FACTORS AFFECTING WEATHER

Visual 2.1.8 (Continued)



Alt Text for graphic: A diagram illustrating the Vernal Equinox – Sun overhead at Equator, Winter Solstice – Sun overhead at Tropic of Capricorn, Autumnal Equinox – Sun overhead at Equator, and Summer Solstice – Sun overhead at Topic of Cancer. A graphic of a globe showing the Earth's rotation, solar radiation, subsolar point, and atmosphere.

FACTORS AFFECTING WEATHER

Visual 2.1.8 (Continued)

- **Day/night temperature differences:** The Sun's radiation reaches only half the planet (the "daylight" side) at any one time. Half the Earth is heating up during the day while the other half, the night side, is cooling down. Sunlight that is striking the planet during the day heats up the Earth's surface—both land and water.

- **Spherical shape:** The amount of radiation reaching the surface varies at different places. Because the Earth is almost a perfect sphere, the sunlight is more concentrated in some areas (e.g., at the equator) and less concentrated in others (the polar regions). This differential heating, along with the rotation of the Earth, creates moving weather.

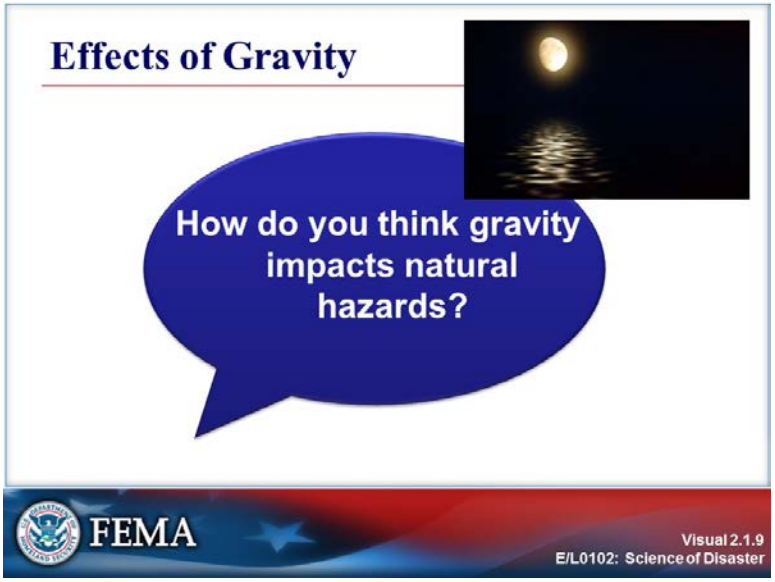
- **The planet's atmosphere:** The Earth's atmosphere is the layer of gas that surrounds the Earth and is held to the Earth by gravity. The atmosphere is a fluid that moves and circulates because of differences in temperature and pressure.

- **The structure of the planet:** The basic structure of the planet—landforms, oceans, and other bodies of water, mountains, deserts, vegetation, and even urban areas—is also important in determining weather.

  The oceans are particularly important because they provide much of the water that evaporates into the atmosphere.

OTHER IMPACTS

Visual 2.1.9



Key Points

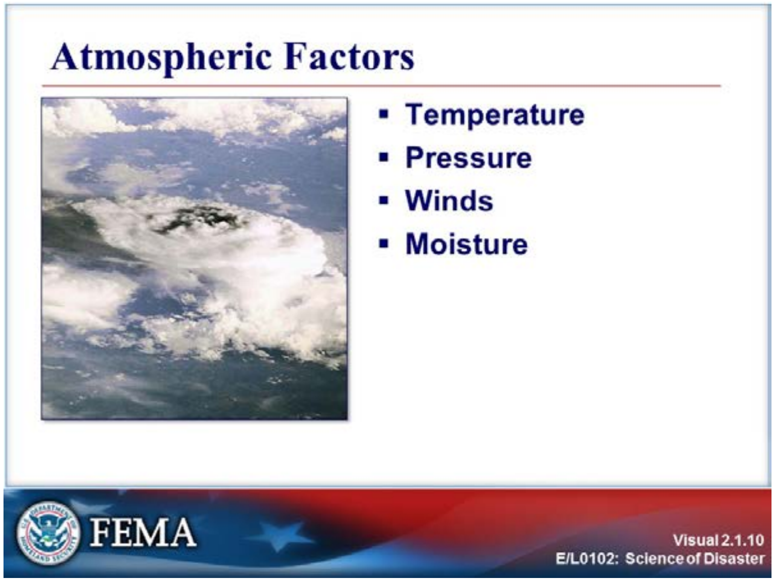
We all have gravitational pull, but ours are trivial compared to those of the Earth, the Sun, and the Moon.

Examples of Gravity in Natural Hazards:

- On the Earth's surface, a plate will subduct beneath another plate because the Earth's gravitational force has a stronger pull on denser rock than on less dense rock.
- In a convection cell inside the Earth, cooler material sinks and hot material rises for the same reason—the cooler material is denser and pulled more strongly.
- On the Earth's surface, water runs downhill because of gravity, eroding mountains and triggering landslides, which also move downhill because of gravity.
- The Moon's gravitational pull affects ocean tides, including those of storm surges.

FACTORS AFFECTING WEATHER

Visual 2.1.10



Key Points

Atmospheric factors that affect weather include:

- **Temperature:** Temperature is a measure of heat describing the molecular energy of an object. As the atmosphere heats up or cools down, its density changes. Warm air expands and rises, cool air contracts and sinks. Variations in temperature, both on a daily and seasonal basis, cause the circulation of the atmosphere as the molecules move to equalize the planet's temperature. Of course, temperatures never actually equalize because of the planet's shape and continual rotation and revolution.

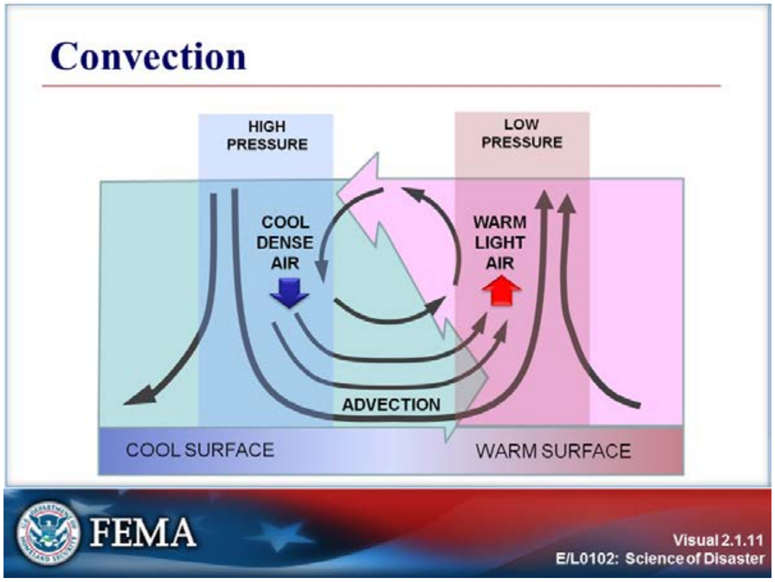
- **Pressure:** Air pressure is the weight of the atmosphere pushing down at a given location. Because air is a gas composed of particles (e.g., water vapor), it is affected by the Earth's gravity.

- **Winds:** The same processes that try to equalize temperature differences over the globe also try to balance the pressure differences between denser and lighter air. These processes create winds that blow from areas with higher pressure to those with lower pressure.

- **Moisture:** While water vapor is not the most abundant gas in the atmosphere, it is very important in terms of weather. In addition to forming liquid and solid particles in clouds that fall as rain or snow, the process of changing from the gaseous state into liquid water or ice releases large amounts of heat that serve as an energy source for weather systems, particularly thunderstorms and hurricanes.

FACTORS AFFECTING WEATHER

Visual 2.1.11



Key Points

In the previous module, we discussed convection in the Earth. Convection also operates in the atmosphere.

Temperature differences cause pressure differences in the atmosphere. Air that is warmer and moister relative to its surroundings becomes buoyant and rises. Air that is colder and drier is heavier and descends.

Since surface pressure is a measure of the weight of the column of air above, a column of warm, moist air has lower surface pressure. Likewise, a column of cold, dry air results in higher surface pressure.

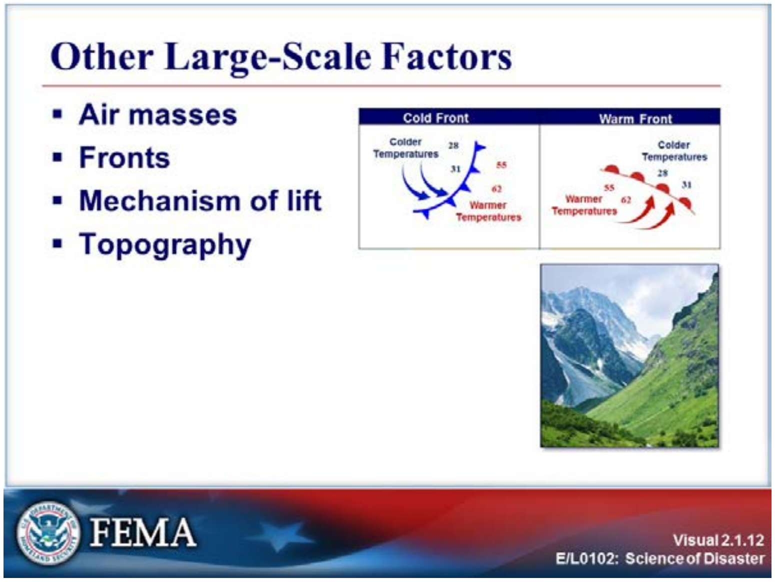
These differences in temperature and pressure cause the atmosphere to circulate:

- When descending air encounters the Earth's surface it spreads out, away from the center of high pressure. The air moves across the earth surface through advection, heating up and collecting moisture. (**Advection** is the transport of an atmospheric property by the wind.)
- As the air becomes warm and moist, it ascends toward the upper atmosphere.
- As the warm moist air rises, it becomes unsettled as it cools and condenses, producing clouds and rain.

It is important to realize that at the Earth's surface, air moves away from regions of high pressure and toward regions of low pressure.

FACTORS AFFECTING WEATHER

Visual 2.1.12



Key Points

As in the global scale, temperature, pressure, and moisture are crucial in creating weather on the synoptic scale. In addition, the following factors are important:

- **Air masses:** If a body of air moves slowly or stays over an extensive area that has fairly uniform temperature and moisture characteristics, the air takes on those characteristics and is called an air mass.

- **Fronts:** As air masses move out of the area in which they form, they come in contact with other air masses with different characteristics. The boundaries between different air masses are called fronts.

    - A cold front is the leading edge of an advancing cold air mass
    - The edge of an advancing warm air mass is a warm front
    - Stationary fronts occur when a front stops moving and neither air mass replaces the other

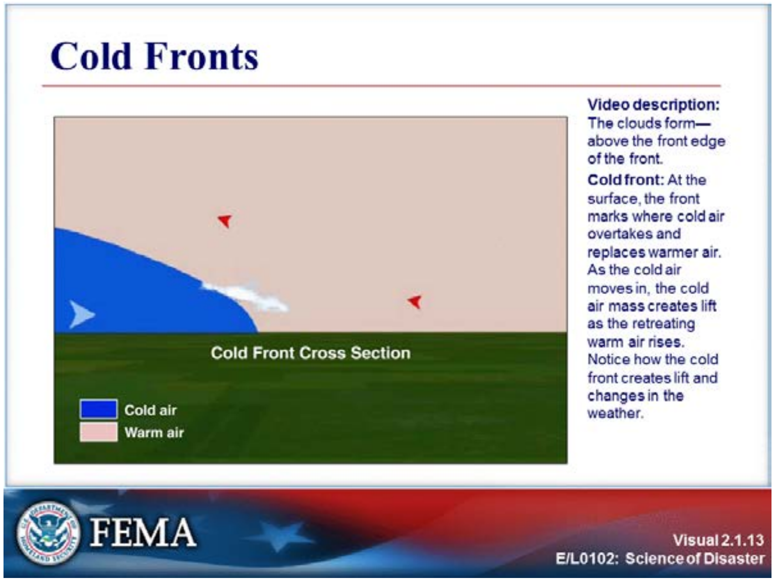
- **Mechanism of lift:** Most hazardous weather conditions require some sort of mechanism for lifting air. These mechanisms include:

    - Air rising in areas of low pressure
    - Fronts acting like a wedge to lift air
    - Air encountering upslopes of mountains, which forces the air upward, resulting in lift

- **Topography:** In addition to creating lift, topography can also affect temperatures. For example, large paved surfaces in urban areas heat and cool at different rates than vegetated areas—a temperature change that translates to local changes in pressure.

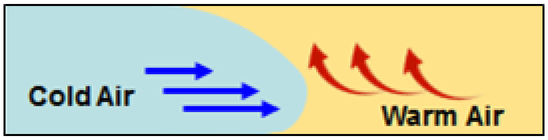
FACTORS AFFECTING WEATHER

Visual 2.1.13



Key Points

Cold front: At the surface, the front marks where cold air overtakes and replaces warmer air. As the cold air moves in, the **cold air mass creates lift** as the retreating warm air rises. Notice how the cold front creates lift and changes in the weather.

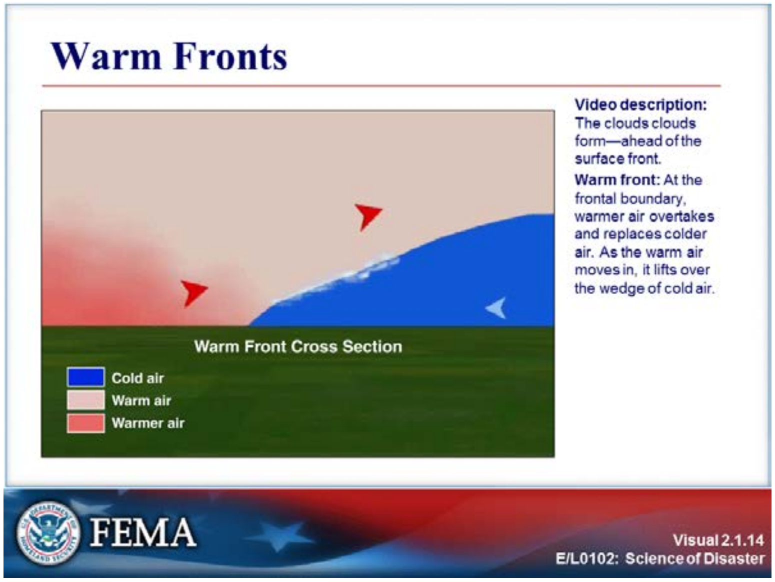


Concerns with cold fronts:

- When the warm moist air is pushed rapidly into the upper atmosphere, the conditions become very unstable.
- During summer, cold fronts typically create a squall line of thunderstorms just in front of the advancing front.
- Cold fronts can easily produce large thunderstorms with lightning, hail, and tornadoes.
- A large amount of rainfall could occur in a short period of time, leading to flooding.
- You should expect a temperature change to colder conditions as the front passes.
- In cold weather, cold fronts produce hazardous winter conditions.
- Because the slope of the cold air mass is steep, temperature, pressure, and weather tend to change dramatically near the front.

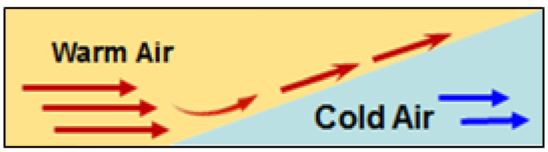
FACTORS AFFECTING WEATHER

Visual 2.1.14



Key Points

Warm front: At the frontal boundary, warmer air overtakes and replaces colder air. As the warm air moves in, it lifts over the wedge of cold air.

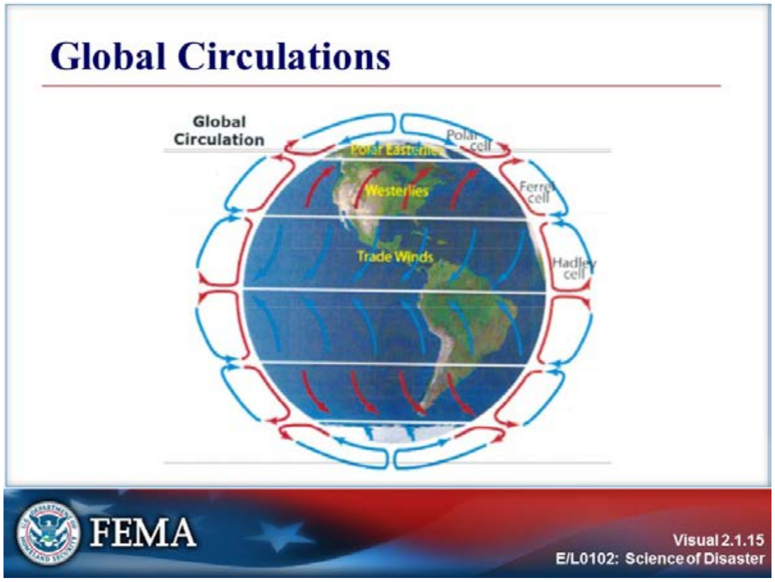


Concerns with warm fronts:

- Warm fronts occur when warm, moist air is slowly pushed up over a cooler air mass.
- The results are rain or snow showers ahead of the warm front. Large, heavy rain or snow could fall during this time.
- The effects of a warm front sweep all the way around the north side of the low pressure. Notice the slope of the warm air mass is relatively gentle. Consequently, warm fronts are seldom as distinct on the surface as cold fronts, and they usually move much more slowly.

CLIMATE FACTORS: ATMOSPHERIC PATTERNS

Visual 2.1.15



Key Points

As you can see, the climate in your area is a function of your location on the planet, topography, proximity to water bodies, etc. But climate can also be affected by long-term global patterns, such as jet streams, trade winds, and El Niño or La Niña. Let's take a closer look at what atmospheric patterns factor into climate, particularly on the global scale.

Climate is greatly affected by three large-scale, semi-permanent **global circulations** of air (convective cells) that result from the rotation of the Earth, its axis, and the distribution of land mass in the two hemispheres.

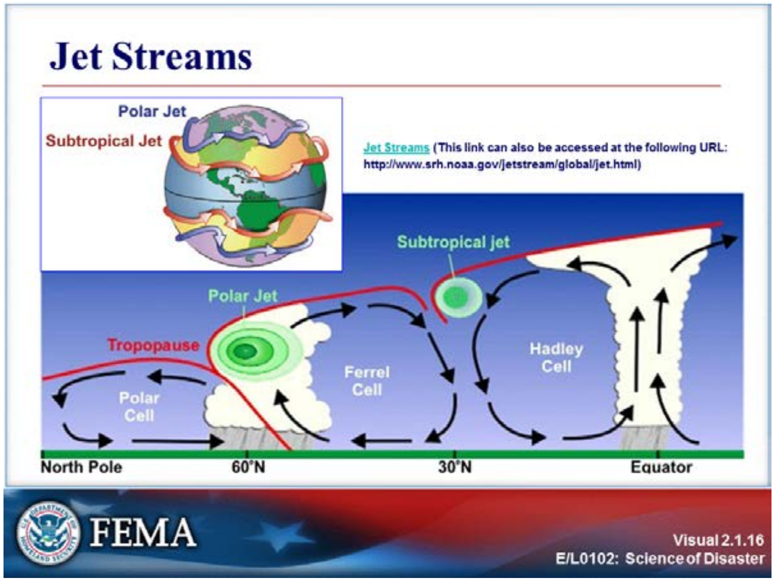
1. **Hadley cell:** In this low-latitude circulation, the movement of air toward the equator rises vertically with heating, resulting in a convection cell that dominates tropical and subtropical climates.
2. **Ferrel cell:** In this mid-latitude atmospheric circulation cell, the air flows poleward and eastward near the surface, and equatorward and westward at higher levels.
3. **Polar cell:** Here the air rises, diverges, and travels toward the poles, resulting in easterly surface winds (polar easterlies).

High-pressure bands exist between these cells at about 30° N/S latitude and at each pole. This high pressure often results in fair and dry/hot weather (e.g., desert conditions around 30° N/S).

Low-pressure bands exist around the equator and 50°-60° N/S. In contrast, the low-pressure bands tend to result in higher precipitation rates due to increased storm formation (especially on the west coasts of continents).

CLIMATE FACTORS: JET STREAMS

Visual 2.1.16



Key Points

The Earth's rotation is also responsible for the jet stream, another key factor in climate.

Jet stream definition: A jet stream consists of relatively strong winds concentrated in a narrow stream in the atmosphere, normally referring to horizontal, high-altitude winds. Jet streams move and behave like rivers but consist of air blowing from west to east.

Temperature and pressure differences: At the same latitudes mentioned on the previous page (30° N/S and 50°-60° N/S) there are great temperature differences as well as pressure differences, resulting in an increase in wind strength in the upper atmosphere.

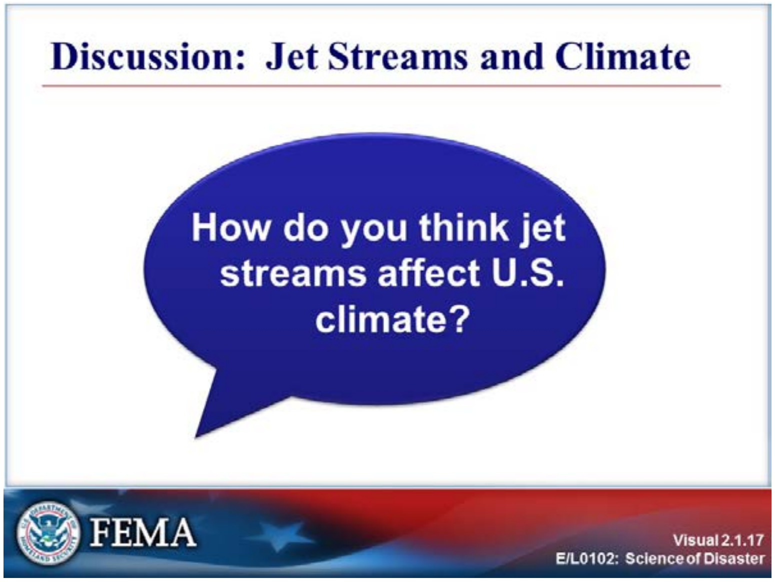
At 50°-60° N/S, there is a jet stream known as the **polar jet.** At 30° N/S, there is a jet stream known as the **subtropical jet.** These jet streams can be 4-to-8 miles high and reach speeds of more than 200 mph.

Jet stream movement: The position and orientation of jet streams vary from day to day. General weather patterns (hot/cold, wet/dry) are closely related to the position, strength, and orientation of the jet stream(s).

As seasons change and the atmosphere fluctuates, the jet streams dip and rise, move and meander, and even briefly disappear and reappear; but they always have a major effect on climate.

CLIMATE FACTORS: JET STREAMS

Visual 2.1.17

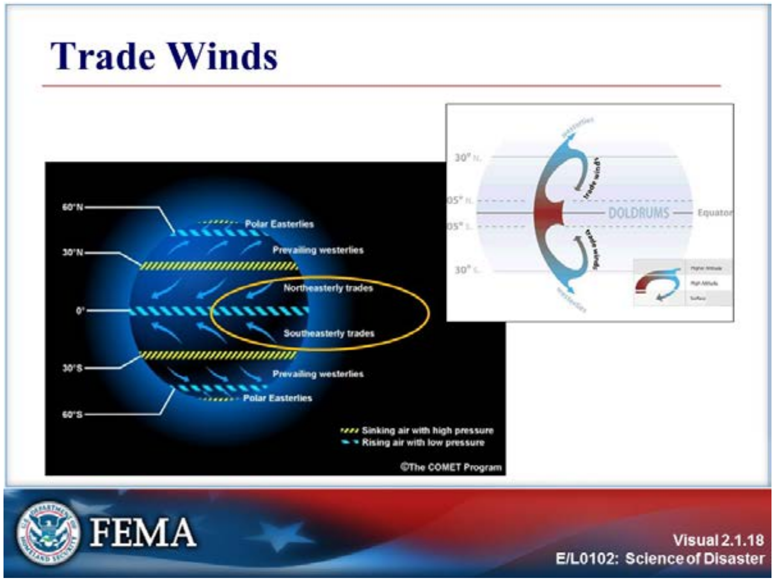


Key Points

<u>Discussion Question</u>: How do you think jet streams affect United States' climate?

CLIMATE FACTORS: TRADE WINDS

Visual 2.1.18



Key Points

Another key factor in understanding climate is the movement of the trade winds. The trade winds:

- Are the wind systems, occupying most of the Tropics, that blow from the subtropical ridges of high pressure toward the equator
- Are major components of the general circulation of the atmosphere
- Are northeasterly in the Northern Hemisphere and southeasterly in the Southern Hemisphere; hence, they are known as the **northeast trades** and **southeast trades**, respectively. The remaining air in both hemispheres (e.g., westerly winds or westerlies) travels toward the poles.
- Have an enormous effect on moisture, temperature, and precipitation patterns, and therefore on climate.

Trade winds affect climate in some notable ways.

- They can steer hurricanes and other storm systems in the Tropics. However, if the trade winds are weakened, storm movement is less predictable.
- If there is an increase in the strength of trade winds, they can move surface ocean waters, prompting the rising of deep, colder waters below ("**cold upwelling**"). This affects ocean temperatures and therefore global weather patterns.

CLIMATE FACTORS: TRADE WINDS

Visual 2.1.18 (continued)

The area where the trade winds converge and force air up into the atmosphere was originally labeled “the **doldrums**” by early sailors, who were well aware of the weak winds and heavy precipitation to be found there.

This area—known now as the Intertropical Convergence Zone (ITCZ)—is essentially a steady band of clouds encircling the globe between the northeast and southeast trade winds near the equator, resulting in frequent showers and thunderstorms.

Like the jet streams, the ITCZ follows the sun and has a position that varies seasonally; in the northern summer it moves north, and in the northern winter it moves south.

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.19

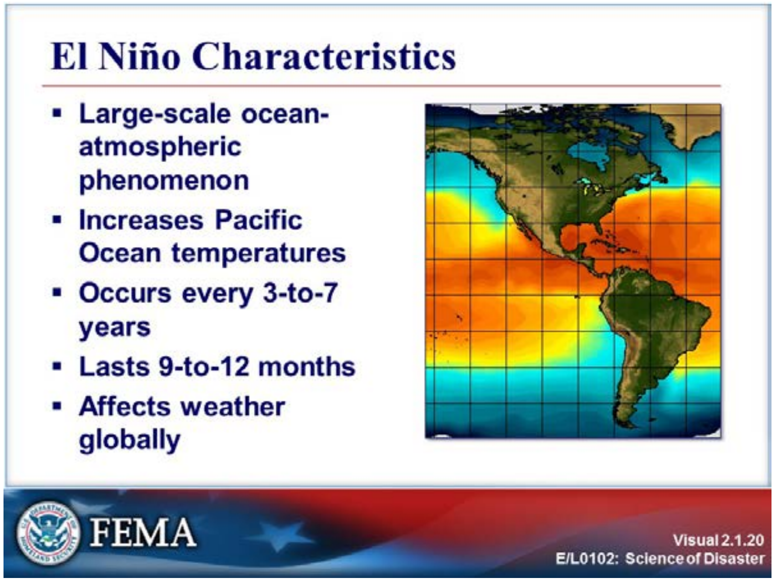
Key Points

The next part of the unit will focus on El Niño and La Niña. This animation, made using data from NOAA satellites, illustrates the onset of an El Niño event in July of 2009.

Discussion Question: What do you notice?

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.20



Key Points

Definition: El Niño constitutes the warm phase of what is called the El Niño/Southern Oscillation (ENSO) cycle. (La Niña is the cool phase of the same cycle.) The ENSO cycle consists of yearly variations in the equatorial Pacific Ocean in:

- Sea-surface temperatures
- Convective rainfall
- Surface air pressure
- Atmospheric circulation

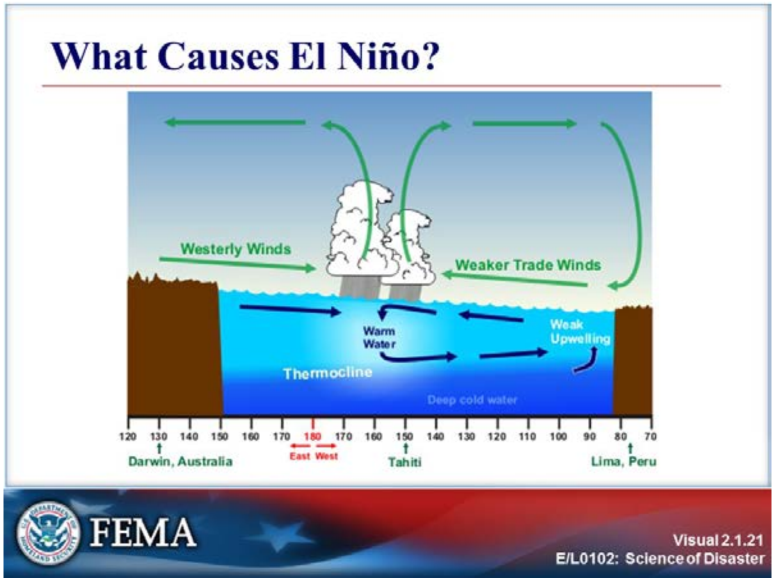
Seasonal outlooks are based on El Niño and La Niña.

El Niño:

- Is associated with a warming of the ocean current along the coasts of Peru and Ecuador
- Is generally associated with dramatic changes in the weather patterns of the region and with changes in weather patterns worldwide
- Generally occurs every 3-to-7 years
- Tends to develop between March and June and is typically much stronger during the winter month.
- Tends to last for 9 to 12 months

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.21



Key Points

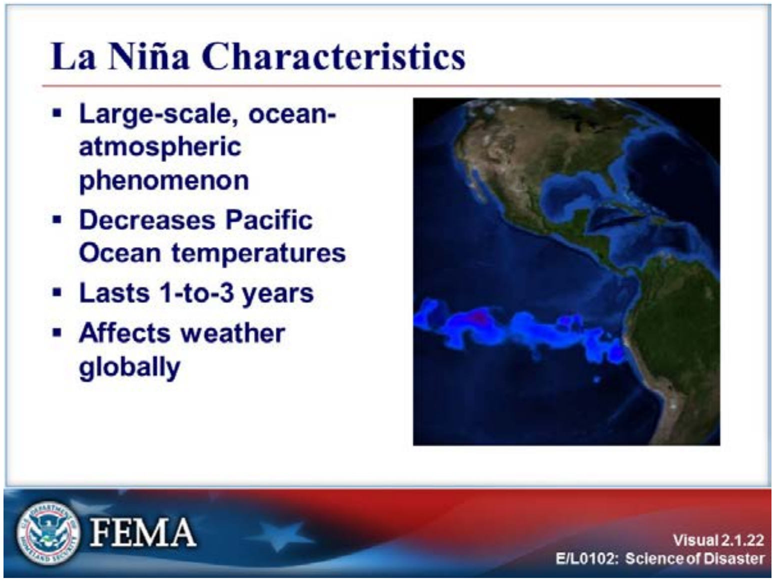
El Niño naturally results from the interactions between the ocean surface and the atmosphere in the tropical Pacific Ocean. The process that leads to El Niño is illustrated in this diagram. In short:

- The trade winds calm and weaken, affecting ocean circulation across the Pacific.
- This results in weak upwelling (i.e., less upward movement of deeper, colder ocean water to replace surface waters) and an increase in sea-surface temperatures.
- This affects precipitation, wind patterns, and, eventually, global weather.

Although the immediate cause of El Niño (weakening trade winds) is known, and scientists have made great progress in studying El Niño, the precise nature and origin of its repetitive cycle remains somewhat of a mystery.

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.22



Key Points

La Niña is another large-scale, ocean-atmospheric climate phenomenon (the cool phase of the ENSO cycle), sometimes referred to as a Pacific cold episode.

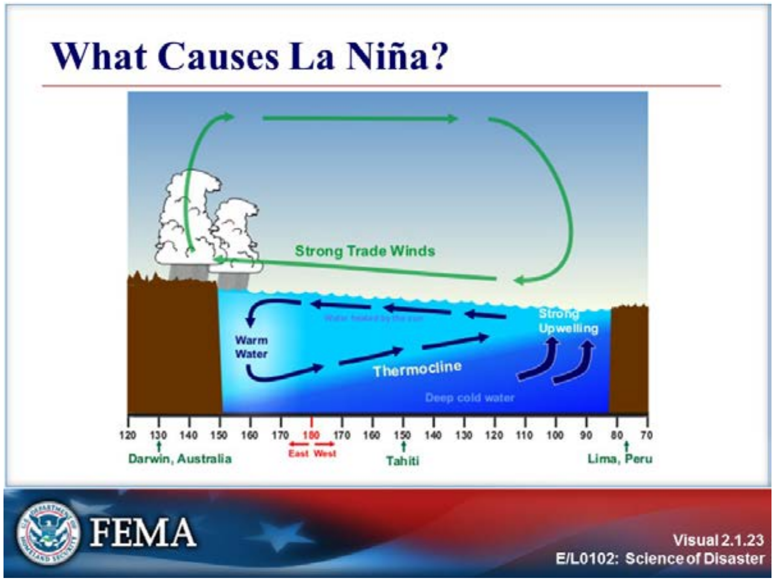
Definition: The preliminary Climate Prediction Center (CPC) definition of La Niña is a phenomenon in the equatorial Pacific Ocean characterized by a negative sea surface temperature departure from normal.

La Niña:

- Is a periodic cooling of surface ocean waters in the eastern tropical Pacific, along with a shift in convection in the western Pacific, further west than the climatological average
- Affects weather patterns around the world
- May last 1-to-3 years
- Tends to develop between March and June
- Is typically much stronger during the winter months

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.23



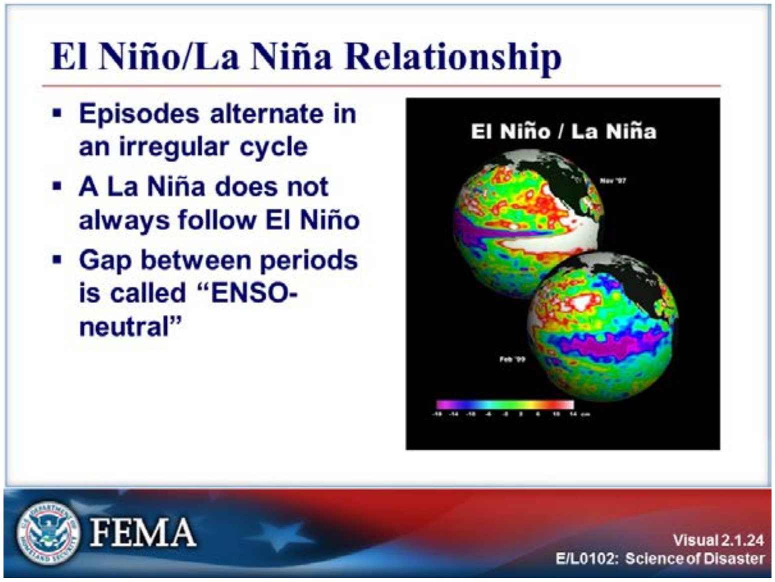
Key Points

Like El Niño, La Niña naturally results from the interactions between the ocean surface and the atmosphere in the tropical Pacific Ocean. The difference is that it begins with the trade winds strengthening, rather than weakening. In short:

- The trade winds strengthen, affecting ocean circulation across the Pacific.
- This results in strong upwelling (i.e., more upward movement of deeper, colder ocean water to replace surface waters) and a decrease in sea-surface temperatures.
- This affects precipitation, wind patterns, and, eventually, global weather.

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.24



Key Points

These two phenomena—which are the main sources of climate variability in many areas of the world—tend to alternate in an irregular cycle. For example, a La Niña episode does not always follow an El Niño episode.

There is also a gap between El Niño periods and La Niña periods called “neutral” or “ENSO-neutral.” In these periods, neither El Niño nor La Niña is present, and ocean temperatures, precipitation patterns, and atmospheric circulation around the equatorial Pacific are close to the long-term averages.

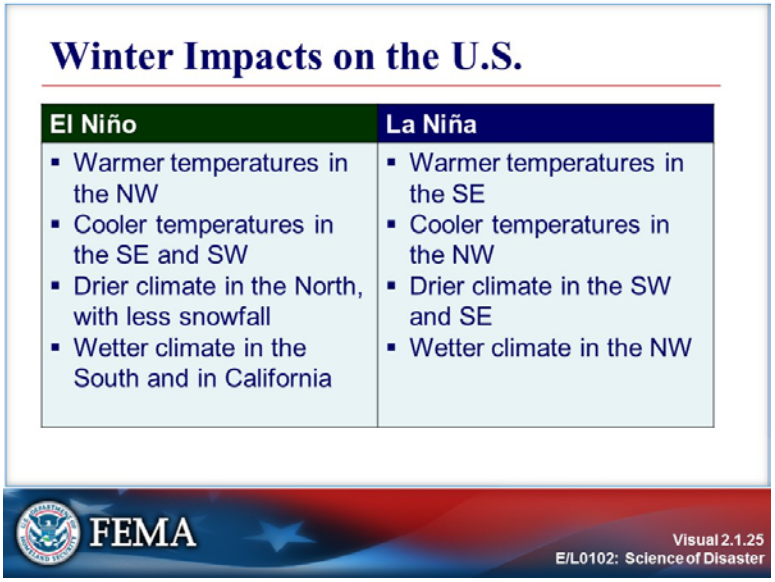
PHOTO:
The image portrays ocean temperature levels during two more moderate El Niño (1997) and La Niña (1999) events.

The major El Niño and La Niña events from the past 300 years are as follows:

El Niño	La Niña
1789-93	
1876-78	
1891	
1925-26	
	1954-56
1972-73	
1973-76	
1982-83	
	1988-89
1997-98	

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.25



Alt Text for Visual 2.1.25

El Niño	La Niña
▪ Warmer temperatures in the NW ▪ Cooler temperatures in the SE and SW ▪ Drier climate in the North, with less snowfall ▪ Wetter climate in the South and in California	▪ Warmer temperatures in the SE ▪ Cooler temperatures in the NW ▪ Drier climate in the SW and SE ▪ Wetter climate in the NW

Key Points

El Niño has several notable climatological impacts on the United States. During the winter season of El Niño years, temperatures are warmer than normal in the Northwest and North Central States and cooler than normal in Southeast and Southwest. The climate is drier in the North and wetter and stormier in the South and in California. These changes can result in the following weather hazards:

- Droughts in the Northwest
- Severe flooding or coastal flooding in the South
- Ice storms in the South
- Severe weather in the Great Lakes area
- Severe weather over the northern Gulf of Mexico and northern Florida. This is due to the shift of the Pacific jet stream, as a strong jet stream is a key ingredient in producing severe weather, such as tornadoes.

It is important to note, however, that **it would be inaccurate to label a hurricane, tropical storm, winter storm, drought, or flood strictly as an El Niño event.** El Niño simply alters or enhances certain climate patterns (e.g., the jet streams) and affects the track of storms and their intensity.

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

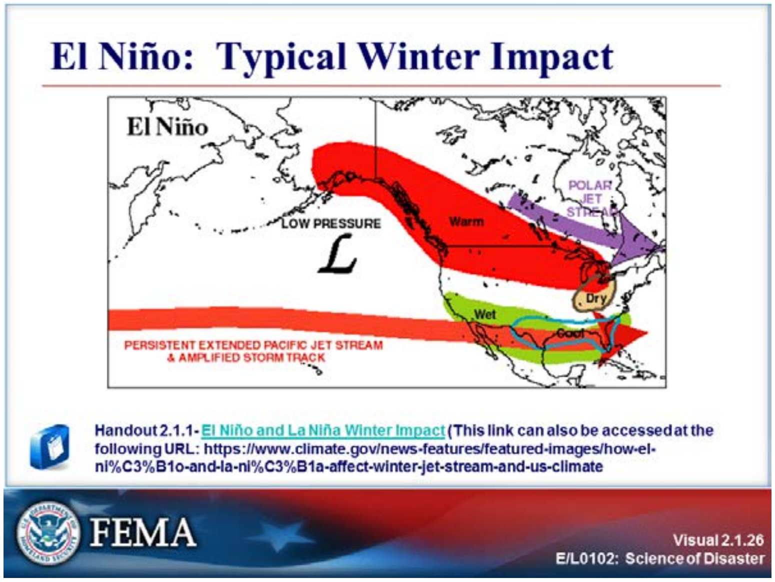
Visual 2.1.25 (Continued)

La Niña also has climatological impacts on the United States. During the late fall and winter seasons of La Niña years, there are generally:

- Warmer than normal temperatures in the Southeast
- Cooler than normal temperatures in the Northwest
- Drier climates in the Southwest and the Southeast
- Wetter and stormier climates in the Northwest

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.26



Key Points

This graph illustrates the typical January- to-March impacts on the United States during a moderate to strong El Niño. Note that:

- There is a strong, persistent jet stream and storm track across the South.
- The North has warmer, milder conditions.

These impacts result from four major changes:

- An extension of the East Asian jet stream eastward into the southwestern United States
- Above average west-to-east flow of jet stream winds across the country
- A shift of the storm track southward, moving from the northern to the southern part of the United States
- A shift of the main region of cyclone formation to the southeast, just west of the coast of California

See color handout 2.1.1: El Niño and La Niña Winter Impact

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.26 (Continued)

El Niño—winter vs. summer: Notice how differently El Niño affects the globe in winter months (December to February) and summer months (June to August). The regions with the greatest precipitation and temperature impacts due to shifts in the jet stream are highlighted with color.

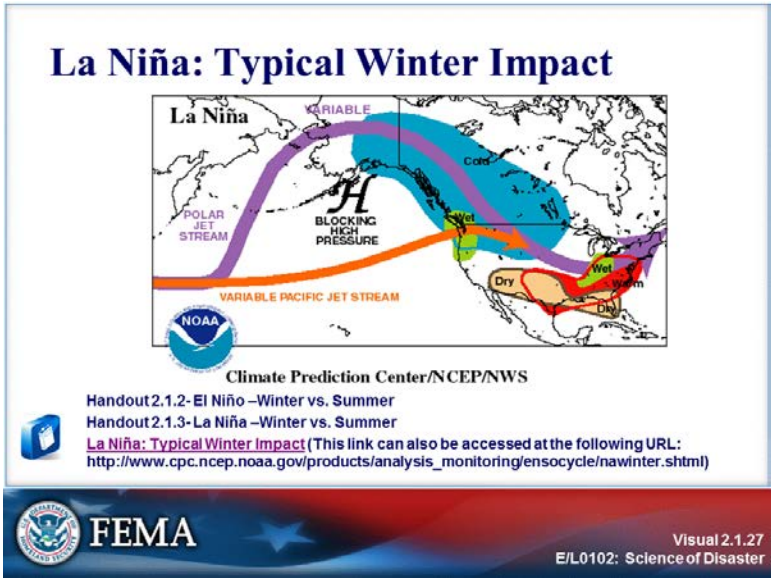
In the summer months, only one small area in the Northwest tends to experience unusually high precipitation. Other than this increase (and the typical heightened tendency for hurricanes to hit), most of the United States is unlikely to suffer any drastic impacts of El Niño during the summer months.

Remember, **El Niño tends to develop between March and June, and it is typically much stronger during the winter months.** This is because the equatorial Pacific sea-surface temperatures are usually at their warmest this time of the year.

See color handout 2.1.2: El Niño –Winter vs. Summer

CLIMATE FACTORS: EL NIÑO AND LA NIÑA

Visual 2.1.27



Key Points

This graph illustrates the typical January-to-March impacts on the United States during a moderate-to-strong La Niña. Note that there is a very wavy jet stream flowing over the United States as well as Canada. This generally results in stormier than average conditions in the northern part of the country, and warmer and less stormy conditions in the southern part.

This impact results from three major changes in atmospheric flow:

- An amplification of the mean wave pattern and increased meridional flow across the continent and the eastern North Pacific
- Increased blocking activity (Black H – “Blocking High Pressure”) over the high latitudes of the eastern North Pacific. (High pressure systems are a bit like the “bullies” of weather—they are big, and push everything else around, including weather systems and even jet streams.)
- The variability of the Pacific jet stream (orange line), with an average jet position that enters North America in the northwestern United States or southwestern Canada.

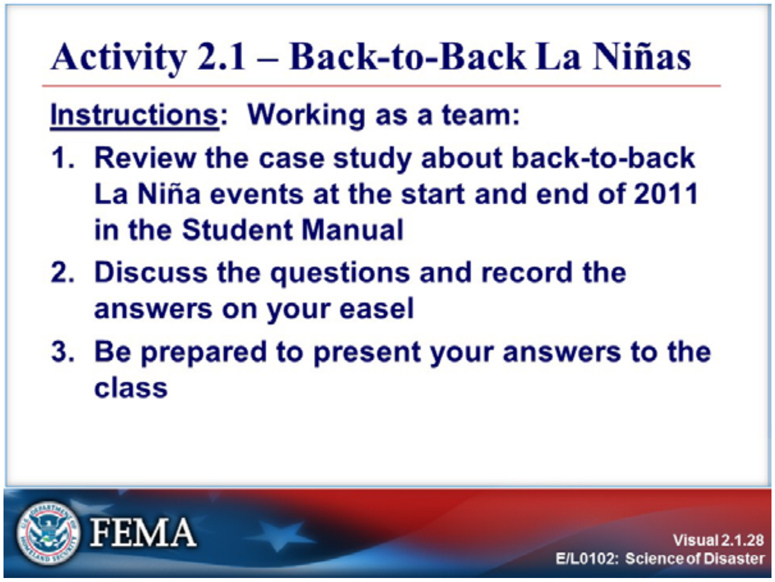
Notice how differently La Niña affects the globe in the winter months (December to February) and the summer months (June to August). The regions with the greatest precipitation and temperature impacts due to shifts in the jet stream are highlighted with color.

Like El Niño, most of the United States is unlikely to suffer any drastic impacts of La Niña during the summer months (again, other than the typical heightened tendency for hurricanes to hit).

See color handout 2.1.3: La Niña –Winter vs. Summer

ACTIVITY 2.1 – BACK-TO-BACK LA NIÑAS

Visual 2.1.28



Key Points

Instructions: Working as a team:

1. Review the case study about back-to-back La Niña events at the start and end of 2011 in the Student Manual.
2. Discuss the questions and record the answers on your easel.
3. Be prepared to present your answers to the class.

ACTIVITY 2.1 – BACK-TO-BACK LA NIÑAS

Visual 2.1.28 (continued)

Case Study: El Niño and La Niña don't always follow each other; occasionally, there are back-to-back El Niño episodes or back-to-back La Niña episodes. It is July and you have received a briefing from your regional National Weather Service meteorologist. You are aware that last year there was a La Niña episode and now current models predict that there will be another episode beginning this fall.

The 12 billion-dollar disaster of 2011 in the U.S. caused $200 billion in damages:

- **Texas, New Mexico, Arizona Wildfires, spring- fall:** 1 million acres in Texas were burned during this year's record wildfire season.
    - The Bastrop Fire in Texas was the most destructive fire in Texas history, destroying more than 1,500 homes.
    - The Wallow Fire consumed more than 500,000 acres in Arizona, making it the largest on record in Arizona.
    - The Las Conchas Fire in New Mexico was also the state's largest wildfire on record, scorching more than 150,000 acres while threatening the Los Alamos National Laboratory.
    - More than 3-million acres have burned across Texas during that wildfire season. Total damage in Texas alone due to loss of property, timber, and agriculture exceeds $750 million. Losses for wildfire activity across all three states exceeds $1 billion.
- **Midwest/Southeast Tornadoes and Severe Weather, June 18–22:** An estimated 81 tornadoes struck across Oklahoma, Texas, Kansas, Nebraska, Missouri, Iowa, and Illinois. Additional wind and hail damage occurred across Tennessee, Georgia, North Carolina and South Carolina. The storms caused more than $1 billion in insured losses, and total losses were greater than $1.3 billion.
- **Hurricane Irene, August 20–29:** Irene first struck the United States as a Category 1 hurricane in eastern North Carolina, then moved northward along the Mid-Atlantic coast. Wind damage in coastal North Carolina, Virginia, and Maryland was moderate, with considerable damage resulting from falling trees and power lines. Irene made its final landfall as a tropical storm in the New York City area and dropped torrential rainfall in the Northeast that caused widespread flooding. More than 7 million homes and businesses lost power during the storm, and Irene caused at least 45 deaths and more than $7.3 billion in damages.
- **Upper-Midwest flooding, summer:** Melting of an above-average snowpack across the northern Rocky Mountains, combined with above-average precipitation, caused the Missouri and Souris rivers to swell beyond their banks across the Upper Midwest. An estimated 11,000 people were forced to evacuate Minot, North Dakota because of the record-high level of the Souris River. Numerous levees were breached along the Missouri River, flooding thousands of acres of farmland. The flooding, which is ongoing, has caused more than $2 billion in damages.

ACTIVITY 2.1 – BACK-TO-BACK LA NIÑAS

Visual 2.1.28 (Continued)

- **Mississippi River flooding, spring-summer:** Persistent rainfall nearly tripled the normal precipitation amounts in the Ohio Valley, and, combined with melting snowpack, caused historical flooding along the Mississippi River and its tributaries. The region suffered $2- to-$4-billion in losses.
- **Southern Plains/Southwest drought, heat wave and wildfires, spring-summer:** Drought, heat waves and wildfires scorched through Texas, Oklahoma, New Mexico, Arizona, southern Kansas, western Arkansas, and Louisiana this year. In Texas and Oklahoma, respectively, 75% and 63% of range and pasture conditions were classified as "very poor" as of mid-August. Wildfire-fighting costs for the region are about $1 million per day. Well over $5 billion in damage has occurred so far, with more than 2,000 homes and structures lost.
- **Midwest/Southeast tornadoes, May 22–27:** Central and southern states saw approximately 180 twisters and 177 deaths within a week. A tornado rated EF-5 on the tornado-damage scale struck Joplin, Missouri, resulting in at least 141 deaths, making it the deadliest single tornado to strike the United States since modern tornado record keeping began in 1950. The total losses were greater than $7 billion, and an estimated $3 billion was needed to rebuild Joplin, which made it the single-costliest tornado in United States history.
- **Southeast/Ohio Valley/Midwest tornadoes, April 25–30:** This outbreak of tornadoes over central and southern states led to 327 deaths. Of those fatalities, 240 occurred in Alabama. The deadliest of the estimated 305 tornadoes in the outbreak was an EF-5 that hit northern Alabama, killing 78 people. Several major metropolitan areas were directly affected by strong tornadoes, including Tuscaloosa, Birmingham, and Huntsville in Alabama, and Chattanooga, Tennessee. Total losses exceeded $9 billion.
- **Midwest/Southeast tornadoes, April 14–16:** An outbreak over central and southern states produced an estimated 160 tornadoes. Despite the large overall number of tornadoes, few were classified as intense, with just 14 EF-3, and no EF-4 or EF-5, tornadoes identified. Total losses were greater than $2 billion. Thirty-eight people died, 22 of them in North Carolina.
- **Southeast/Midwest tornadoes, April 8–11:** An outbreak of tornadoes over central and southern states saw an estimated 59 tornadoes. Total losses were greater than $2.2 billion.
- **Midwest/Southeast tornadoes, April 4–5:** An outbreak of tornadoes over central and southern states saw an estimated 46 tornadoes. Total losses were greater than $2.3 billion. Nine people died.
- **Groundhog Day blizzard, Jan. 29–Feb. 3:** A large winter storm hit many central, eastern, and northeastern states. Chicago was brought to a virtual standstill when 1-to-2 feet of snow fell across the city. Total losses were greater than $2 billion, and the storm killed 36 people.

ACTIVITY 2.1 – BACK-TO-BACK LA NIÑAS

Visual 2.1.28 (Continued)

Additionally:

- 3 million residents lost power during an unseasonably early nor'easter storm from October 29–31.
- 19 tropical storms formed in the Atlantic during this year, the third-busiest season on record.

Some events in other countries that resulted from back-to-back La Niñas included:

- Historic droughts in East Africa and Northern Mexico
- The wettest 2-year period (2010–2011) in Australia's history, relieving a decade-long dry spell
- The coolest year for the globe on record (2011) since 2008. (However, temperatures remained above the 30-year average because of climate change.)

ACTIVITY 2.1 – BACK-TO-BACK LA NIÑAS

Visual 2.1.28 (Continued)

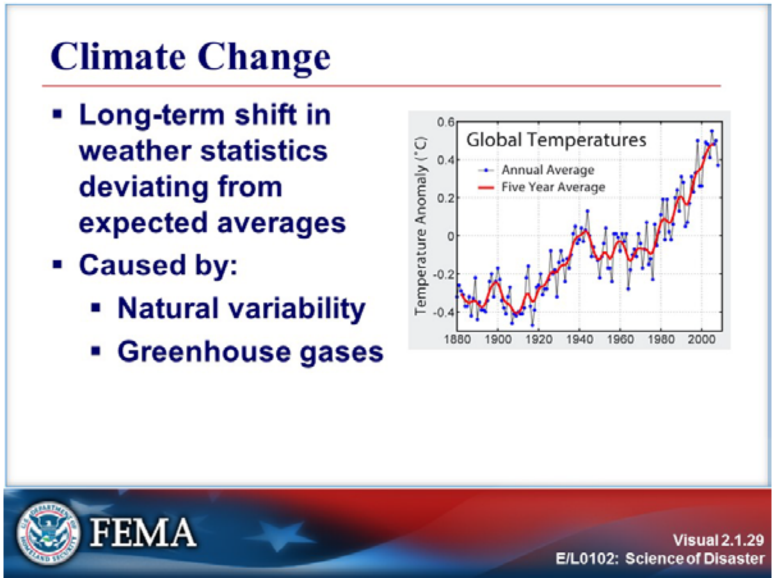
Activity 2.1 Worksheet

1. What do you think are some of the “expected side effects” of the La Niña associated weather events in your region?

2. Knowing that back-to-back events tend to amplify the general effects of the condition, what can you do to increase the preparedness of your community?

CLIMATE CHANGE

Visual 2.1.29



Key Points

Another major factor in climate variability is climate change. Climate change is broadly defined as a long-term shift in weather statistics that deviates from expected averages. Scientists have determined that we are, in fact, in a period of climate change; the last few decades have been the warmest period on record (i.e., since the mid-19th century).

This climate change ("global warming") is caused by two factors:

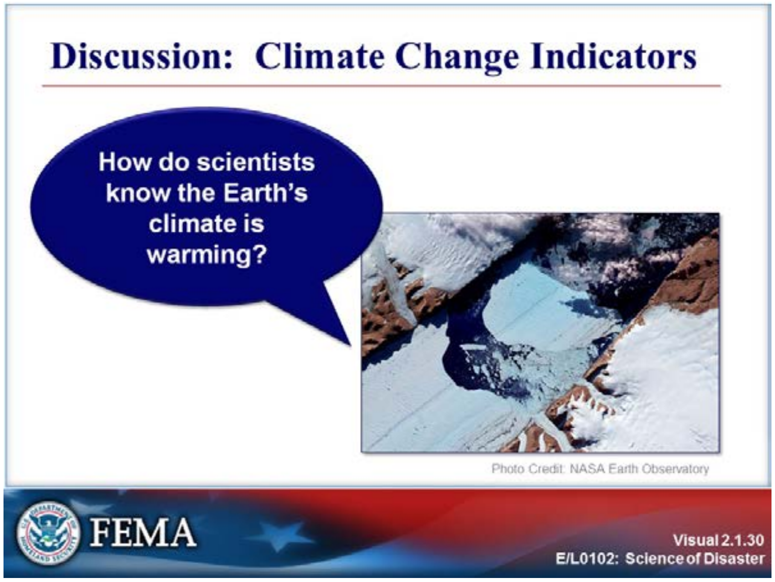
- **Natural variability:** Climate change is a naturally occurring phenomenon that is related to complex interactions between the oceans, the atmosphere, and land masses, as well as changes in the amount of solar radiation.

- **Greenhouse Gasses:** The greenhouse effect was first identified and studied in the early 1800s. Scientists observed that certain gases in the atmosphere such as water vapor, carbon dioxide, and methane absorbed natural long wavelength radiation emitted from the Earth. This process effectively warms the Earth above the temperature we would expect simply from our distance from the sun. The greater the abundance of greenhouse gasses, such as carbon dioxide and methane, in the atmosphere, the greater the degree of warming on the planet. The current level of CO_2 in the atmosphere is the highest in 650,000 years. The Intergovernmental Panel on Climate Change (IPCC) concluded in 2007 that "most of the observed increase in the globally averaged temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

Note: The record of global average temperatures was compiled by NASA's Goddard Institute for Space Studies. The "zero" on this graph corresponds to the mean temperature from 1961 to 1990, as directed by the Intergovernmental Panel of Climate Change (IPCC).

CLIMATE CHANGE

Visual 2.1.30



Key Points

Global warming has significant implications for both weather circulation and patterns (e.g., coastal sea levels, the thawing of the permafrost, the global circulation of weather), and non-weather events (e.g., species migration).

Discussion Question: How do scientists know the Earth's climate is warming, and what are the implications of that warming?

- **Weather and Climate**
  - U.S. and Global Temperature
  - High and Low Temperatures
  - U.S. and Global Precipitation
  - Heavy Precipitation
  - Drought
  - Tropical Cyclone Activity
- **Oceans**
  - Ocean Heat
  - Sea Surface Temperature
  - Sea Level
  - Ocean Acidity
- **Snow and Ice**
  - Arctic Sea Ice
  - Glaciers
  - Lake Ice
  - Snowfall
  - Snow Cover
  - Snowpack
- **Society and Ecosystems**
  - Streamflow
  - Ragweed Pollen Season
  - Length of Growing Season
  - Leaf and Bloom Dates
  - Bird Wintering Ranges
  - Heat-Related Deaths

Source for EPA climate change (This link can also be accessed at the following URL: https://www.epa.gov/climatechange)

CLIMATE CHANGE

Visual 2.1.30 (continued)

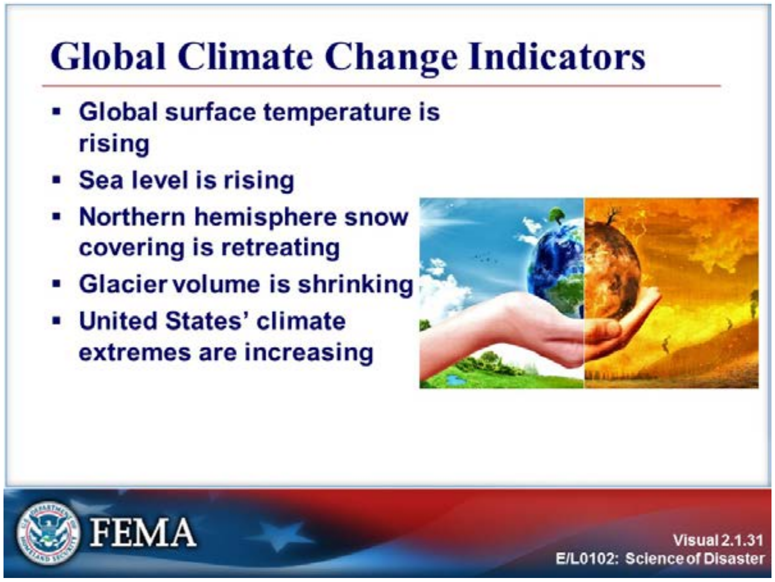
Attributing single events to climate change is difficult.

Imagine a professional baseball player that hits 10 home runs in one season. Then, after using steroids in the off-season, that same player hits 20 home runs. Although the overall increase in home runs may be attributable to steroid use, it is difficult to attribute any single home run to the power of the drugs, rather than the natural skill of the player.

Similarly, it is difficult to attribute any one weather event to climate change, rather than to natural variability resulting from global interactions.

CLIMATE CHANGE

Visual 2.1.31



Key Points

Global Surface Temperature is rising. Measurements **from both land-based and ocean-based instruments show a consistent rise in temperatures in the 20**th century. Measurements show that average temperature as increased by approximately 1.4°F since the early 20th century. The 20 warmest years have occurred since 1981, and 10 of the warmest years have occurred in the last 12 years.

Sea Level is Rising. "Global mean sea level has been rising at an average rate of approximately 1.7 mm/year over the past 100 years. Since 1993, global sea level has risen at an accelerating rate of around 3.5 mm/year." (This link can also be accessed at the following URL: http://www.ncdc.noaa.gov/indicators/) Sea level rises for two reasons: (1) Water expands as it heats up. As the oceans warm, their volume will increase and take up more space. More than half of the sea level rise is a result of the oceans warming. (2) Sea level rises because ice caps on continents melt. As more continental ice sheets melt, more water goes into the oceans. Melting sea ice does not cause sea level to rise.

Northern Hemisphere Snow Cover is Retreating. Satellites have been used to measure snow and ice cover since 1966. Eight of ten of the smallest May-measured snow covers have occurred since 2005. The smallest record of northern hemisphere snow cover was 2010.

Glacier Volume is Shrinking. The *2014 Bulletin of the American Meteorological Society State of the Climate* report indicates that glacier loss continues, and that the rate of glacier mass loss is accelerating. "Mean annual glacier losses per decade were -221 millimeters for the 1980s, -389 millimeters for the 1990s, and -726 millimeters for the 2000s. Since 1980, glaciers worldwide have lost a cumulative 16.8 meters of water equivalent." This loss will have profound impact on water availability in coming years.

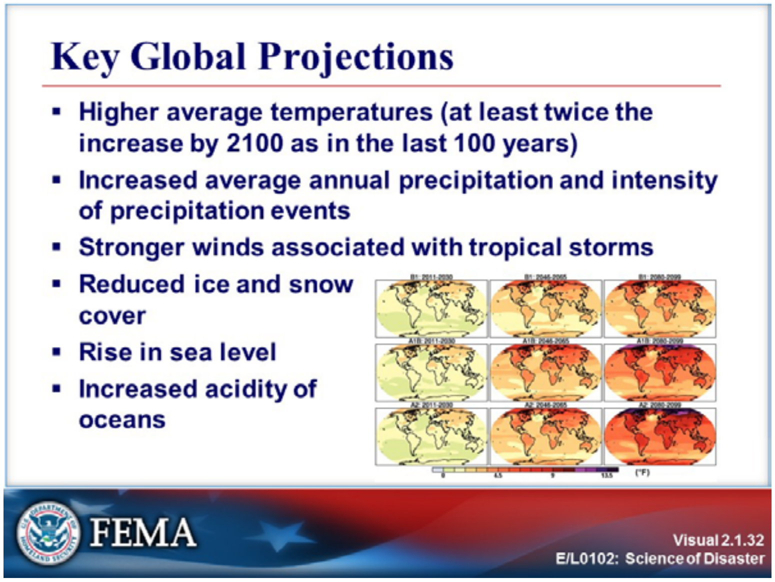
CLIMATE CHANGE

Visual 2.1.31 (continued)

United States Climate Extremes Are Increasing. The Climate Extremes Index is a measure of the number of rare extreme events across the contiguous United States. These events include temperature, precipitation, and storm intensity. The long-term average of extreme events should be 20 percent to account for the top and bottom 10 percent of extremes. Any value above 20 percent would indicate more extreme conditions. The last four decades has exhibited an increasing number of extreme events. 2015 showed a 41.2 percent and 2012 showed a 48.28 percent value areas.

CLIMATE CHANGE

Visual 2.1.32



Alt Text for Visual 2.1.32
Key Global Projections

- Higher average temperatures (at least twice the increase by 2100 as in the last 100 years)
- Increased average annual precipitation and intensity of precipitation events
- Stronger winds associated with tropical storms
- Reduced ice and snow cover
- Rise in sea level
- Increased acidity of oceans

Projected changes in global average temperatures under three emissions scenarios (rows)—low, medium, and high emissions

Key Points

Based on their study of the 26 indicators, scientists project higher average temperatures, increased amount and intensity of precipitation, and other changes. Below are some key projections for the United States:

Temperature

By 2100, the average United States. temperature is projected to increase by about 4°F to 11°F, depending on emissions scenario and climate model.

- An increase in average temperatures worldwide implies more frequent and intense extreme heat events or heat waves. The number of days with high temperatures above 90°F is expected to increase throughout the United States, especially in areas that already experience heat waves.

CLIMATE CHANGE

Visual 2.1.32 (Continued)

Precipitation

- Northern areas are projected to become wetter, especially in the winter and spring. Southern areas, especially in the West, are projected to become drier.
- Heavy precipitation events will likely be more frequent. Heavy downpours that currently occur about once every 20 years are projected to occur about every 4 to 15 years by 2100, depending on location.
- More precipitation is expected to fall as rain rather than snow, particularly in some northern areas.
- The intensity of Atlantic hurricanes is likely to increase as the ocean warms. Climate models project that for each 1.8°F increase in tropical sea surface temperatures, the rainfall rates of hurricanes could increase by 6-to-8 percent, and the wind speeds of the strongest hurricanes could increase by about 1-to--8 percent.
- Cold-season storm tracks are expected to continue to shift northward. The strongest cold-season storms are projected to become stronger and more frequent.

Seal Level Change

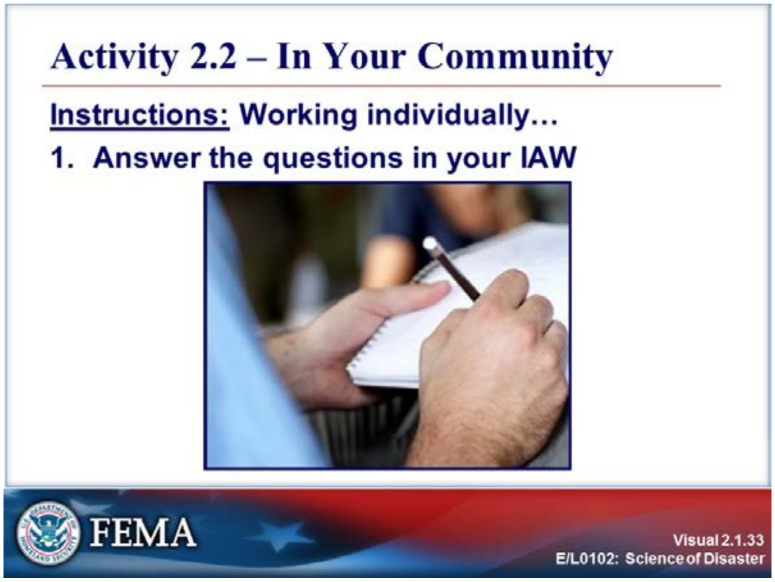
Regional and local factors will influence future relative sea level rise for specific coastlines around the world. For example, relative sea level rise depends on land elevation changes that occur as a result of subsidence (sinking) or uplift (rising). Assuming that these historical geological forces continue, a 2-foot rise in global sea level by 2100 would result in the following relative sea level rise:

- 2.3 feet at New York City
- 2.9 feet at Hampton Roads, Virginia
- 3.5 feet at Galveston, Texas
- 1 foot at Neah Bay in Washington State

Relative sea level rise also depends on local changes in currents, winds, salinity, and water temperatures, as well as proximity to thinning ice sheets.

ACTIVITY 2.2 –IN YOUR COMMUNITY

Visual 2.1.33



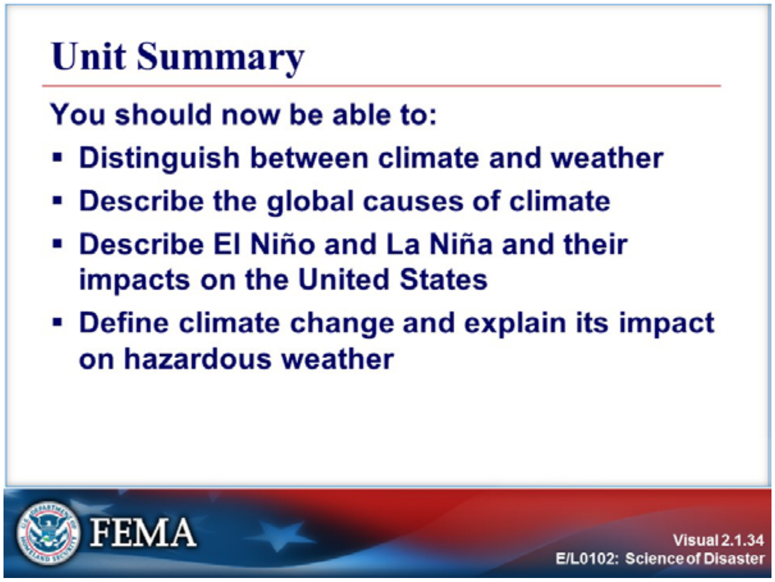
Key Points

Instructions: Working individually…

1. Answer the questions in your IAW.

UNIT SUMMARY

Visual 2.1.34



Key Points

UNIT 2. CONVECTIVE STORMS

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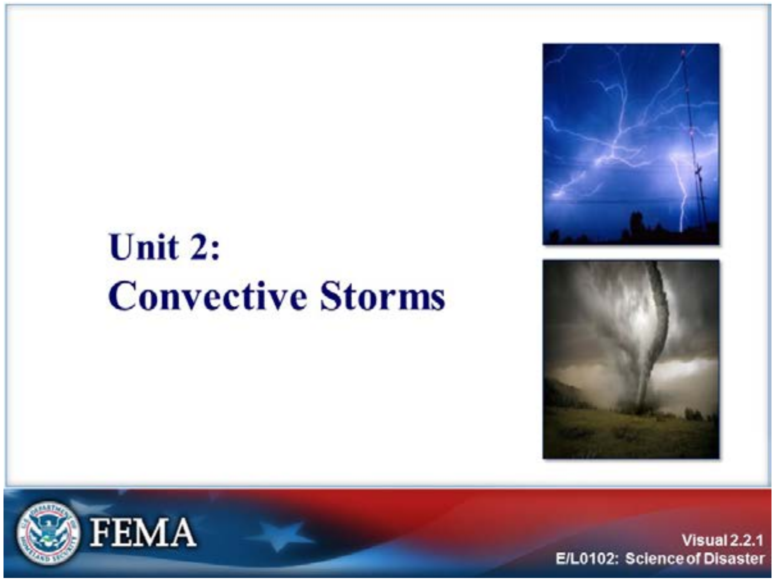
INTRODUCTION

Visual 2.2.1



Key Points

This unit will present key points about the science of convective storms, including thunderstorms and tornadoes.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Thunderstorms	20 minutes
Tornadoes • Activity 2.3 – 2011 Joplin, Mo Case Study	65 minutes
Unit Summary	5 minutes
Total Time	**1 hour 35 minutes**

INTRODUCTION

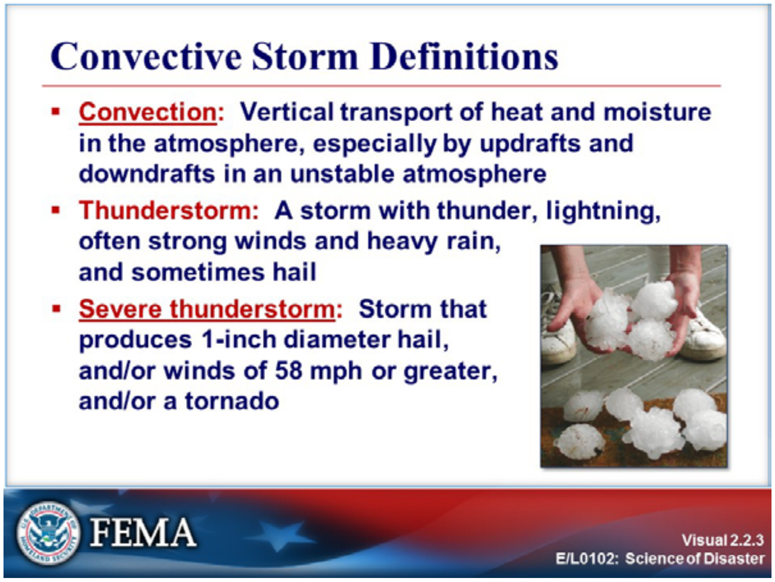
Visual 2.2.2

Key Points

Review the unit objectives as listed on the visual.

INTRODUCTION

Visual 2.2.3



Alt Text for Visual 2.2.3
Convective Storm Definitions

- Convection: Vertical transport of heat and moisture in the atmosphere, especially by updrafts and downdrafts in an unstable atmosphere
- Thunderstorm: A storm with thunder, lightning, often strong winds and heavy rain, and sometimes hail
- Severe thunderstorm: Storm that produces 1-inch diameter hail, and/or winds of 58 mph or greater, and/or a tornado

Key Points

Convection: As we have seen earlier, convection refers to transport of heat and moisture by the movement of a fluid. In meteorology, the term is used specifically to describe vertical transport of heat and moisture in the atmosphere, especially by updrafts and downdrafts in an unstable atmosphere. Although the terms “convection” and “thunderstorms” are often used interchangeably, thunderstorms are only one weather phenomenon that involves convection. (Source: NOAA)

If the mid-to-upper atmosphere is cool (denser) while the lower atmosphere is warm or moist (less dense), then the lower atmosphere becomes buoyant and unstable and begins to rise, initiating convection. This process of convection can be the result of a combination of factors, including:

- Daytime heating (the afternoon is a peak time for thunderstorms because this is when the ground is warmest).
- Landscape (e.g., if moving air hits a mountain, it is forced upward).
- The lifting of warm air over cold air along a front.

INTRODUCTION

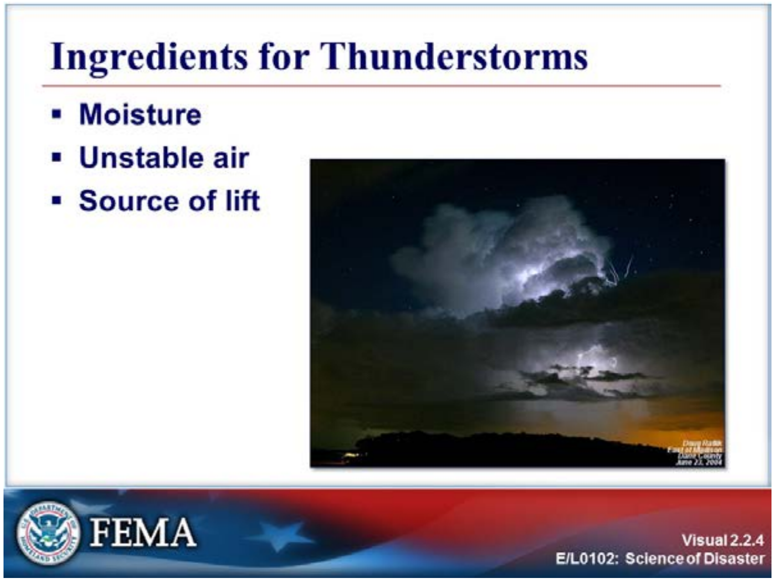
Visual 2.2.3

Thunderstorm: A thunderstorm is defined as a storm with thunder, lightning, often strong winds and heavy rain, and sometimes hail.

A **severe thunderstorm** is defined as a thunderstorm that produces any one or more of the following conditions: 1-inch diameter hail (the size of a quarter), winds of 58 mph or greater, and/or a tornado. Severe thunderstorms can also produce heavy rain, and flash floods. They have strong vertical wind shear.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.4



Key Points

The three ingredients necessary for thunderstorm formation are:

- Moisture (e.g., water vapor from the Atlantic, Pacific, Gulf of Mexico, or Great Lakes)
- Unstable air (i.e., an environment in which warm, rising air can maintain upward motion)
- A source of lift (e.g., cold fronts, warm fronts, gust fronts, sea breezes, or lake breezes)

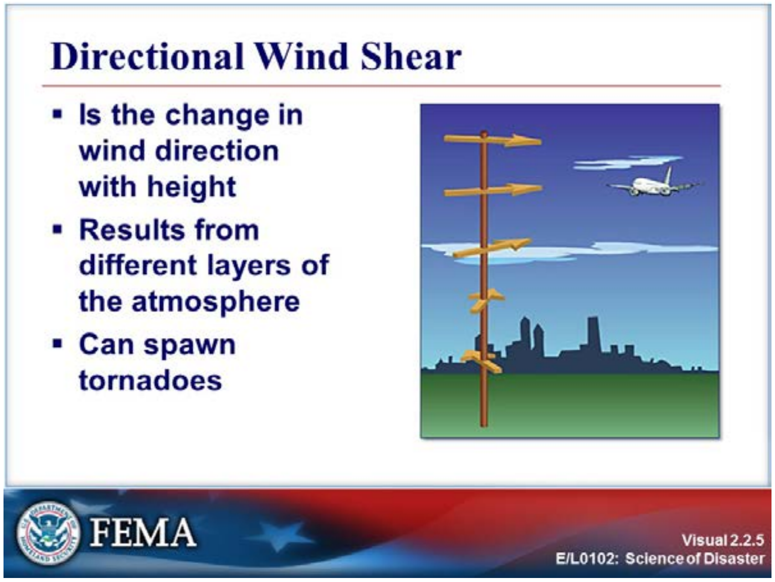
In short, thunderstorms require warm, humid air rising in an unstable environment.

As discussed in the previous unit, a cold front is the leading edge of an advancing cold air mass. At the surface, these fronts mark where cold air overtakes and replaces warmer air.

During the summer, cold fronts often initiate thunderstorms. (In cold weather, they produce hazardous winter conditions.)

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.5



Key Points

Next we will look at some key components of thunderstorms, including wind shear, speed shear, lightning, and thunder.

- **Wind shear:**
  - o Is the rate at which wind velocity changes from point to point in a given direction
  - o Can be speed shear (where speed changes between the two points, but not direction), direction shear (where direction changes between the two points, but not speed), or a combination of the two

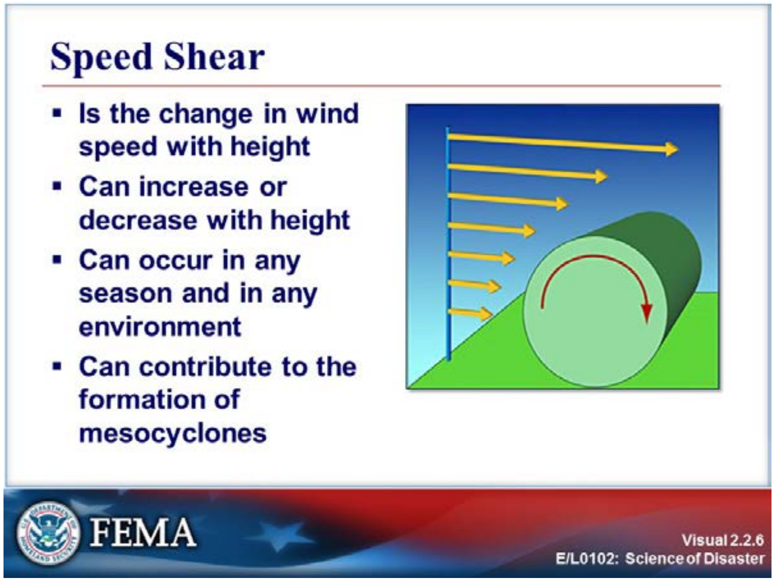
- **Directional wind shear** is the change in wind direction with height resulting from the different layers of the atmosphere.

  For example, say that the image on the visual is looking north. The wind near the surface is blowing to the northwest. However, as the elevation increases, the direction veers (changes direction in a clockwise motion), changing to south, then southwest, and finally west. This illustrates the danger that directional wind shear can pose for aircrafts, particularly during landing or takeoff.

- **Vertical directional wind shear**—which is a rising, twisting motion—can result in wind rotation and even spawn a tornado. In fact, because wind shear can make a roaring sound, it is often confused with a tornado.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.6



Key Points

Speed shear is the change in wind speed with height.

Speed shear can also decrease with height, resulting in stronger winds at the surface, and can occur in any season, and in any environment.

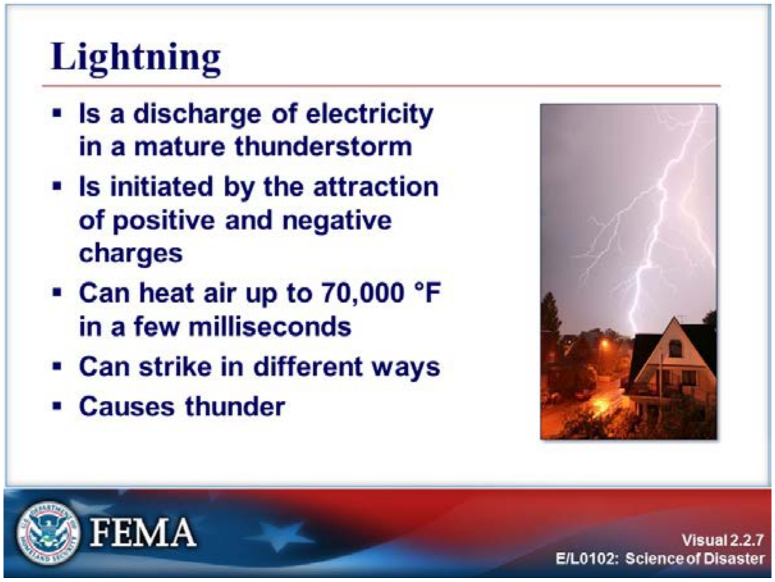
The image on the visual illustrates how, with an increase in height, there is an increase in wind speed. This tends to create a rolling affect to the atmosphere and is believed to be a key component in the formation of mesocyclones.

- A **mesocyclone** is a vortex of air, approximately 2 to 50 miles in diameter within a convective storm. Mesocyclones are most often associated with a localized low-pressure region within a severe thunderstorm. Such thunderstorms can feature strong surface winds and severe hail. Mesocyclones often occur together with updrafts in supercells where tornadoes may form.

- Mesocyclones are believed to form when strong changes of wind speed and/or wind shear set parts of the lower part of the atmosphere spinning in invisible tube-like rolls. The convective updraft of a thunderstorm then draws up this spinning air, tilting the rolls' orientation upward (from parallel to the ground to perpendicular) and causing the entire updraft to rotate as a vertical column.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.7



Key Points

Lightning characteristics: Lightning:

- Is a discharge of electricity in a mature thunderstorm
- Is initiated by the attraction of positive and negative charges. When the electrical potential builds up to overcome resistance of the air in the atmosphere, lightning will occur.
- Can strike in different ways, including:
  - o Within a cloud
  - o From cloud to cloud
  - o From cloud to surrounding air
  - o From cloud to ground
- Creates thunder.

Lightning dangers: Lightning is a serious danger, and strikes the United States an estimated 20 million times a year. You can be struck by lightning even if you are away from the thunderstorm; if you are close enough to hear the thunder, you are close enough to be struck by lightning.

- In the United States, lightning kills an average of 54 people every year.
- In 2011, there were 26 fatalities in 18 states and Guam.
- Hundreds more are permanently injured every year.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.7 (Continued)

People struck by lightning suffer from a variety of long-term, debilitating symptoms, including:

- Memory loss
- Attention deficit.
- Sleep disorders
- Chronic pain
- Dizziness
- Stiffness in joints
- Irritability
- Fatigue
- Muscle spasms
- Depression

Thunder: Even though lightning only has a diameter of 1-2 inches (2-to-5 cm), it can heat air up to 70,000 °F (39,000 °C) in just a few milliseconds. This sudden and drastic increase in temperature causes the surrounding air to expand violently at a rate faster than the speed of sound. This results in a shock wave that—after extending 30 feet—becomes an ordinary sound wave or thunder.

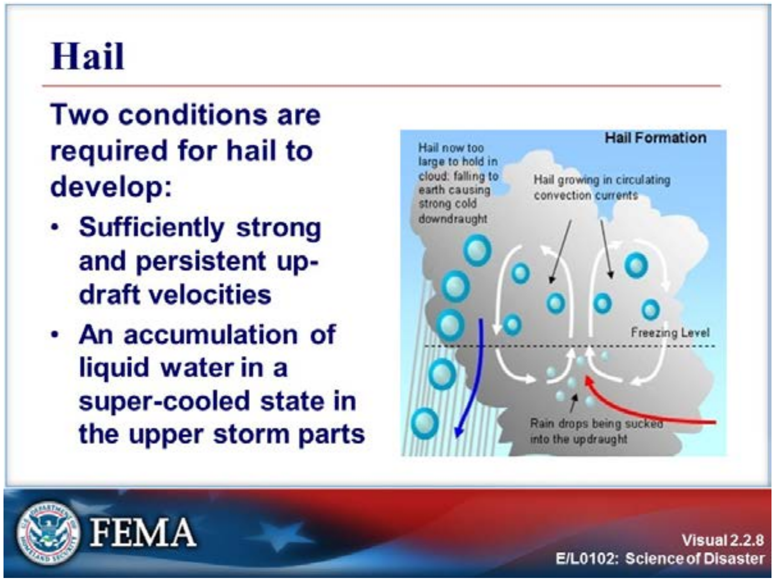
How close is the storm? Light from lightning travels at the speed of 186,000 miles per second. Sound travels at a much slower rate—only about 1 mile every 5 seconds. This explains why the light from lightning reaches us before the sound of thunder.

Knowing this information, you can use a “trick” to estimate how close a storm is to you.

1. Count the number of seconds it takes between the time you see a lightning flash and before you hear the thunder.
2. Each 5 seconds counted equals one mile. For example, if you count 15 seconds, the flash was 3 miles away. Anything under 6 miles is still in the high danger zone.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.8



Alt Text for Visual 2.2.8
Hail
Two conditions are required for hail to develop:

- Sufficiently strong and persistent up-draft velocities
- An accumulation of liquid water in a super-cooled state in the upper storm parts

Image of hail formation graph where rain drops are sucked into cloud and circulate until they form ice balls. Once the hail gets too large, it falls to the earth.

Key Points

Studies of thunderstorms indicate that two conditions are required for hail to develop: sufficiently strong and persistent up-draft velocities and an accumulation of liquid water in a super-cooled state in the upper parts of the storm. Hailstones are formed as water vapor in the warm surface layer rises quickly into the cold upper atmosphere. The water vapor is frozen and begins to fall; as the water falls, it accumulates more water vapor. This cycle continues until there is too much weight for the updraft to support and the frozen water falls too quickly to the ground to melt along the way.

Hail may be spherical, conical, or irregular in shape and can range in size from barely visible in size to grapefruit-sized dimensions. Hailstones equal to or larger than a penny are considered severe.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

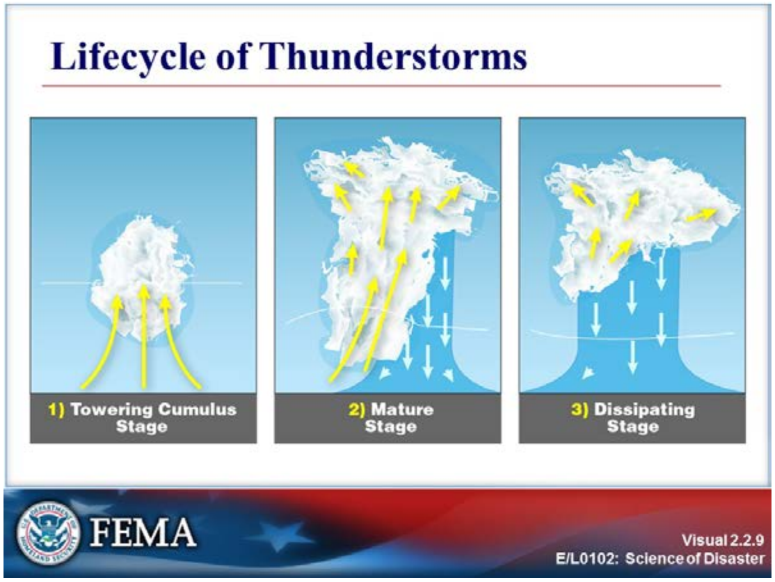
Visual 2.2.8 (continued)

NWS Hail Size Estimates	
Size	**Inches in Diameter**
Pea	1/4 inch
Marble/mothball	1/2 inch
Dime/Penny	3/4 inch
Nickel	7/8 inch
Quarter	1 inch
Ping-Pong Ball	1 1/2 inch
Golf Ball	1 3/4 inches
Tennis Ball	2 1/2 inches
Baseball	2 3/4 inches
Tea cup	3 inches
Grapefruit	4 inches
Softball	4 1/2 inches

Hail falls in swaths that can be from t20 to 100 miles long and from 5 to 30 miles wide. A hail swath is not a large continuous path of hail but generally consists of a series of hail cells that are produced by individual thunderstorm clouds traveling in the same area.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.9



Key Points

This diagram illustrates the three stages of thunderstorm development:

- **Stage 1: Towering Cumulus Stage or Developing Stage.** Stage 1 consists entirely of updraft—a small-scale current of rising air. In this stage, clouds have a puffy, cauliflower appearance. There is no rain yet.

- **Stage 2: Mature Stage.** Stage 2 consists of both updraft and downdraft. In this stage, a "fuzzy," flat cloud formation resembling an anvil forms at the top of the storm, but parts of the cloud are still distinct. The characteristic anvil shape results from warm air being unable to rise any further, and spreading out laterally. Severe weather occurs in this stage.

  Strong downdrafts may result in downbursts (outward burst of damaging winds on or near the ground) or microbursts (strong, concentrated downbursts). Downburst winds can produce damage similar to a strong tornado. Although usually associated with thunderstorms, downbursts can occur with showers too weak to produce thunder.

- **Stage 3: Dissipating Stage.** Stage 3 consists entirely of downdraft—a small-scale column of air that rapidly sinks toward the ground. In this stage, the whole cloud begins to dissipate and appears "fuzzy." This stage occurs when the storm no longer has enough warm air rising to sustain it, and it begins to die out.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.10

Key Points

This video explains updraft and downdraft in greater detail.

Video Transcript:

Just about any thunderstorm can produce severe weather, but the most dangerous weather often occurs with a supercell storm. A supercell is a highly organized thunderstorm that's capable of producing a variety of violent weather.

Supercells form in atmospheric conditions that help them to sustain themselves for long periods of time, so their lifetimes may be measured in hours instead of minutes. The most significant tornadoes and the largest hail usually come from supercell thunderstorms.

Every thunderstorm starts with what is called an updraft. The updraft consists of warm and humid air that rises much like a hot air balloon. The stronger the updraft, the more likely the storm is to produce severe weather. In the most intense storms, the air in an updraft may be over 100 miles an hour going straight up.

No matter how powerful an updraft may be, rain and hail will eventually move outside of the strongest updraft, and gravity will bring the rain-cooled air and precipitation to the ground. This forms the second part of a thunderstorm, the downdraft.

THUNDERSTORMS: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.10 (Continued)

A downdraft may bring any combination of rain, hail, and strong winds to the ground. When the downdraft reaches the surface, it has nowhere to go but sideways. Rain-cooled dense air in the downdraft will spread out in all directions.

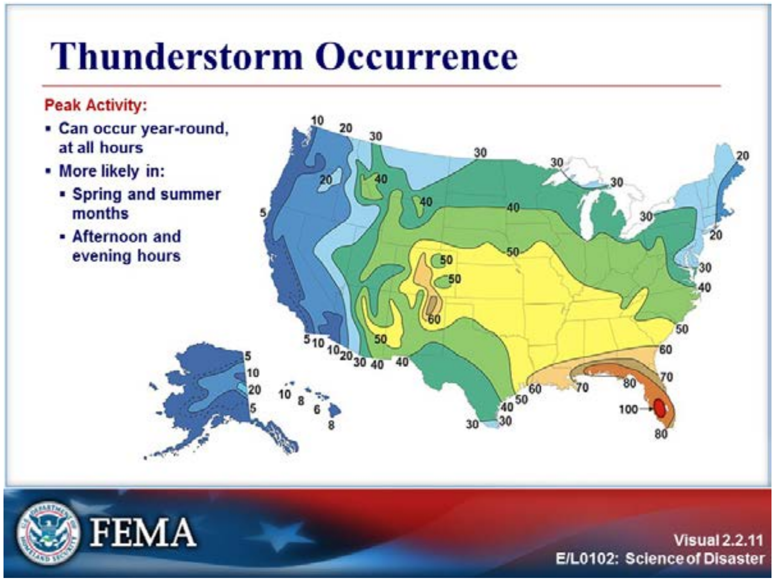
A supercell has an updraft and a downdraft. But what makes a supercell special is its rotating updraft. This rotation in the storm makes the updraft more intense and helps make the storm more persistent and much more organized.

Here's a supercell off to the west, and we can see the updraft on the southern part of the storm. We know it's the updraft area because of the smooth flat cloud base and the absence of rain. You may hear this referred to as the rain-free base or the updraft base area. It looks like this because the air—in this case we call it inflow—is flowing into the storm and rising up into the base of the storm.

This usually keeps most of the hail and rain from falling straight back down. The rainy downdraft can be seen to the north of the updraft, and it's pretty easy to tell that we're looking at air coming down out of the storm and blowing away from the storm. This is the outflow part of the storm. Knowing the location of updraft and downdraft is really important when it comes to identifying where a tornado might be developing.

THUNDERSTORMS: OCCURRENCE

Visual 2.2.11



Key Points

Geographical distribution: This map shows the average number of thunderstorm days each year throughout the United States. The areas in yellow, tan, brown, and red represent the highest occurrences of thunderstorms per year, and the areas in blue and green represent the lowest.

- **Florida is especially susceptible to thunderstorms.** This is due to the warm, moist air from the Gulf of Mexico and Atlantic Ocean, the humidity, and the high surface temperatures. The southeastern coastal areas have the highest number of thunderstorms, and the area between Tampa and Orlando in Florida has the highest frequency of cloud-to-ground lightning.

- **There is a high occurrence of thunderstorms in the mid-section of the United States (yellow, tan), especially around the Rocky Mountains.** Recall that convection (the vertical transport of heat and moisture in an unstable atmosphere) can result from a mountainous landscape—if moving air hits a mountain, it results in strong upward motions of air.

- **Unlike the east coast, the west coast has a low number of thunderstorms per year.** This is due to a lack of the three conditions necessary for thunderstorms: moisture, sources of lift, and unstable air. Cooler Pacific waters result in less moisture, less humidity, and cooler, more stable air. Regions along the Pacific west coast also have the least cloud-to-ground lightning.

THUNDERSTORMS: OCCURRENCE

Visual 2.2.11 (Continued)

Peak activity: Although thunderstorms can occur year-round and at all hours, thunderstorms are more likely to occur in the warmth of spring and summer months and in the afternoon and evening hours. For example:

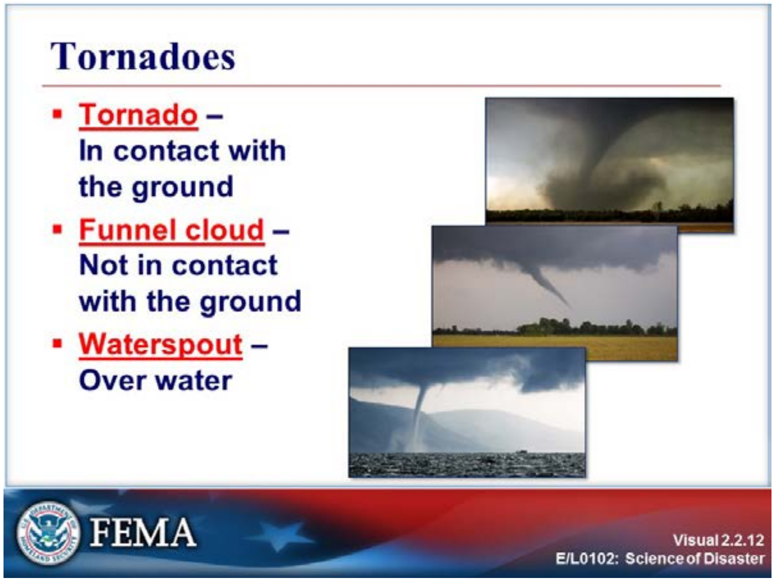
- For the Gulf coast and southeastern states, thunderstorms frequently occur in the afternoon.
- In the plains states, thunderstorms frequently occur in the late afternoon and at night.

Recall that, because of diurnal temperature variation, the ground is warmest in the afternoon from daytime heating, resulting in unequal heating, greater instability in the air, and higher chances of thunderstorm formation.

However, at any given moment, there are an estimated 1,800 thunderstorms occurring around the globe.

TORNADOES: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.12



Key Points

A rotating updraft—the result of wind shear—is the key to the development of a tornado, and it is this rotation or spinning that creates the well-known funnel shape. Rotating winds include tornadoes, funnel clouds, and waterspouts.

- A **tornado** is a rapidly rotating column of air that comes in contact with the ground. These columns of air are byproducts or side effects of severe thunderstorms.
- A **funnel cloud** is slightly different than a tornado, in that it is a rapidly rotating column of air that is not in contact with the ground.
- **Waterspouts** are tornadoes that form over water.

Other terms you will hear associated with the severe thunderstorms that cause tornadoes, include the following:

- **Supercell thunderstorm** is a thunderstorm that has a deep, steadily rotating updraft or a “mesocyclone” that can reach speeds of more than 100 miles per hour. These thunderstorms can produce extremely large hail, extreme winds, flash flooding, and violent tornadoes; in fact, almost all major tornadoes in the United States result from supercell thunderstorms.

TORNADOES: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.12 (Continued)

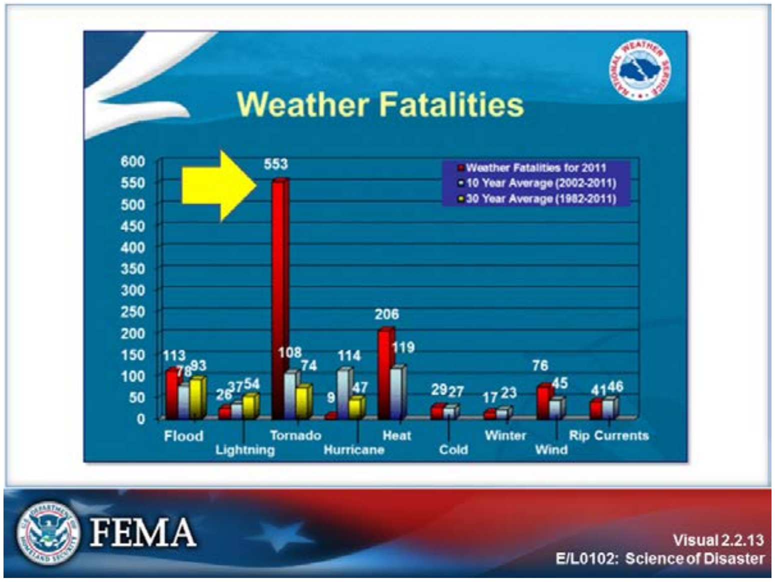
- **Squall line** is a line of closely spaced and usually severe thunderstorms. Squall lines often occur along or ahead of a cold front and can spawn tornadoes. Squall lines usually advance rapidly into a warm moist air mass, which then feeds into the updrafts of the oncoming thunderstorms and maintains them. If a squall line slows or stalls, it usually weakens because it does not have a new supply of warm, moist air.

- **Tornadic activity** is a loosely defined expression that refers to conditions that are likely to spawn tornadoes and also to the tornadoes that are presently occurring or have already occurred. Note that in some cases, tornadoes are not visible because they have not picked up debris.

- **Tornado outbreak** is another loosely defined term that refers to a number of tornadoes that occurred during a single weather event. A single supercell thunderstorm can produce more than one tornado, but most of the tornadoes in an outbreak occur from separate thunderstorms, often from a line of such storms that constitute a squall line.

TORNADOES: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.13



Alt Text for Visual 2.2.13

Weather Type	Weather Fatalities	10 Year Average (2002-2011)	30 Year Average (1982-2011)
Flood	113	78	93
Lightning	26	37	54
Tornado	553	108	74
Hurricane	9	114	47
Heat	206	119	NA
Cold	29	27	NA
Winter	17	23	NA
Wind	76	45	NA
Rip Currents	41	46	NA

Key Points

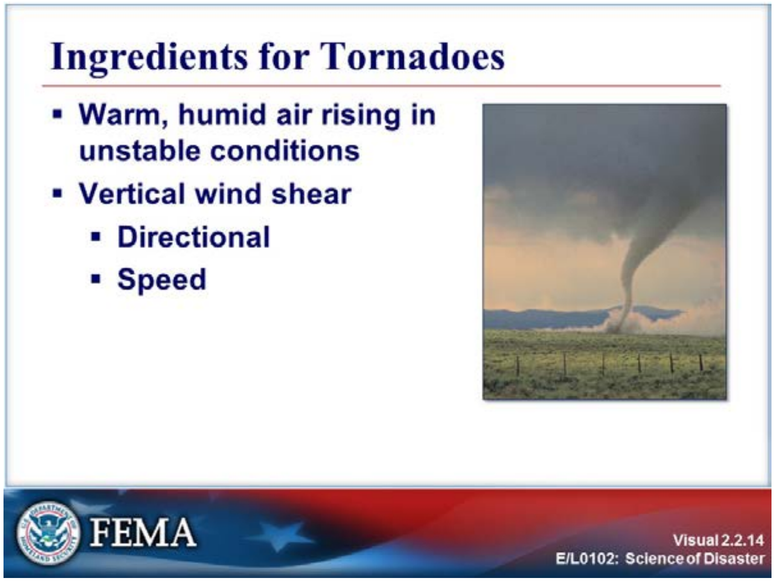
Tornadoes can be tremendously destructive, both of property and human lives.

As you can see in this chart, tornadoes were uniquely devastating in 2011, and they far outstrip the fatalities in any other category for that year.

The tornado in Joplin, Missouri, on May 22, 2011, caused an estimated $2.8 billion in damage, using 2011 dollars (adjusted for older years using the consumer price index).

TORNADOES: INGREDIENTS AND CHARACTERISTICS

Visual 2.2.14



Key Points

Because tornadoes are a by-product of thunderstorms, the ingredients for tornadoes are the same as the ingredients for thunderstorms. In order for a tornado to form, there must be:

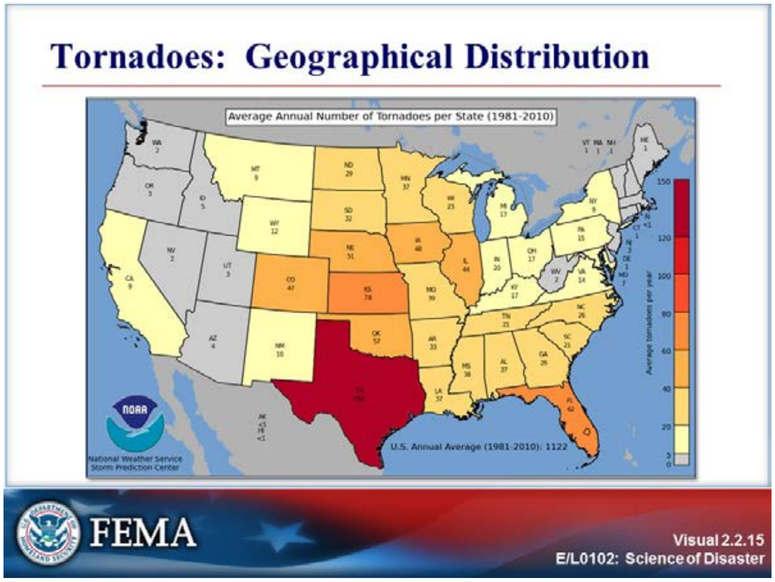
- Warm, humid air rising in an unstable environment
- Vertical wind shear (directional and/or speed)

The visible column of a tornado is composed of water droplets formed by condensation in the funnel. The vortex (or multiple vortices) pulls in air from near the ground, along with dirt and debris. The dirt and debris block light, giving the tornado a dark color.

The fast-moving winds of a tornado (either flowing into the tornado or in the main tornadic circulation) are what cause most of the damage.

TORNADOES: OCCURRENCES

Visual 2.2.15



Key Points

Like thunderstorms, tornadoes are not limited to any particular part of the country. In fact, tornadoes have occurred in every single state in the United States.

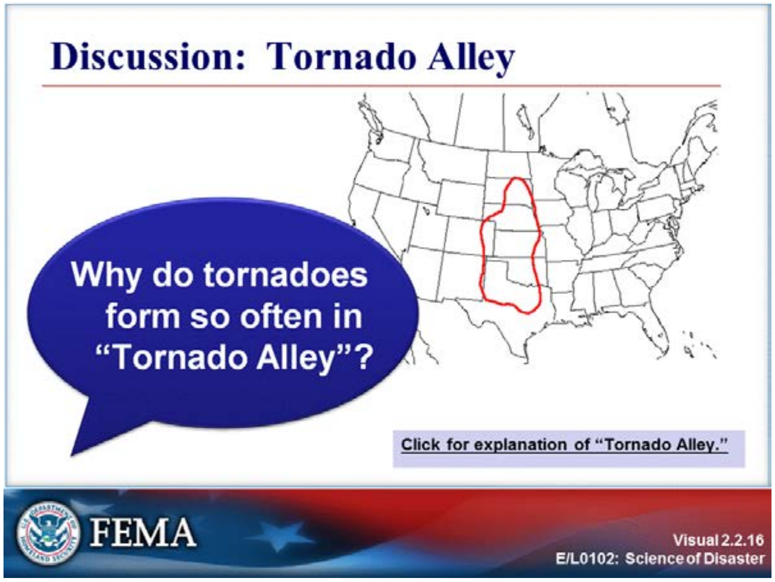
However, some areas are more susceptible to tornadoes due to their unique climate and landscape.

This map shows the geographic distribution of tornadoes across the United States from 1981 to 2010. The two areas with the highest frequency of tornadoes are:

- Florida, because of the high frequency of thunderstorms, as well as the influence of tropical storms and hurricanes
- The section of the country referred to as “Tornado Alley”

TORNADOES: OCCURRENCES

Visual 2.2.16



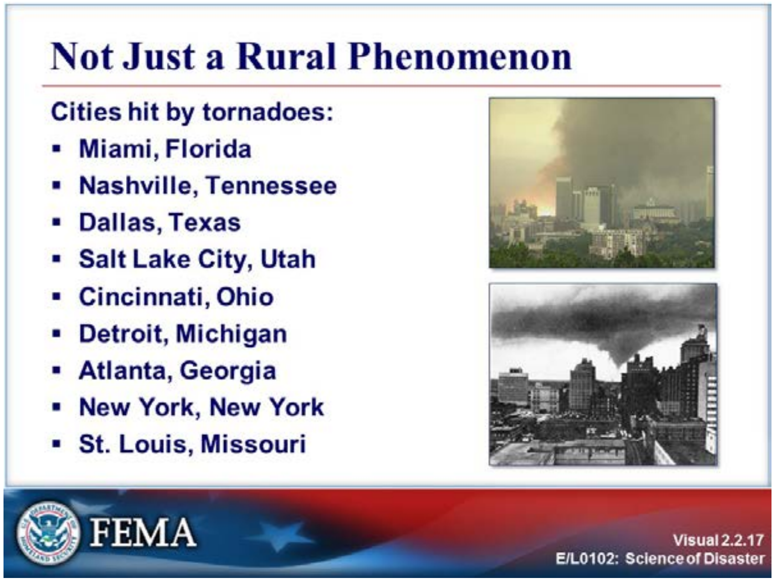
Key Points

"Tornado Alley" is a nickname given to a region of the central United States that experiences a disproportionately high frequency of tornadoes every year. This area stretches from central Texas to northern Iowa. The thunderstorm that brought down Flight 191 in the case study occurred in the afternoon, in the summer, in "Tornado Alley."

Discussion Question: Why do tornadoes form so often in "Tornado Alley"?

TORNADOES: OCCURRENCES

Visual 2.2.17



Key Points

It is a common myth that tornadoes do not strike urban areas or cities. Tornadoes have, in fact, hit many urban areas and cities, including those listed on the visual.

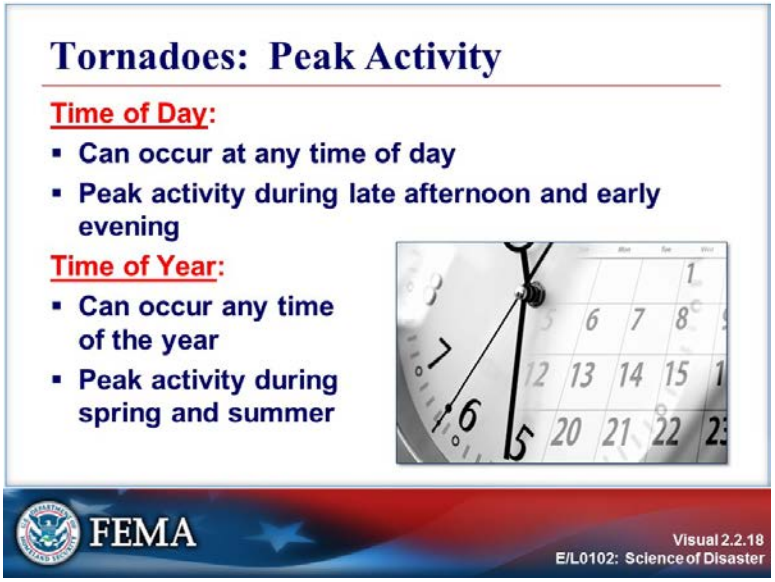
The next several pages will present key information about the geographical and seasonal trends of convective storms in the United States.

PHOTO:

The images on the visual show tornadoes striking the cities of Salt Lake City, Utah (top) and Dallas, Texas (bottom).

TORNADOES: OCCURRENCES

Visual 2.2.18



Key Points

Time of Day: Tornadoes can occur at any time of day. Peak activity occurs during late afternoon and early evening. In the southeast, many tornadoes do occur in the night and morning hours.

Time of Year: Tornadoes can occur any time of the year. Peak activity occurs during spring and summer.

The frequency of tornado formation is closely related to the clash of warm and cold air masses in the progression of the warm season. As a result:

- Early spring tornadoes tend to occur in the southeast and south-central regions.
- Late spring tornadoes generally occur farther north, in and around Kansas and Nebraska.
- In mid-summer, most of Tornado Alley is susceptible to tornadoes.
- In late summer, the upper Midwest and Ohio valleys tend to have stronger tornadoes.
- In late autumn, the pattern shifts back southward.

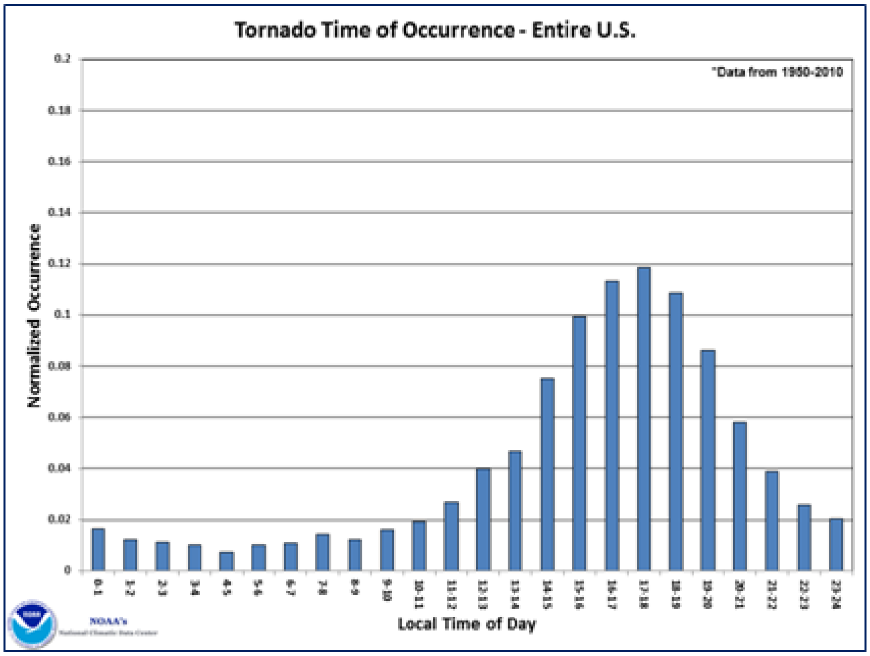
Although the winter months have historically yielded the fewest tornadoes, deadly winter outbreaks can and do occur.

More detail is provided in the following graphs.

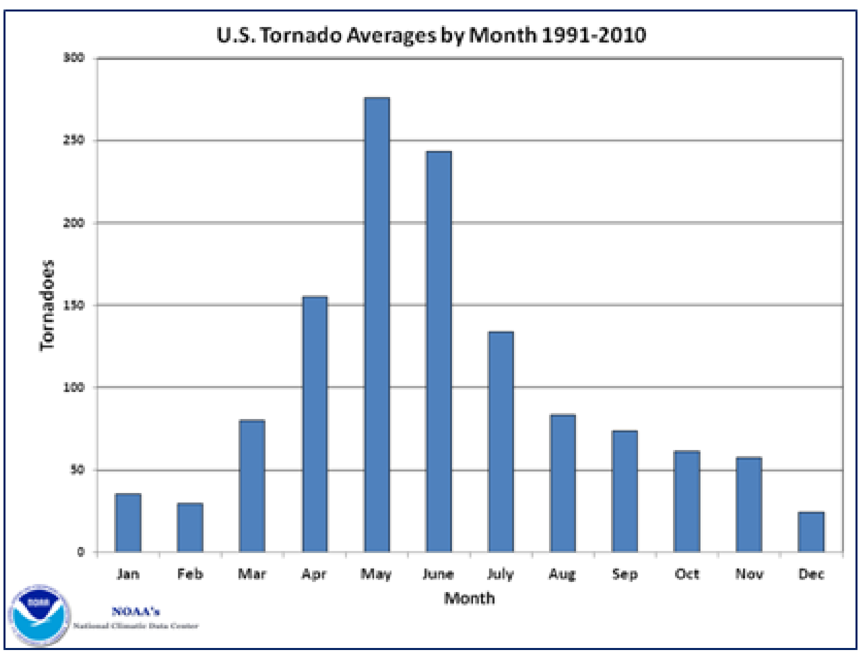
TORNADOES: OCCURRENCES

Visual 2.2.18 (Continued)

This graph shows the average time of day at which tornadoes occurred across the United States from 1980 to 2010, with peak activity in late afternoon and early evening.



This graph shows the average monthly number of tornadoes from 1991 to 2010 in the United States. Although the peak month is May, tornado activity is not limited to any particular time of year. However, tornadoes—like thunderstorms—happen most frequently in the spring and summer months.



TORNADOES: OCCURRENCES

Visual 2.2.19

Alt Text for Visual 2.2.19

2011: Deadly Tornado Season

- 1,704 confirmed tornadoes, 553 confirmed fatalities in the United States
- Contributing factors:
  - La Niña's effect on jet stream
  - Influx of moist and humid air
  - Formation of massive thunderstorms in Tornado Alley spanning multiple States

Key Points

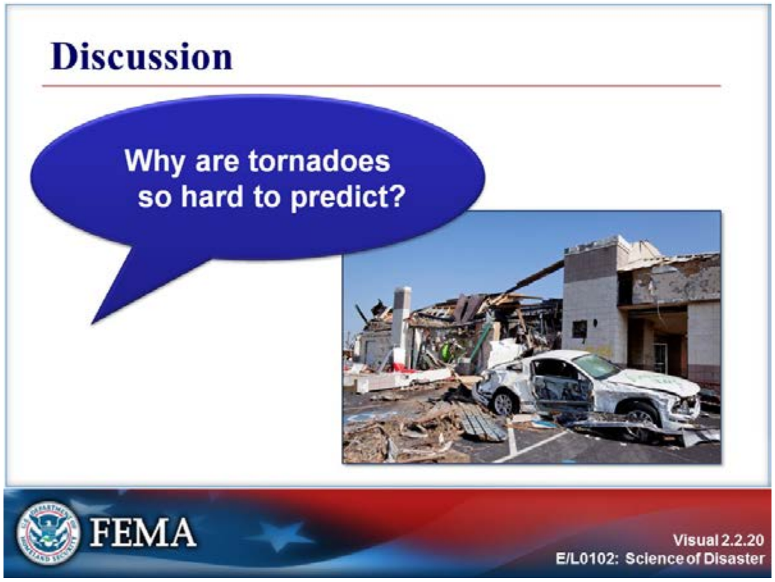
The 2011 outbreak of tornadoes across the southern United States (which included the massively destructive tornado in Joplin, Missouri) was devastating and record breaking.

- On the **mesoscale** and **synoptic scale**, the 2011 tornado outbreak resulted from the formation of massive thunderstorms in Tornado Alley, fed from an influx of moist and humid air. The thunderstorms stretched across multiple states, spawning tornadoes that lasted as long as 10 minutes.

- On a **global scale**, researchers have concluded that La Niña played a factor in the 2011 tornado outbreak. As you learned in the previous unit, La Niña affects the position of the jet stream, intensifying and shifting weather patterns on a national scale. The position of the jet stream during the 2011 outbreak was similar to its position during two other massive tornado outbreaks in 2002 and 1974.

TORNADOES: PREDICTION

Visual 2.2.20



Key Points

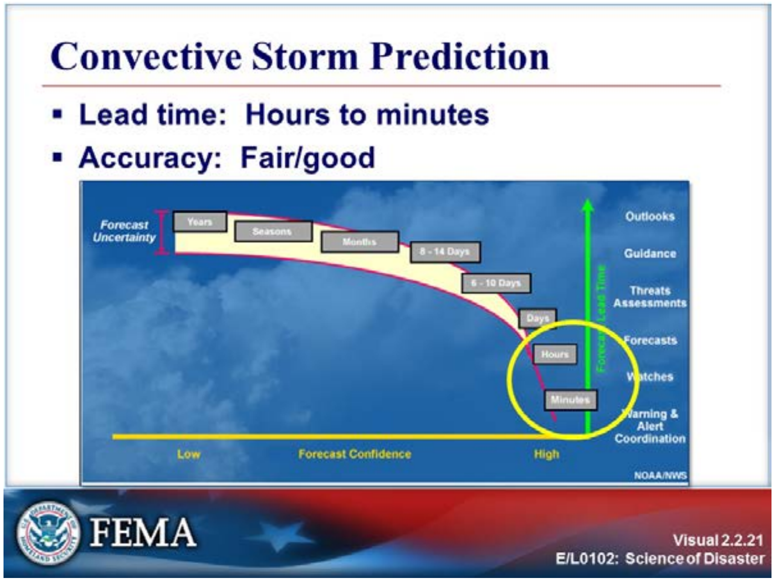
Forecasters generally use the following sources of information to predict these tornado outbreaks:

- Radar technology, including Doppler radar.
- Satellite imagery
- Computer models
- Weather balloons
- People on the ground e.g., storm chasers, reporters, emergency managers, victims, etc.).

Discussion Question: Why are tornadoes so hard to predict?

TORNADOES: PREDICTION

Visual 2.2.21



Key Points

Forecasts of severe convective weather are based on a combination of:

- Extrapolation of current conditions
- Climatology
- Application of conceptual models (experience)
- Guidance from numerical forecast models

Although the lead time for predicting convective storms can be low (hours to minutes), the accuracy is generally fair to good.

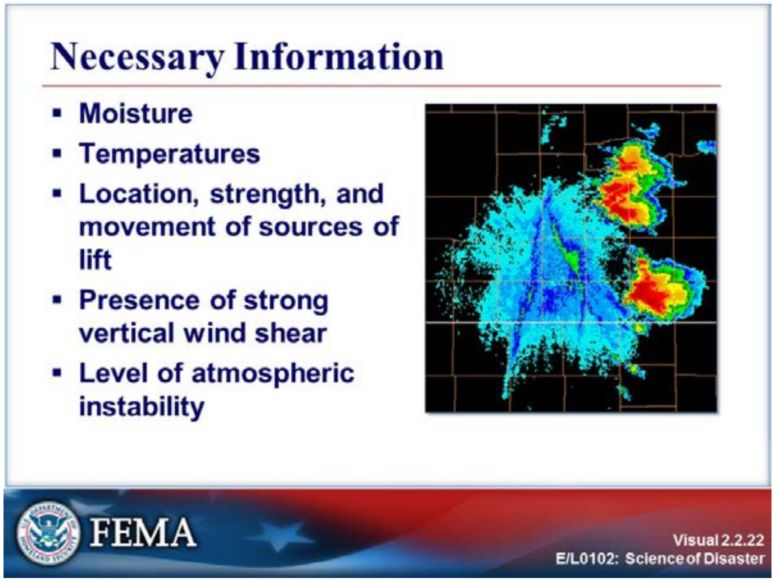
In general, forecasts are best expressed probabilistically because:

- The current state of the atmosphere is never completely known.
- Atmospheric flow can vary in time and space from smooth and uniform to turbulent and chaotic.

The number of tornado warnings is high, but false warnings are also high.

TORNADOES: PREDICTION

Visual 2.2.22



Key Points

Forecasters need the following types of information in order to make predictions:

- Moisture and temperatures
- The location, strength, and movement of fronts, drylines, and other boundaries between air masses that tend to provide lift
- The presence of strong vertical wind shear
- The level of atmospheric instability

They draw this information from multiple sources, including:

- **Radar reflectivity.** Forecasters will often look for signs of rotation or hook echo, which is a radar reflectivity pattern characterized by a hook-shaped extension of a thunderstorm echo, usually in the right-rear part of the storm (relative to its direction of motion). Warnings are issued if a hook echo is detected, because a hook echo is often associated with a mesocyclone.

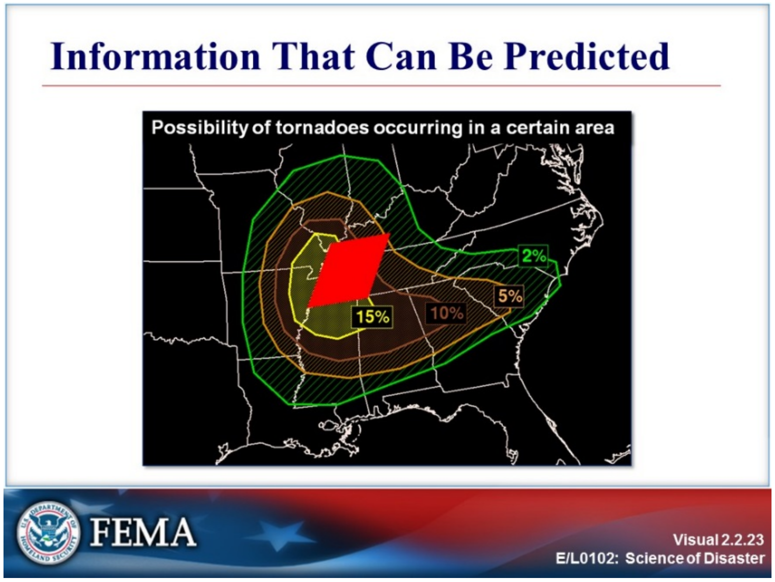
- **Satellite imagery.** Satellite imagery is used to track the weather systems that can spawn thunderstorms.

- **Radiosondes.** Radiosondes provide sounding data measuring thermodynamic parameters (to assess instability and updraft strength) and wind parameters (to assess shear).

Most severe thunderstorm/tornado watches and warnings are based on expected high atmospheric instability and strong winds.

TORNADOES: PREDICTION

Visual 2.2.23



Key Points

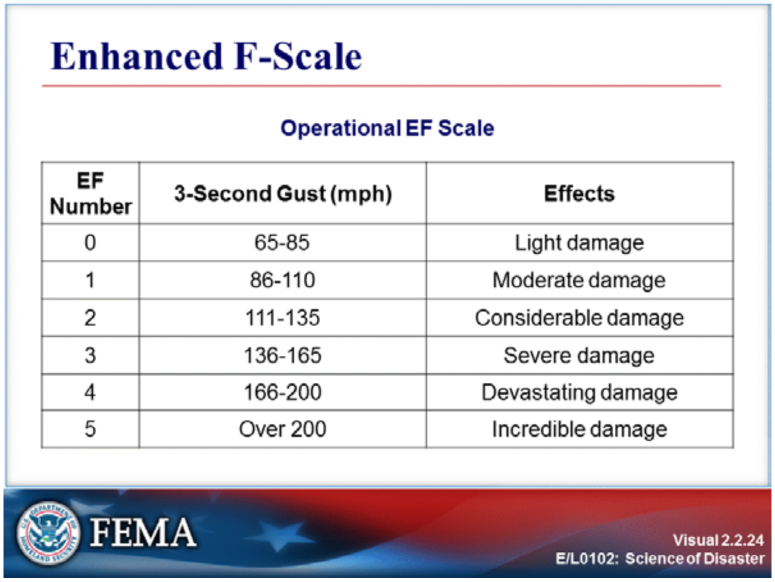
In advance of a tornado, what forecasters are able to predict with relative accuracy is the **possibility of tornadoes occurring in a certain area.**

For example, this visual shows a hypothetical tornado outlook with ranges of probability of occurrence ranging from 2 percent to 15 percent, depending on the location. The rhombus shape represents a tornado watch that might be issued for near-term threats.

As the event gets closer, the prediction normally sheds some uncertainty, and forecasters are better able **to narrow the tornado warning to a more precise area.**

TORNADOES: CLASSIFICATION

Visual 2.2.24



Alt Text for Visual 2.2.24
Enhanced F-Scale

Operational EF Scale		
EF Number	3-Second Gust (mph)	Effects
0	65-85	Light damage
1	86-110	Moderate damage
2	111-135	Considerable damage
3	136-165	Severe damage
4	166-200	Devastating damage
5	Over 200	Incredible damage

Key Points

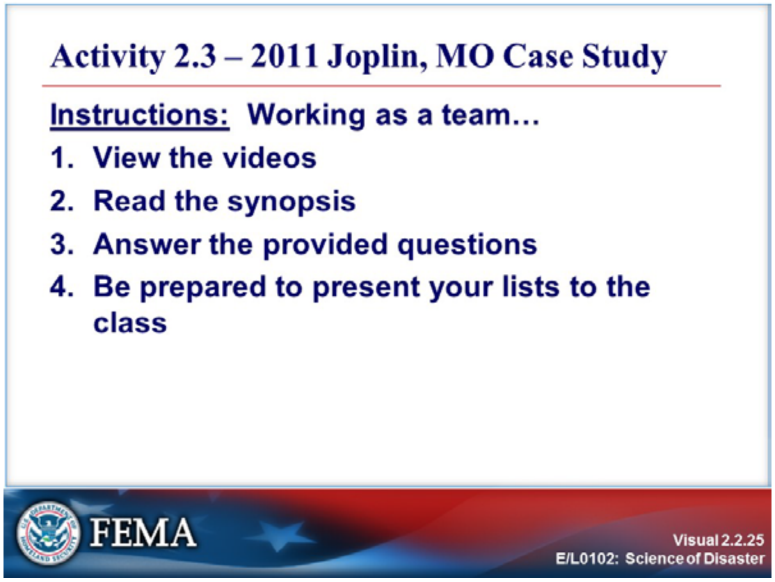
The F-Scale: In 1971, Severe Storms Researcher Ted Fujita introduced a scale for characterizing tornadoes by area and intensity and extrapolating wind speed from tornado-caused damage. The F-Scale became the heart of the tornado database, which contains a record of all tornadoes in the United States from 1950 to the present day.

The EF-Scale: In 2007, an enhanced version of the scale came into use. This Enhanced F-Scale has the same basic structure as the original scale, and it supports and maintains the original tornado database. However, it more accurately estimates wind speeds as they correlate to the damage that has been caused (primarily to buildings).

It is important to understand that this scale is used to classify a tornado **after** the tornado occurs. (For example, if a tornado moves through a neighborhood, the type, area, and extent of damage will be assessed to determine a wind speed range, and finally an EF number, e.g., EF-2.)

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25



Key Points

Instructions: Working as a team…

1. View the videos.
2. Read the synopsis.
3. Answer the provided questions.
4. Be prepared to present your lists to the class.

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25 (Continued)

Activity 2.3 – Job Aid 1

The **2011 Joplin tornado** was a catastrophic EF5-rated multiple-vortex tornado that struck Joplin, Missouri, late in the afternoon of Sunday, May 22, 2011. It was part of a larger late-May tornado outbreak and reached a maximum width of nearly 1 mile (1.6 km) during its path through the southern part of the city.[6] It rapidly intensified and tracked eastward across the city, and then continued eastward across Interstate 44 into rural portions of Jasper County and Newton County.[7] It was the third tornado to strike Joplin since May 1971.[8]

Overall, the tornado killed 158 people (with an additional four indirect deaths), injured some 1,150 others, and caused damages amounting to a total of $2.8 billion. It was the deadliest tornado to strike the United States since the 1947 Glazier–Higgins–Woodward tornadoes, and the seventh-deadliest overall. It also ranks as the costliest single tornado in United. States history.

In a preliminary estimate, the insurance payout was expected to be $2.2 billion; the highest insurance payout in Missouri history, higher than the previous record of $2 billion in the April 10, 2001 hail storm, which is considered the costliest hail storm in history as it swept along the I-70 corridor from Kansas to Illinois.[9] Estimates earlier stated Joplin damage could be $3 billion. By July 15, 2011, there had been 16,656 insurance claims.[10]

Meteorological synopsis

The tornado initially touched down just east of the Kansas state line near the end of 32nd Street at 5:34 pm CDT (22:34 UTC) and tracked due east, downing a few trees at EF0 intensity. Eyewitnesses and storm chasers reported multiple vortices rotating around the parent circulation in this area.[11][12] Civil defense sirens sounded in Joplin 20 minutes before the tornado struck in response to tornado warnings issued by the National Weather Service, but many Joplin residents did not hear them.[13] The tornado rapidly strengthened to EF1 intensity as it continued through rural areas towards Joplin, snapping trees and power poles and damaging outbuildings. The widening tornado then tracked into the more densely populated southwest corner of Joplin, near the Twin Hills Country Club. Several homes were heavily damaged at EF1 to EF2 strength at a subdivision in this area. The tornado continued to strengthen as it ripped through another subdivision just east of Iron Gates Rd. Numerous homes were destroyed at EF2 to EF3 strength at that location, and multiple vehicles were tossed around, some of which were thrown or rolled into homes.[11]

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25 (Continued)

Activity 2.3 – Job Aid 1 (Continued)

EF5 damage to the St. John's Regional Medical Center, which later had to be torn down due to deformation of its foundation and underpinning system.

Aerial view of the St. John's Regional Medical Center campus

Destroyed area in the tornado's damage path.

The now massive wedge tornado then crossed S Schifferdecker Avenue, producing its first area of EF4 damage as several small but well-built commercial buildings were flattened. Consistent EF4 to EF5 damage was noted east of S Schifferdecker Avenue and continued through most of southern Joplin. Numerous homes, businesses, and medical buildings were flattened in this area, with concrete walls collapsed and crushed into the foundations. A large steel-reinforced step and floor structure leading to a completely destroyed medical building was "deflected upward several inches and cracked." Steel trusses from some of the buildings were "rolled up like paper", and deformation/twisting of the main support beams was noted. Multiple vehicles were thrown and mangled or wrapped around trees nearby.

Several 300-pound concrete parking stops anchored with rebar were torn from a parking lot in this area, and were thrown up to 60 yards away. Iowa State University wind engineer Parka Sarkar was able to calculate the force needed to remove the parking stops, and he found that winds exceeding 200 mph were needed to tear them from the parking lot.[14] Damage became remarkably widespread and catastrophic at and around the nearby St. John's Regional Medical Center. The hospital lost many windows, interior walls, ceilings, and part of its roof, and its life flight helicopter was also blown away and destroyed. Six fatalities were reported there, and the nine-story building was so severely damaged that it was deemed structurally compromised and was later torn down. An engineering survey of the building revealed that the foundation and underpinning system were damaged beyond repair. According to the NWS office in Springfield, Missouri, such extreme structural damage to such a large and well-built structure was likely indicative of winds at or exceeding 200 mph.

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25 (Continued)

Activity 2.3 – Job Aid 1 (Continued)

Vehicles in the hospital parking lot were thrown and mangled beyond recognition, including a semi-truck that was thrown 125 yards and wrapped completely around a debarked tree. Wind-rowing of debris was noted in this area, and additional concrete parking stops were removed from the St. John's parking lot as well. Virtually every house in neighborhoods near McClelland Boulevard and 26th Street was flattened, some were swept completely away, and trees sustained severe debarking.

As the tornado tracked eastward, it maintained EF5 strength as it crossed Main Street between 20th and 26th Streets. Virtually every business along that stretch was heavily damaged or destroyed, and several institutional buildings were destroyed. It tracked just south of downtown, narrowly missing it. Entire neighborhoods were leveled in this area with some homes swept away, and trees were stripped completely of their bark. At some residences, reinforced concrete porches were deformed or, in some cases, completely torn away. Damage to driveways was noted at some residences as well. Numerous vehicles were tossed up to several blocks away from the residences where they originated, and a few home owners never located their vehicles.

A large church, Greenbriar Nursing Home, Franklin Technology Center, St. Mary's Catholic Church and School, and Joplin High School were all destroyed along this corridor. No one was in the high school at the time; the high school graduation ceremonies held about 3 miles (4.8 km) to the north at Missouri Southern State University had concluded shortly before the storm. Pieces of cardboard were found embedded sideways into stucco walls that remained standing at Joplin High School. Steel beams and pieces of fencing were deeply embedded into the ground in fields near the high school as well, and steel fence posts were bent to the ground in opposite directions. A school bus was thrown into a nearby bus garage. The Greenbriar nursing home was completely leveled, with 21 fatalities occurring there alone. As the tornado crossed Connecticut Avenue further to the east, it destroyed several large apartment buildings, Dillon's grocery, and a bank. Only the concrete vault remained at the bank, and a wooden 2x4 board was found speared completely through a concrete curb at one location as well. The tornado then approached Range Line Road, the main commercial strip in the eastern part of Joplin, flattening additional neighborhoods along 20th Street.

The now heavily rain-wrapped tornado continued at EF5 intensity as it crossed Range Line Road. In that corridor between about 13th and 32nd Streets, the damage continued to be catastrophic, and the tornado was at its widest at this point, being nearly 1 mile (1.6 km) wide. As the tornado hit the Pizza Hut at 1901 South Range Line Road, store manager Christopher Lucas herded four employees and 15 customers into a walk-in freezer. Since the door could not be shut, Lucas wrapped a bungee cable holding the door shut around his arm until he was sucked into the tornado, where he died. The tornado completely destroyed Walmart Supercenter No. 59, a Home Depot store, and numerous other businesses and restaurants in this area, many of which were flattened. Numerous metal roof trusses were torn from the Home Depot building and were found broken and mangled in nearby fields. Cars that originated at the Home Depot parking lot were found hundreds of yards away. Asphalt was scoured from parking lots at Walmart and a nearby pizza restaurant, and large tractor-trailers were thrown up to 200 yards away.

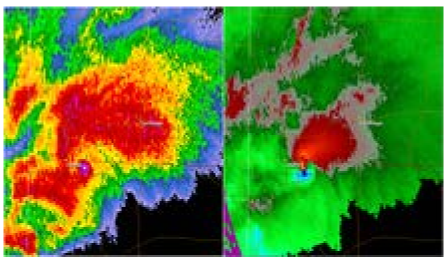
ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25 (Continued)

Activity 2.3 – Job Aid 1 (Continued)

An Academy Sports + Outdoors store along Range Line sustained major structural damage, and a chair was found impaled legs-first through an exterior stucco wall at that location. A nearby three-story apartment complex was also devastated, and two cell phone towers were found collapsed onto the remains of the apartments.

Numerous cars were thrown and piled on top of each other, 100-pound manhole covers were removed from roads and thrown, ground scouring occurred, and a Pepsi distribution plant was completely leveled in this area.. Additional calculations of the manhole covers in Joplin by Parka Sarkar revealed that winds had to have exceeded 200 mph for the manhole covers to be removed. Many fatalities occurred in this area, and damage was rated as EF5.



Radar image of the supercell that produced the Joplin tornado. (This link can also be accessed at the following URL: https://www.ncdc.noaa.gov/sotc/tornadoes/201105)

Extreme damage continued in the area of Duquesne Road in Southeast Joplin. Many houses and industrial and commercial buildings were flattened in this area as well. The industrial park near the corner of 20th and Duquesne was especially hard hit with nearly every building flattened. Several large, metal warehouse structures were swept cleanly from their foundations, and several heavy industrial vehicles were thrown up to 400 yards away in this area. One of the many warehouses affected was a Cummins warehouse, a concrete block and steel building, which was destroyed. The last area of EF5 damage occurred in the industrial park, and a nearby Fastrip gas station and convenience store was completely destroyed. Many homes were destroyed further to the east at EF3 to EF4 strength in a nearby subdivision, and East Middle School sustained major damage.

The tornado then continued on an east to east-southeast trajectory towards Interstate 44 where it weakened. Nonetheless, vehicles were blown off the roadway and mangled near the U.S. Route 71 (Exit 11) interchange. The damage at and around the interchange was rated EF2 to EF3. The weakening tornado continued to track into the rural areas of southeastern Jasper County and northeastern Newton County where damage was generally minor to moderate, with trees, mobile homes, outbuildings, and frame homes damaged mainly at EF0 to EF1 strength. The tornado lifted east of Diamond at 6:12 pm CDT (23:12 UTC) according to aerial surveys. The tornado's total track length was at least 22.1 miles (35.6 km) long. Overall, 6,954 homes were destroyed, 359 homes had major damage, and 516 homes had minor damage. A total of, 158 people were killed, and 1,150 others were injured along the path. A separate EF2 tornado touched down near Wentworth from the same supercell about 25 miles (40 km) east-southeast of Joplin.

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

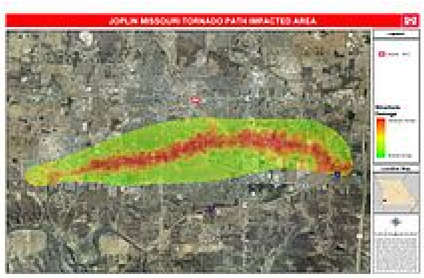
Visual 2.2.25 (Continued)

Activity 2.3 – Job Aid 1 (Continued)

Rating dispute

On June 10, 2013, an engineering study found no evidence of EF5 structural damage in Joplin due to the poor quality of construction of many buildings. However, the EF5 rating stood, as the National Weather Service in Springfield, Missouri, stated that their survey teams found only a very small area of EF5 structural damage and that it could have easily been missed in the survey (at and around St. John's Medical Center). Additionally, the basis for the EF5 rating in Joplin was mainly contextual rather than structural, with non-conventional damage indicators, such as removal of concrete parking stops, manhole covers, reinforced concrete porches, driveways, and asphalt were used to arrive at a final rating of EF5. It was concluded that these specific instances of damage were indicative of winds exceeding 200 miles per hour. The presence of wind-rowed structural debris; instances of very large vehicles such as buses, vans, and semi-trucks being thrown hundreds of yards to several blocks from their points of origin; the fact that some home-owners never located their vehicles; and the overwhelming extent and totality of the destruction in Joplin were also taken into consideration to conclude EF5 intensity.

Aftermath and impact



United States Army Corps of Engineers map showing the extent of the damage

A preliminary survey of the tornado damage by the National Weather Service office in Springfield, Missouri, began on May 23. The initial survey confirmed a violent tornado rated as a high-end EF4. Subsequent damage surveys, however, found evidence of more intense damage, and so the tornado was upgraded to an EF5 with estimated winds over 200 mph (320 km/h), peaking at 225 to 250 mph (360 to 400 km/h).

According to the local branch of the American Red Cross, about 25 percent of Joplin was destroyed, but the city's emergency manager stated that the number was between 10 and 20percent, with roughly 2,000 buildings destroyed. According to the National Weather Service, emergency managers reported damage to 75 percent of Joplin. In total, nearly 7,000 houses were destroyed (most of which were flattened or blown away), and more than 850 others were damaged. Communications were lost in the community, and power was knocked out to many areas. With communications down, temporary cell towers had to be constructed. By May 24, three towers owned by AT&T and Sprint had been restored.

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25 (Continued)

Activity 2.3 – Job Aid 1 (Continued)

Due to the severe damage caused by the tornado, the travelling Piccadilly Circus was unable to perform, as scheduled. As a result, the circus employees brought their two adult elephants to help drag damaged automobiles and other heavy debris out of the roadway to make a path for first responders.

East of Joplin, a Risk Management Plan facility released 3,000 to 5,000 pounds (1,400 to 2,300 kg) of anhydrous ammonia; it was contained within 2 days.

The catastrophe and risk-modeling firm, Eqecat, Inc, has estimated the damage at one billion to three billion dollars, but it noted that the true damage is not yet known, since the firm does not have access to data on uninsured losses. More than 17,000 insurance claims had been filed by mid-June. The impact on the insurance industry is not so much the number of claims, but the cumulative effect of such a large number of total losses. More than 2,500 local people employed in insurance have been involved in some capacity. It is assumed that State Farm will assume the largest share of these losses, having a market share of 27 percent for homeowners insurance and 21 percent for automobile insurance.

The $2.8 billion in damage is the largest amount for a tornado since 1950.

Casualties

As of May 2012, the official death toll from National Weather Service was listed at 158 while the City of Joplin listed the death toll at 161 (160 direct). The list was up to 162, until one man's injuries were found to be unrelated to the event. In one indirect fatality, a policeman was struck by lightning and killed while assisting with recovery and cleanup efforts the day after the storm. Shortly after the tornado, authorities had listed 1,300 people as missing, but the number quickly dwindled as they were accounted for. Many people were reported to have been trapped in destroyed houses. Seventeen people were rescued from the rubble the day after the tornado struck.

The Missouri Emergency Management Agency reported more than 990 injured. Of 146 sets of remains recovered from the rubble, 134 victims had been positively identified by June 1. Due to the horrific injuries suffered by some victims, some different sets of remains were from a single person. On June 2, it was announced that four more victims had died.

Six people were killed when St. John's was struck by the tornado. Five of those deaths were patients on ventilators who died after the building lost power, and a backup generator did not work. The sixth fatality was a hospital visitor.

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25 (Continued)

Activity 2.3 – Job Aid 1 (Continued)

The *Joplin Globe* reported that 54 percent of the people died in their residences, 32 percent died in non-residential areas and 14 percent died in vehicles or outdoors. Joplin officials after the tornado announced plans to require hurricane ties or other fasteners between the houses and their foundations (devices add about $600 US to the construction costs). Officials rejected a proposal to require concrete basements in new houses. Officials noted that only 28 percent of Joplin's new homes had basements as of 2009, compared with 38 percent two decades before.

Officials said they rescued 944 pets and reunited 292 with owners.

On June 10, 2011, it was announced that a rare fungal infection, zygomycosis, had been noted to cause at least eight serious cases of wound infection among the injured survivors, confirmed by reports to the Missouri Department of Health and Senior Services.[

Response

President Obama greets a tornado survivor on May 29, 2011

Immediately following the disaster, emergency responders were deployed within and to the city to undertake search and rescue efforts. Governor Jay Nixon declared a state of emergency for the Joplin area shortly after the tornado hit, and ordered Missouri National Guard troops to the city. By May 23, Missouri Task Force One (consisting of 85 personnel, four dogs, and heavy equipment) arrived and began searching for missing persons. Five heavy rescue teams were also sent to the city a day later. Within two days, numerous agencies arrived to assist residents in the recovery process. The National Guard deployed 191 personnel and placed 2,000 more on standby to be deployed if needed. In addition, the Missouri State Highway Patrol provided 180 troopers to assist the Joplin Police Department and other local agencies with law enforcement, rescue, and recovery efforts that also included the deployment of five ambulance strike teams, and a total of 25 ambulances in the affected area on May 24 as well as well as more than 75 Marines from the Fort Leonard Wood Army Base.

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25 (Continued)

Activity 2.3 – Job Aid 1 (Continued)

Social Media Response

The tornado also highlighted a new form of disaster response, using social media. This type of disaster response is now known as Social Media Emergency Management. News outlets began aggregating images and video from eyewitnesses shared through social media. Public, citizen-led Facebook groups and websites, such as Joplin Tornado Info coordinated information, needs, and offers. The results were so effective that the project became a finalist in the 2011 Mashable Awards for Best Social Good Cause Campaign.

Media handling

President Barack Obama toured the community on May 29, flying into Joplin Regional Airport and speaking at a memorial at the Taylor Performing Arts Center at Missouri Southern State University about 2 miles (3 km) north of the worst of the devastation. Obama had been on a State visit to Europe at the time of the storm. Members of the controversial Westboro Baptist Church were also scheduled to protest the same day in Joplin, but they did not show up. There was a massive counter protest that was organized in response to the Westboro protest, in which thousands of protesters showed up holding signs saying, "God Loves Joplin" and "We Support You Joplin."

Engineers have criticized the tilt-up construction of the Home Depot in which all but two of its walls collapsed in a domino effect after the tornado lifted the roof, killing seven people in the front of the store (although 28 people in the back of the store survived when those walls collapsed outwards). Home Depot officials said they disagreed with the study published by *The Kansas City Star* and said they would use the tilt-up practice when they rebuild the Joplin store. On June 1, The Home Depot said it would have a new temporary 30,000-square-foot (2,800 m^2) building built and operational within 2 weeks. In the meantime, it opened for business in the parking lot of its demolished building. On June 20, The Home Depot opened a temporary 60,000-square-foot (5,600 m^2) building constructed by the company's disaster recovery team.

In May 2012, the Missouri National Guard released documents showing that four soldiers looted video game equipment and a digital camera from a ruined Walmart during cleanup efforts. According to the investigative memo, they believed the merchandise was going to be destroyed. All the soldiers were demoted and had a letter of reprimand placed in their personnel file, but they were never prosecuted, even though many civilian looters were prosecuted.

ACTIVITY 2.3 – 2011 JOPLIN, MISSOURI, CASE STUDY

Visual 2.2.25 (Continued)

Activity 2.3 – Joplin, Missouri, Case Study Worksheet

1. What conditions made this storm so devastating?

2. What were complicating factors during this tornado incident?

3. What are some ideas to mitigate against repeats of the problems?

VIDEO: METEOROLOGIST

Visual 2.2.26

Key Points

In this video, meteorologist Jeff Penner, breaks down the Joplin weather system that created the deadliest, single tornado since modern record keeping began in 1950.

Video Transcript:

May 22nd 2011, 5 years ago, was a very, very bad day in Joplin and we're gonna take a little bit at the meteorology: how did the weather set up? Well with a low pressure area in South Dakota, there is a cold front right through Omaha and near Kansas City and Oklahoma. Warm front off to the north, and then a dry line down to the south.

Here's Joplin down here, so we had a warm, humid air mass from the Gulf of Mexico, we had a hot dry air mass coming in out of Oklahoma, and a cooler, drier air mass coming in out of Kansas. All intersecting in southeast Kansas and southwest Missouri, and also you had a jet-stream moving from west to east above all of this.

So you had convergence at the surface of all these air masses, and the winds are coming in from the southeast of the low levels while the upper levels are going in from the west and southwest. There was shear turning of the winds with height, and everything was there for thunderstorm development. That's where we had some of these super cells form. When they formed, it was so humid that they became very big thunderstorms and began to rotate and, unfortunately, one of those produced a very large tornado right over Joplin. But now it wasn't just Joplin on that day they got hit it was a whole severe weather outbreak from eastern Oklahoma all the way up into the great lakes. There were 75 tornado reports, 359 reports of hail, and 409 reports of wind for a total of 843 reports of severe weather.

VIDEO: METEOROLOGIST

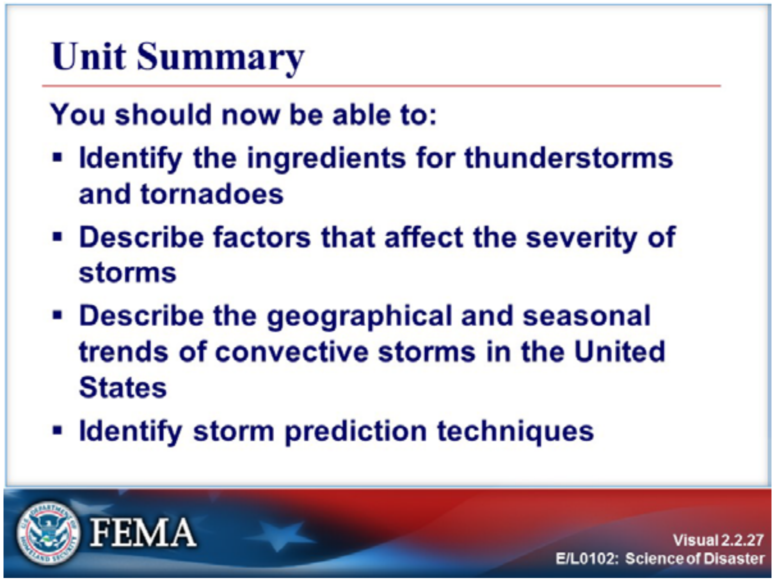
Visual 2.2.26 (Continued)

There is even some severe weather in our area and Lafayette County; there are a couple smaller tornadoes on the eastern part of our viewing area, and then it moved off to the east. So, quite an active day 5 years ago

Here's a look at the satellite picture from that day. Here's Kansas City; Joplin's here; see these bumps in the cause? These are anvil, this whole white area, the anvil of the thunderstorms that the bumps the overshooting top— that's where the top of the thunderstorm shoots above the anvil into the lower part of the stratosphere. That means there's some intense rising motion you can see in southeast Kansas--there were some and even in Central Missouri and then these move right in to the Joplin area. The radar is very impressive when you see a radar image like this and a very dangerous signature, the hook, see the red here. This is Joplin and there's a hook and the reason why there's a hook, the rain is wrapping around the thunderstorm and the tornadoes usually are right in there. Uunfortunately, it's right over the city of Joplin, as things continue to move, there are very impressive signatures on radar. The track at this is where it was at five--right through the middle part of the city north of 32nd Street and south of Duquesne there--right through the city. It was in the evening; people were out--just absolutely horrific, Let's hope nothing like this ever happens again in a city because that is just horrible.
The Joplin tornado facts: one-mile wide, 200 miles-per-hour winds as strong as it was on the ground for 38th minutes; 7,000 homes destroyed. And there is a picture of the tornado--a very violent day in Joplin and in southwest Missouri. This is tornado season, so just keep in mind the peak for our area is April and May, It's been quiet so far but in the next week to 10 days and early June, it's gonna be active a lot, so keep an eye to the sky. On average of sixty-eight tornadoes in Kansas and Missouri, that's one tornado per day on average, so have a plan in place; know how to get warnings when they're issued; stay safe, Stay with 41 Action News, and we will keep you advised

UNIT SUMMARY

Visual 2.2.27



Alt Text for Visual 2.2.27
Unit Summary
You should now be able to:
Identify the ingredients for thunderstorms and tornadoes
Describe factors that affect the severity of storms
Describe the geographical and seasonal trends of convective storms in the United States
Identify storm prediction techniques

Key Points

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UNIT 3. TROPICAL CYCLONES

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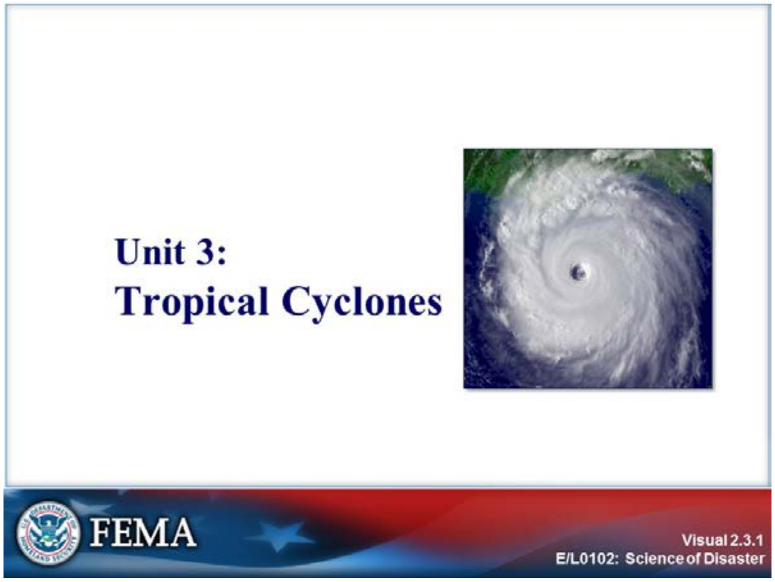
INTRODUCTION

Visual 2.3.1



Key Points

This unit will present key points about the science of tropical cyclones and hurricanes.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Introduction to Cyclones	5 minutes
Hurricanes	15 minutes
Storm Surge	20 minutes
Hurricane Analysis and Prediction • Activity 2.4 – New D-FIRM Maps	45 minutes
Unit Summary	5 minutes
Total Time	**1 hour 35 minutes**

INTRODUCTION

Visual 2.3.2

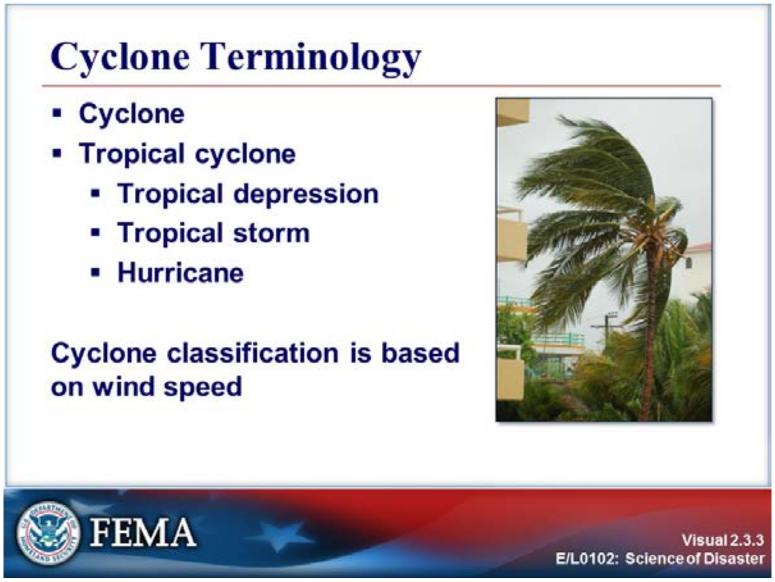
Key Points

Review the unit objectives as listed on the visual.

- Distinguish between tropical depression, tropical cyclone, tropical storm, and hurricane
- Describe the global context of tropical cyclone formation and movement
- Identify the ingredients of hurricanes
- Describe the components of a hurricane
- Describe storm surge and factors that affect its severity

INTRODUCTION TO CYCLONES

Visual 2.3.3



Key Points

What are cyclones? Let's begin with some important cyclone-related definitions:

- **Cyclone:** An atmospheric closed-circulation, low-pressure system rotating counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

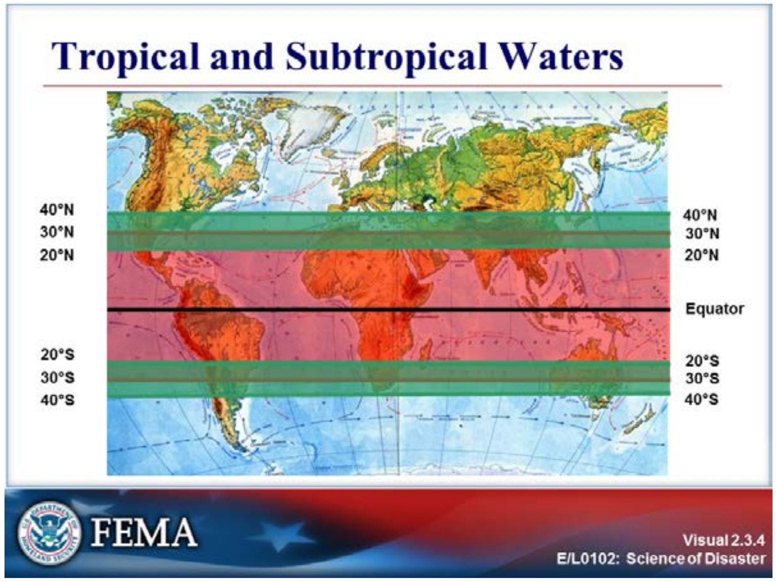
- **Tropical cyclone:** A cyclone with a warm core originating over tropical or subtropical waters, with surface wind circulation about a well-defined center. Once formed, a tropical cyclone is maintained by extraction of heat energy from the ocean and heat export aloft. Types of tropical cyclones include:

  - **Tropical depression:** A tropical cyclone with winds of 38 mph or less.
  - **Tropical storm:** A tropical cyclone with winds of 39 - 73 mph.
  - **Hurricane:** A tropical cyclone with winds of 74 mph or more.

As you can see, the hierarchy of tropical depression, tropical storm, and hurricane is based on wind speeds. Although tropical depressions and tropical storms do not produce winds and storm surge as severe as those of hurricanes, they can still result in damaging winds and high rainfall amounts that cause freshwater flooding and tornadoes.

INTRODUCTION TO CYCLONES

Visual 2.3.4



Key Points

A tropical cyclone can originate over tropical or subtropical waters.

The area in middle on this visual shows the region of **tropical waters** that is accepted by major experts. This region:

- Stretches from 30° N to 30° S.
- Has sea surface temperatures (SSTs) of 80 °F or higher.
- Is where the greatest potential for cyclones to develop exists.

Unlike extratropical cyclones, which derive energy from the horizontal temperature contrasts in the atmosphere, a tropical cyclone is maintained by the extraction of heat energy from the ocean at high temperature and heat export aloft.

The areas above and below the tropical waters on the map indicate **subtropical waters**—the two regions that make up the border between tropical waters and more temperate regions.

INTRODUCTION TO CYCLONES

Visual 2.3.4 (Continued)

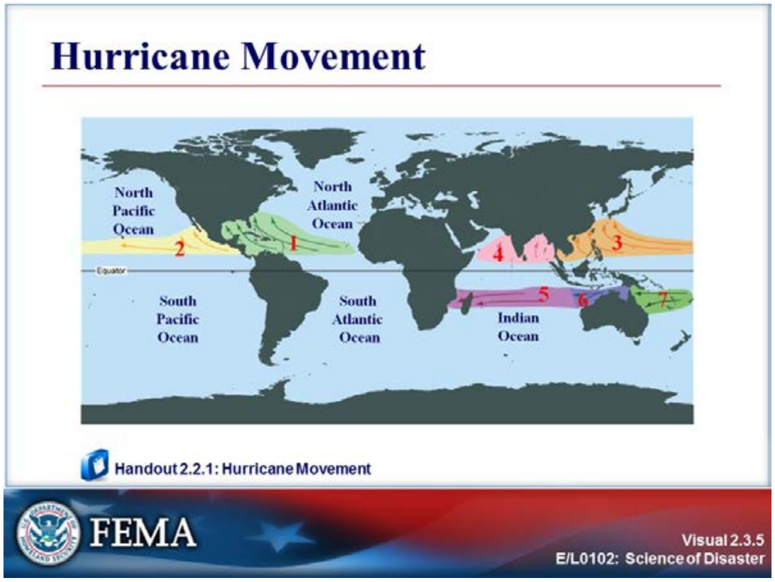
Like tropical cyclones, subtropical cyclones are no frontal, synoptic-scale cyclones. However, unlike tropical cyclones, they:

- Have characteristics of extratropical cyclones—namely, existing in a weak to moderate horizontal temperature gradient region.
- Have a radius of maximum winds which is farther out (60 - 125 miles from the center) than what is observed for purely “tropical” systems.
- Have a less symmetric wind field and distribution of convection.
- Have maximum sustained winds not stronger than about 33 m/s (74 mph).

Often, subtropical cyclones transform into true tropical cyclones. For example, Hurricane Otto (October 2010) began as a subtropical cyclone before becoming fully tropical.

INTRODUCTION TO CYCLONES

Visual 2.3.5



Key Points

This map illustrates the seven "basins" where tropical cyclones form on a regular basis.

The same type of storm (tropical cyclone) is called by different names in different regions of the world.

- **Hurricanes** occur in Regions 1 and 2**.** The term hurricane is generally used for tropical cyclones east of the International Dateline to the Prime (Greenwich) Meridian.

- **Typhoons** occur in the Western Pacific, in Region 3**.** The term typhoon is generally used for Pacific tropical cyclones north of the Equator and west of the International Dateline.

- **Tropical cyclones** occur in Regions 4, 5, 6, and 7**.** This area includes the Indian Ocean and southwestern Pacific Ocean.

For the rest of this unit we will focus primarily on hurricanes. Most U.S. hurricanes are formed off the coast of Africa and move to the United States, sometimes lasting over 2 weeks over the ocean. But how do hurricanes travel from one continent to the other?

Most Northern Hemisphere hurricanes forming between 5° and 30° N typically move from east to west in the trade winds.

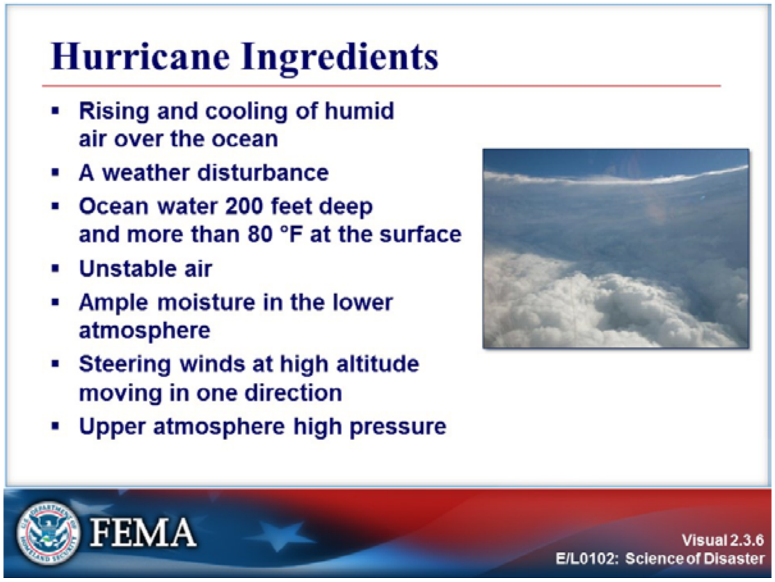
As hurricanes are pushed westward, they sometimes turn north or northwest out in the Atlantic, then curve toward the northeast, as a result of shifting winds in the middle and upper levels of the atmosphere.

Storms that do move up the east coast usually pick up speed around North Carolina, and may travel at speeds up to 70 mph.

See color handout 2.2.1: Hurricane Movement

HURRICANES: FORMATION

Visual 2.3.6



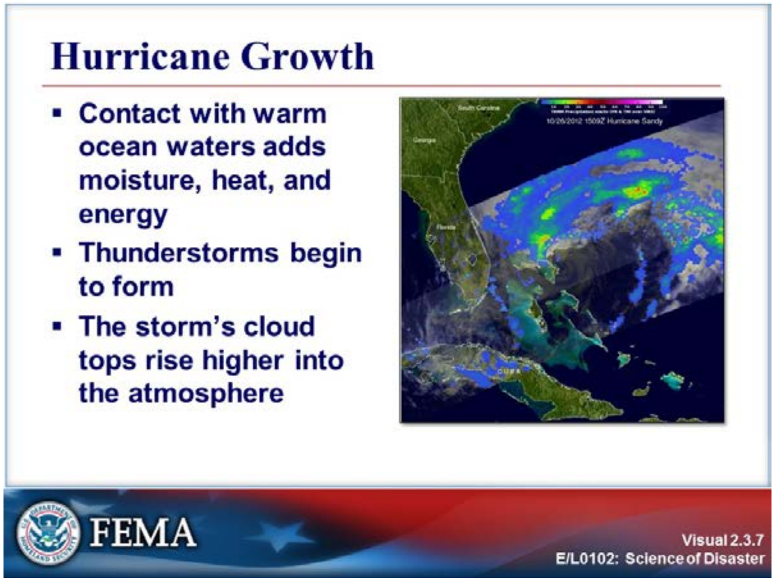
Key Points

Hurricanes are generated by the rising and cooling of humid air over the ocean, in combination with the following ingredients:

- A weather disturbance.
- Warm ocean water about 200 feet deep (60 m) and over 80 °F (27 °C).
- Unstable air (so the warm, moist air will continue rising).
- Ample moisture in the lower atmosphere (to supply heat energy).
- Steering winds at high altitude moving in one direction (to move the storm along without breaking it up).
- Upper atmosphere high pressure (to help move out the rising air of the storm).

HURRICANES: FORMATION

Visual 2.3.7



Key Points

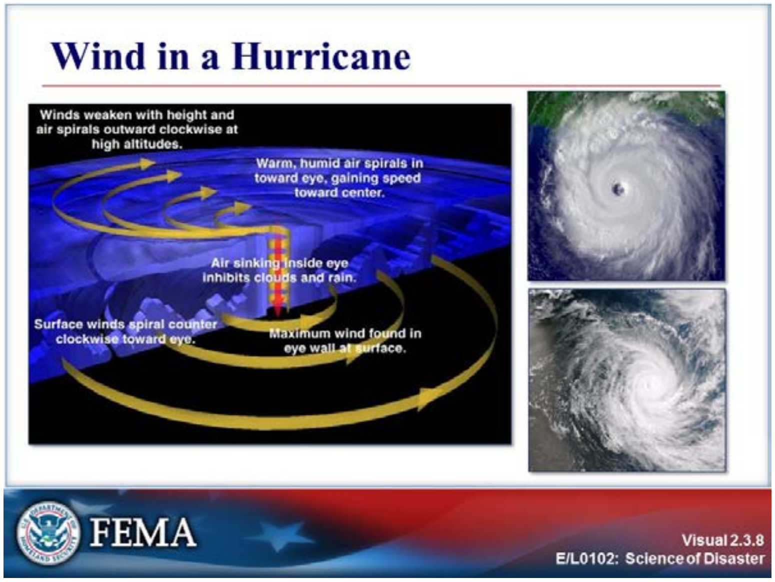
As the storm grows:

- Contact with warm ocean waters adds moisture, heat, and energy.
- Thunderstorms begin to form. In fact, on satellite imagery, the early stages of a tropical cyclone appear as a somewhat unorganized cluster of thunderstorms.
- The storm's cloud tops rise higher into the atmosphere. The storm remains intact and gains strength if the winds at these high levels of the atmosphere remain relatively light (meaning little to no wind shear).

With the right ocean and weather conditions, the storm can continue to strengthen until it becomes a tropical depression (winds less than 38 mph). It is at this point that the storm will take on its characteristic spiral appearance, resulting from both the Earth's rotation and wind flow.

HURRICANES: COMPONENTS

Visual 2.3.8



Key Points

Hurricane winds blow counter-clockwise around the center, or eye, of the storm in the Northern Hemisphere, and clockwise around the eye of the storm in the Southern Hemisphere

The main structural components of a hurricane are:

- Rainbands on the outer edges.
- The eye.
- The eyewall.

PHOTOS:

Left: **Shows a cross-section diagram of a hurricane, illustrating how wind moves throughout the system.**

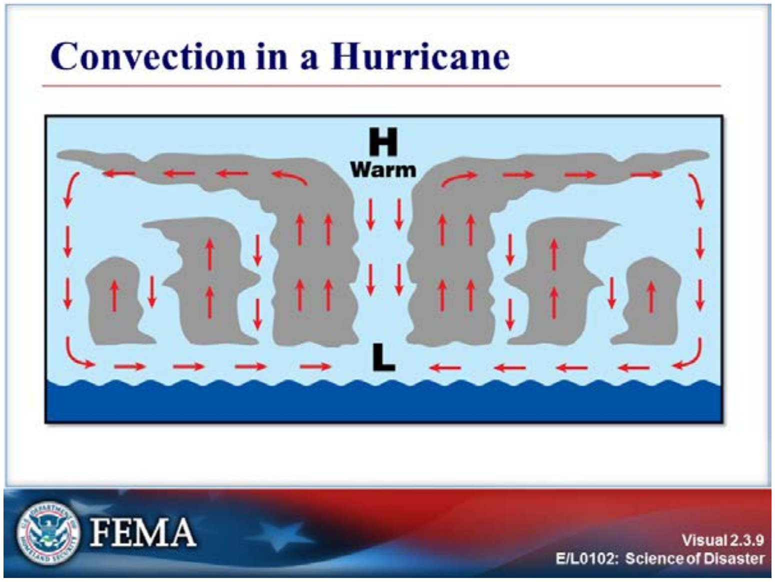
Right, Top: **Hurricane Katrina before it slammed into the Gulf Coast in 2005**

Right, Bottom: **Cyclone Claudia in the Southern Indian Ocean, 2012.**

Credit: NASA/NOAA

HURRICANES: COMPONENTS

Visual 2.3.9



Key Points

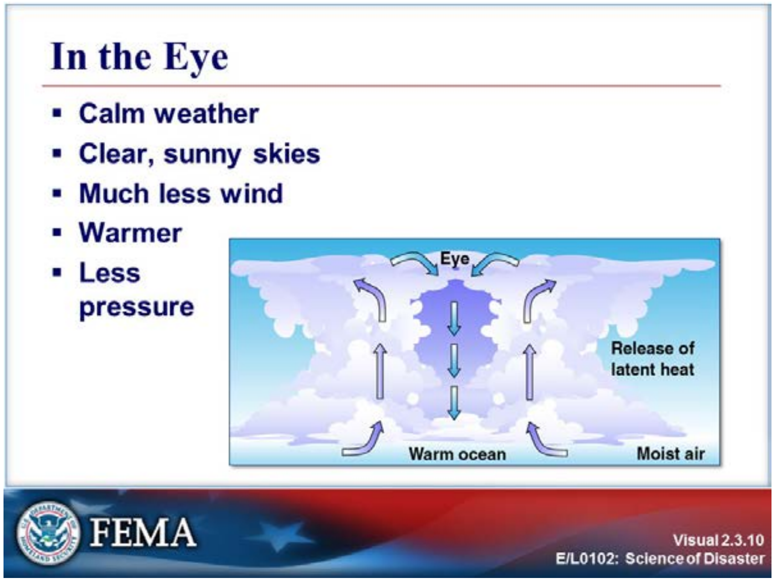
Recall that convection is a key element in all storms.

Convection in a hurricane:

- Occurs in the eyewall and forms and maintains the eye.
- Is organized into long, narrow rain bands. These bands are oriented in the same direction as the horizontal wind, and because they seem to spiral toward the center of a hurricane, are sometimes called spiral bands.
- Is fueled by the warm ocean surface water that supplies heat and moisture to the surface air spiraling in toward the center of the hurricane.

HURRICANES: COMPONENTS

Visual 2.3.10



Key Points

The eye of a hurricane:

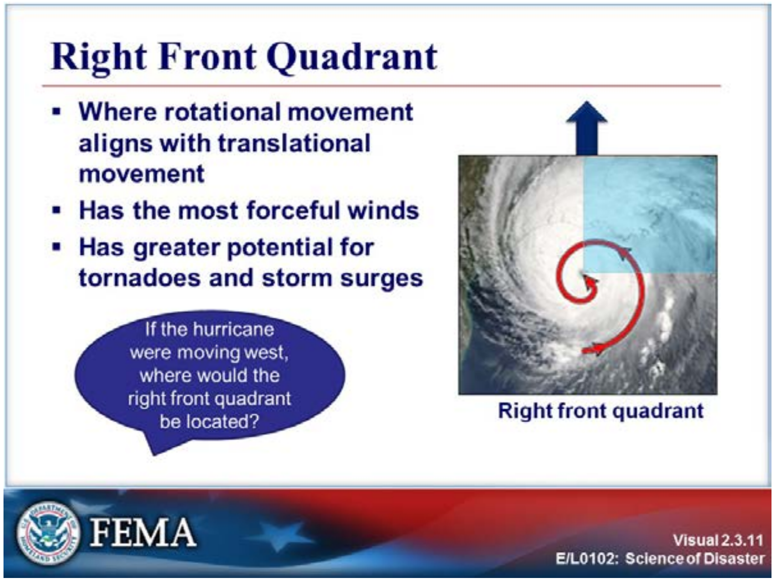
- Is the roughly circular area of comparatively light winds that encompasses the center of a severe hurricane.
- Is either completely or partially surrounded by the eyewall cloud, an organized band or ring of cumulonimbus clouds.

In the eye of the hurricane:

- The weather is calm, with clear, sunny skies. Dry, calm air is descending, and wind velocity dramatically decreases.
- It is much warmer.
- The pressure drops significantly. (Remember, a hurricane has closed wind circulation around a well-defined low pressure center that is warmer than the surrounding air.)

HURRICANES: COMPONENTS

Visual 2.3.11



Key Points

Unlike the eye, which is calm, the right front quadrant of a storm has the most forceful and damaging winds, as well as a heightened potential for tornadoes and storm surge. This is why regions that are projected to be hit by this quadrant are often of the greatest concern.

The intensity of the right front quadrant results from two types of movement:

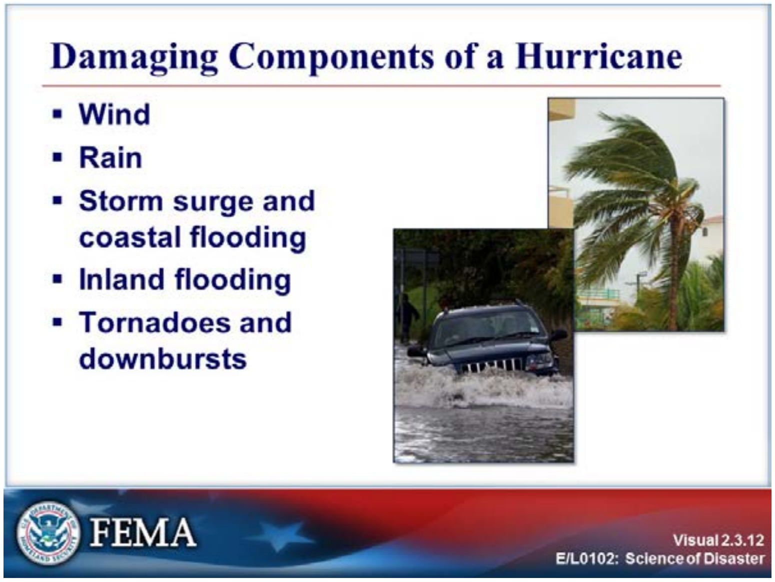
- The rotational movement of the circulation (red arrows).
- The translational movement of the storm actually traveling in its path (blue arrow).

In the right front quadrant, the rotational movement most closely aligns (points in the same direction) as the translational movement. The two movements are essentially added together for a compounded effect, resulting in the most forceful winds (i.e., the greatest power).

Discussion Question: The hurricane shown on the visual is moving to the north, and the right front quadrant is the northeast quadrant. If the hurricane were moving west, where would the right front quadrant be located?

HURRICANES: COMPONENTS

Visual 2.3.12



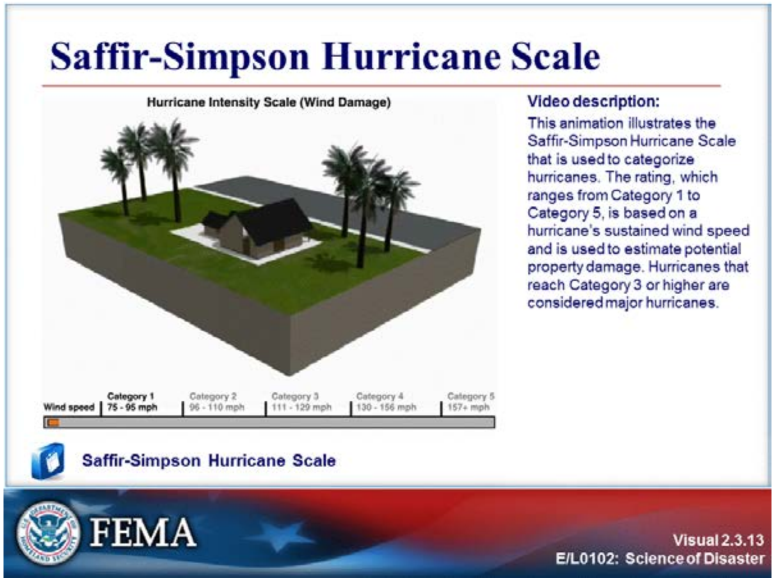
Key Points

Damaging components of a hurricane include:

- Wind.
- Rain.
- Beach erosion and structural damage from storm surge and breaking waves.
- River flooding and flash flooding inland from torrential rains.
- Tornadoes. (Tornadoes occur mostly in the outer fringes—e.g., 100-200 miles away, not in the eye—because updrafts stabilize the eye.)

HURRICANES: CATEGORIZATION

Visual 2.3.13



Key Points

This animation illustrates the Saffir-Simpson Hurricane Scale that is used to categorize hurricanes. The rating, which ranges from Category 1 to Category 5, is based on a hurricane's sustained wind speed and is used to estimate potential property damage. Hurricanes that reach Category 3 or higher are considered major hurricanes.

The Saffir-Simpson Hurricane Scale is provided on the next page.

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HURRICANES: CATEGORIZATION

Visual 2.3.13 (Continued)

Saffir-Simpson Hurricane Scale

		Barometric Pressure		Storm Surge		Avg. Wind Speed		
Category	**Example**	**mbar**	**In.**	**M**	**ft**	**kph**	**mph**	**Damage**
Normal (No storm)		1,000	29.92	0	0	0	0	
Tropical Storm				<1.2	<4	62 - 119	39 - 74	
1	Danny (1997)	980	>28.94	1.2 - 1.5	4 - 5	119 - 153	74 - 95	**Minor** damage to trees and unanchored mobile homes.
2	Bertha (1996) Isabel (2003)	965 - 979	28.5 - 28.93	1.8 - 2.4	6 - 8	154 - 177	96 - 100	**Moderate to major** damage to trees and mobile homes, windows, doors, some roofing. Low coastal roads flooded 2 to 4 hours before arrival of hurricane eye.
3	Alicia (1983) Fran (1996)	945 - 964	27.91 - 28.49	9 - 12	2.7 - 2.2	178 - 209	111 - 130	**Major** damage: Large trees down, small buildings damaged, mobile homes destroyed. Low-lying escape routes flooded 3 to 5 hours before arrival of hurricane eye. Land below 1.5 meters above mean sea level flooded 13 kilometers inland.
4	Hugo (1989)	920 - 944	27.17 - 27.9	4 - 5.5	13 - 18	210 - 249	130 – 156*	**Extreme** damage: Major damage to windows, doors, roofs, coastal buildings. Flooding many kilometers inland. Land below 3 meters above mean sea level flooded as far as 10 kilometers inland.
5	Camille (1969) Gilbert (1988) Andrew (1992) Mitch (1998)	920	27.17	>5.5	>18	>249	>157	**Catastrophic** damage: Major damage to all buildings less than 4.5 meters above sea level and 500 meters from shore. All trees and signs blown down. Low-lying escape routes flooded 3 to 5 hours before arrival of hurricane.

*The scale underwent a modification for 2012, broadening the Category 4 wind speed range by one mile per hour (mph) at each end of the range, yielding a new range of 130-156 mph.

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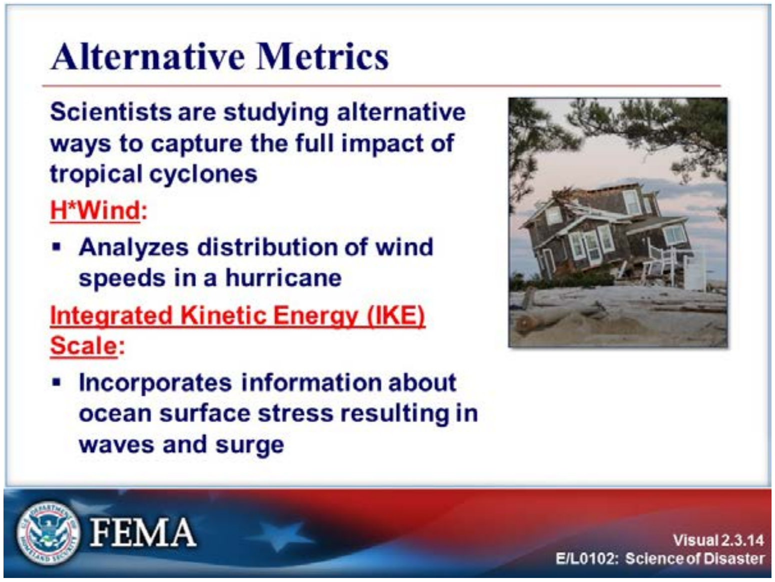
HURRICANES: CATEGORIZATION

Visual 2.3.14



Alt Text for Visual 2.3.14
Alternative Metrics
Scientists are studying alternative ways to capture the full impact of tropical cyclones
H*Wind:
- Analyzes distribution of wind speeds in a hurricane

Integrated Kinetic Energy (IKE) Scale:
- Incorporates information about ocean surface stress resulting in waves and surge

Key Points

Scientists are continually researching alternative ways to capture the full impact of tropical cyclones beyond the Saffir-Simpson Intensity Scale, which focuses on wind damage. Examples of ongoing research projects include H*Wind and the Integrated Kinetic Energy Scale.

- **H*Wind:**

  H*Wind is designed to improve understanding of the extent and strength of the wind field, and to improve the assessment of hurricane intensity. Wind measurements from a variety of observation platforms over a 4 to 6 hour period are used to develop an objective analysis of the distribution of wind speeds in a hurricane.

  The H*Wind “snapshot” products are provided in image and gridded form for research purposes and have been especially useful for storm surge and wave forecasting applications. The swath map is a relatively new product that is also available in image and gridded form as well as GIS shape files. The swath maps are helpful for damage and loss assessment.

  More information on H*Wind (This link can also be accessed at the following URL: http://www.aoml.noaa.gov/hrd/data_sub/wind.html)

HURRICANES: CATEGORIZATION

Visual 2.3.14 (Continued)

- **Integrated Kinetic Energy (IKE):**

  Tropical cyclone damage potential, as currently defined by the Saffir-Simpson scale and the maximum sustained surface wind speed in the storm, fails to consider the area impact of winds likely to force surge and waves or cause particular levels of damage.

  Whereas the Saffir-Simpson scale only reports top wind speeds, IKE integrates the wind speed with how wide an area in which the winds are blowing.

  Integrated kinetic energy, computed from H*Wind products, captures the physical process of ocean surface stress forcing waves and surge while also taking into account structural wind loading and the spatial coverage of the wind.

  The IKE framework:

  - Incorporates information about the ocean surface stress that results in waves and surge.
  - Also takes into account the destructive potential of wind.
  - Is based on the familiar 1- 5 range of the Saffir-Simpson scale, but with more exact, decimal numbering (i.e., storms as weak as 0.1 or as strong as 5.9).

- **What IKE tells us about Hurricane Sandy:**

  IKE better conveys the destructive power from both a hurricane's wind and storm surge. For example, the IKE scale helps explain why Hurricane Sandy (2012), which quickly weakened after landfall, created such widespread flooding and damage. The storm surge, combined with a full moon and high tide, affected hundreds of miles of highly populated coastline.

  The metric also incorporates the storm's enormous size. Sandy's wind field was so large that tropical storm force winds (45 mph) extended 485 miles out from the center at landfall. (Out at sea, the wind field reached a maximum extent of 520 miles.)

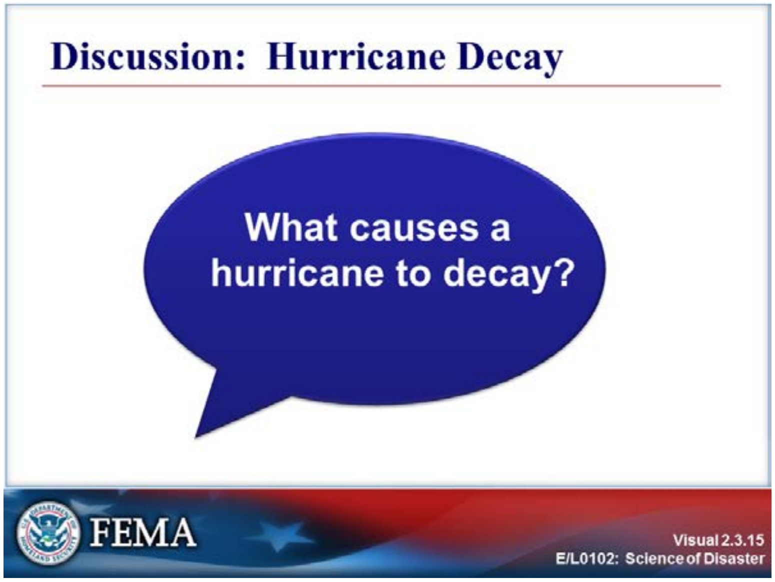
  In modern records, Sandy's IKE ranks second among all hurricanes at landfall, higher than devastating storms like Hurricanes Katrina, Andrew, and Hugo, and second only to Hurricane Isabel in 2003.

  Scientists hope that IKE will present a more accurate picture of the potential destruction that can result from a hurricane, particularly from storm surge, before it makes landfall.

  Additional information, including a tool for calculating an IKE value based on operational wind radii at the four quadrants of a storm, (This link can also be accessed at the following URL: http://www.aoml.noaa.gov/hrd/ike/index.html.)

DISCUSSION

Visual 2.3.15

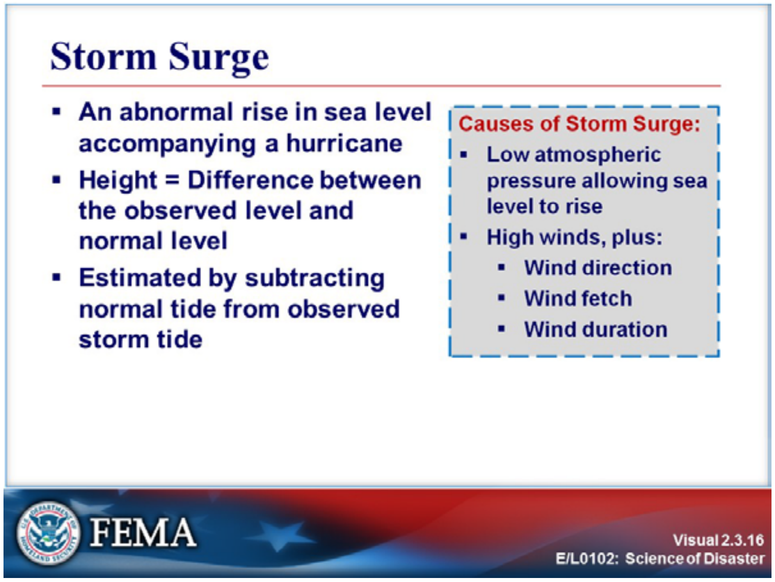


Key Points

<u>Discussion Question</u>: What causes a hurricane to decay?

STORM SURGE

Visual 2.3.16



Alt Text for Visual 2.3.16

Storm Surge

- An abnormal rise in sea level accompanying a hurricane
- Height = Difference between the observed level and normal level
- Estimated by subtracting normal tide from observed storm tide

Causes of Storm Surge:

- Low atmospheric pressure allowing sea level to rise
- High winds, plus:
  - Wind direction
  - Wind fetch
  - Wind duration

Key Points

A storm surge basically is the push of water onto land.

- A storm surge is an abnormal rise in sea level accompanying a hurricane or other intense storm, the height of which is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone.
- A storm surge is topped by destructive waves, presenting a threat to life and property.
- Storm surge can be 50 to 100 miles wide, and more than 15 feet deep at its peak.
- Storm surge also has the potential to reach very long distances inland. For example, in 1957, Hurricane Audrey inundated the southwestern coast of Louisiana as far as 25 miles inland.

STORM SURGE

Visual 2.3.16 (Continued)

Causes of storm surge: Unlike a tsunami, which is normally caused by a strong earthquake, a storm surge is caused by:

- Low atmospheric pressure allowing the sea level to rise. (There is less push down on the sea surface.)

- High winds associated with hurricanes, as well as:

  - **Wind direction:** The biggest surges are caused by wind blowing at a right angle onto land from the water.

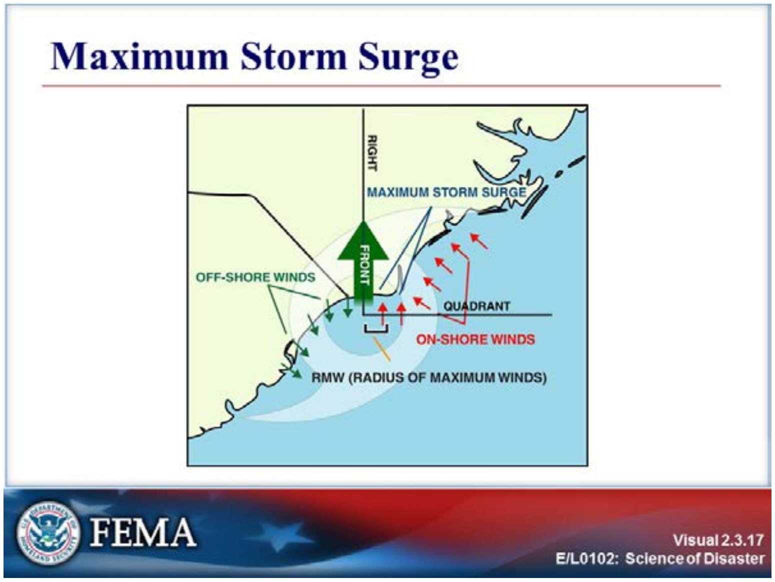
  - **Wind fetch:** Fetch is the area in which ocean waves are generated by the wind. It also refers to the length of the fetch area, measured in the direction of the wind. Fetch can allow for more water to be dragged up against the shore.

  - **Wind duration:** The longer the wind blows onto shore, the more water piles up.

  With intense storms, the impact of the low pressure associated with storm surge is relatively small in comparison to the wind moving the water toward the shore.

STORM SURGE

Visual 2.3.17



Key Points

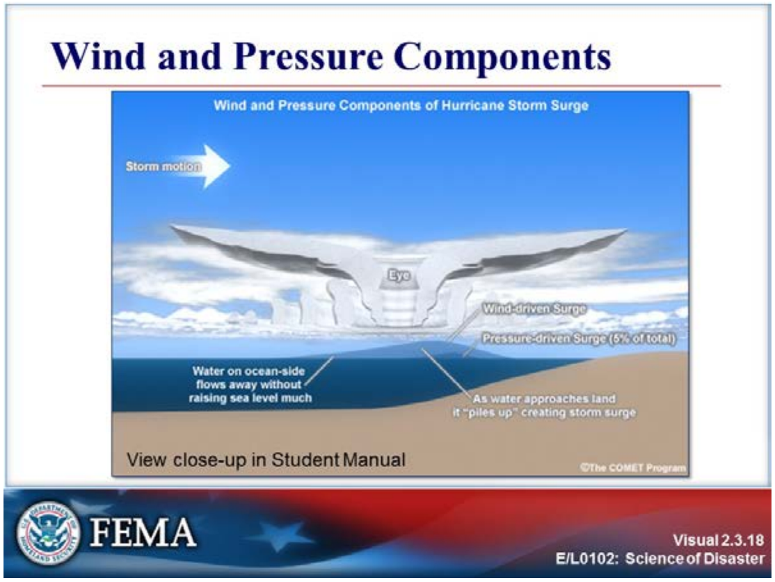
The speed, power, direction, and fetch of hurricane winds all mean that storm surge is highest on the right front quadrant of a land-falling hurricane.

This diagram shows a hurricane hitting a coastline with a concave shape. All the ingredients for the maximum amount of water in a surge are present. The green arrows represent an area of lesser concern because off-shore winds are pushing the water out; the right front quadrant (red arrows), however, represents an area of great concern.

(It is important to remember that the “north” of the hurricane is relative to the hurricane’s movement and direction. The axis rotates with the movement of a hurricane.)

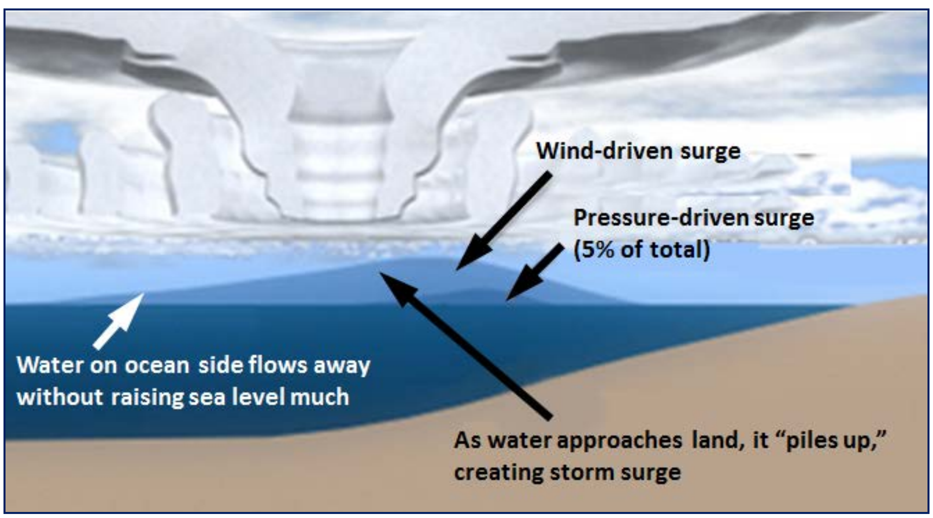
STORM SURGE

Visual 2.3.18



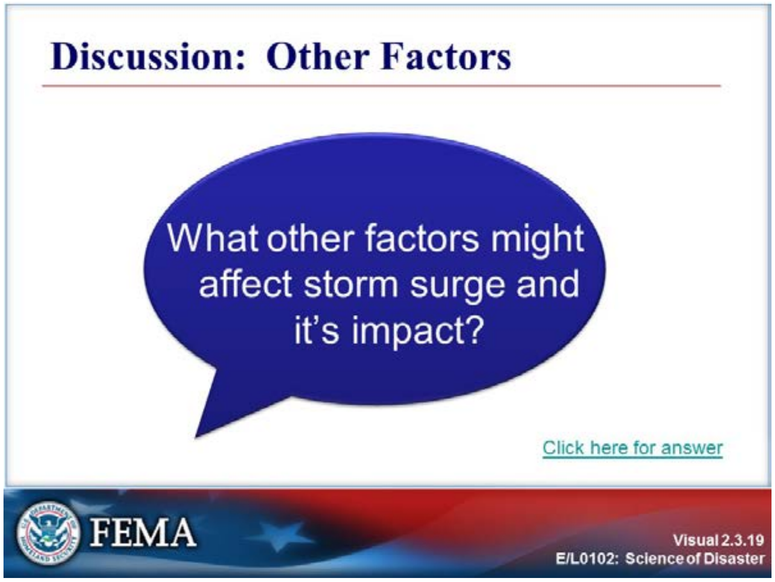
Key Points

This diagram shows an example of storm surge and its wind and pressure components.



STORM SURGE

Visual 2.3.19

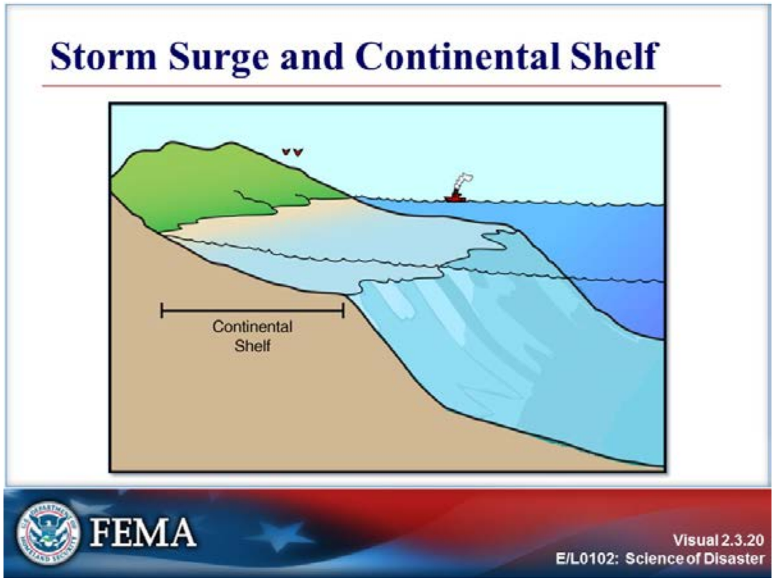


Key Points

<u>Discussion Question</u>: What other factors besides wind and pressure might affect the strength of a storm surge and its impact?

STORM SURGE

Visual 2.3.20



Key Points

The continental shelf (the submerged extension of land out to sea) is also a factor in the strength of storm surge.

STORM SURGE

Visual 2.3.21

Key Points

As shown in this animation, a shallower continental shelf (or a more gradual slope) makes it easier for a storm surge to come onto land.

For example, the Gulf coast has very shallow continental shelves compared to the Atlantic coast, so the storm surges in the Gulf there tend to be much higher.

STORM SURGE

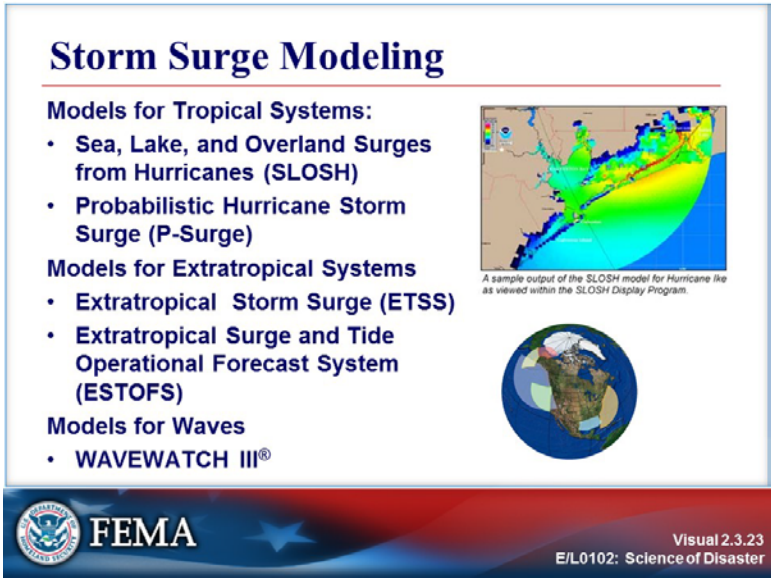
Visual 2.3.22

Key Points

This animation shows a deeper continental shelf (or a steeper slope). In this scenario, it is more difficult for the storm surge to gather the necessary force to push water onto dry land.

STORM SURGE MODELING

Visual 2.3.23



Alt Text for Visual 2.3.23
Storm Surge Modeling
Models for Tropical Systems:

- Sea, Lake, and Overland Surges from Hurricanes (SLOSH)
- Probabilistic Hurricane Storm Surge (P-Surge)

Models for Extratropical Systems

- Extratropical Storm Surge (ETSS)
- Extratropical Surge and Tide Operational Forecast System (ESTOFS)

Models for Waves

- WAVEWATCH III®

Image of a SLOSH model output and the Extratropical Basins

Key Points

SLOSH – The Sea, Lake and Overland Surges from Hurricanes (SLOSH) computer model was developed by the National Weather Service for coastal inundation risk assessment and the prediction of storm surge. It estimates storm surge heights resulting from historical, hypothetical, or predicted hurricanes. SLOSH computes storm surge by taking into account a storm's atmospheric pressure, size, forward speed, track, and winds. The calculations are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, levees, and other features.

SLOSH Display Program aids emergency managers in evacuation planning by aiding emergency managers with visualizing storm surge vulnerability. The SLOSH model and the display program are two different tools. The National Weather Service uses the SLOSH model to forecast storm surge and model storm surge vulnerability; emergency managers and others use the display program to visualize the SLOSH data.

STORM SURGE MODELING

Visual 2.3.23 (Continued)

P-Surge - Numerical storm surge models depend on an accurate forecast of the hurricane's track, intensity, and size but even the best hurricane forecasts still have considerable uncertainty. The National Hurricane Center's forecast landfall location, for example, can be in error by tens of miles even during the final 12 to 24 hours before the hurricane center reaches the coast. These limitations can make the single, deterministic SLOSH surge forecasts incorrect. To help overcome these limitations, forecasters use probabilistic storm surge (P-surge) forecasts.

The Probablistic Hurricane Storm Surge (P-Surge) model predicts the likelihood of various storm surge heights above a datum or above ground level based on an ensemble of SLOSH model runs using the official hurricane advisory. Graphical output shows the storm surge heights which have a certain probability of being exceeded and the probability of storm surge exceeding a certain height

These storm surge heights and probabilities are based on the historical accuracy of hurricane track and wind speed forecasts, and an estimate of storm size. P-Surge also computes the probability of surge above ground to more clearly communicate where the surge will occur.

ETSS - To predict the surge accompanying an extratropical storm, the NWS runs the Extratropical Storm Surge Model (ETSS). This model is a variation on the SLOSH model, which is used for hurricane storm surge forecasting. ETSS predicts storm surge flooding along U.S. coastlines but is not able to predict the extent of overland flooding.

Because extratropical storms have larger time and length scales than tropical storms, the ETSS model uses the basic SLOSH model, but with winds and pressures generated from the Global Forecast System atmospheric model, which is particularly useful for forecasting storm surge associated with East Coast Nor'easters and in western Alaska where storm surge associated with extratropical cyclones can devastate low-lying coastal communities.

Coverage for the model includes the east, west, and Gulf coasts of the continental United States and the Bering Sea and Arctic regions of Alaska (See map).

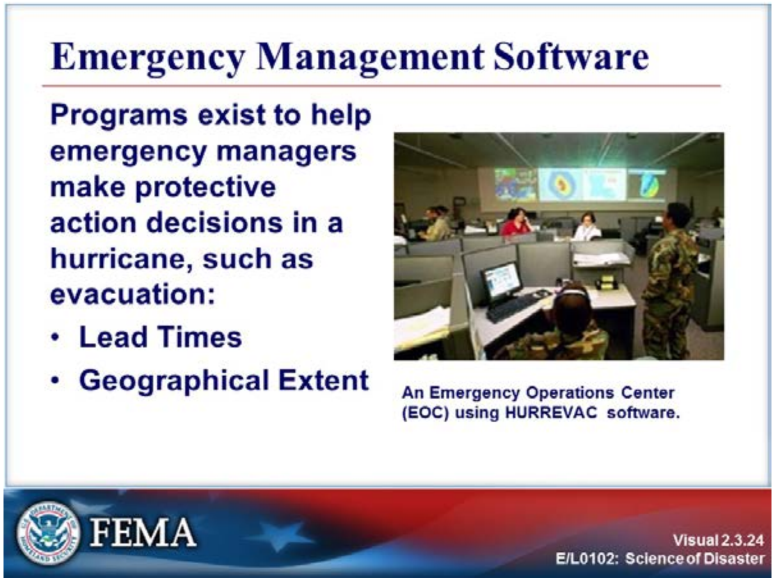
ESTOFS - The Extratropical Surge and Tide Operational Forecast System, a new generation hydrodynamic modeling system, was developed for the Atlantic and Gulf coasts. ESTOFS provides real-time forecasts of surges with tides.

WAVEWATCH III® - NOAA created WAVEWATCH III® to provide consistent and reliable predictions of potentially dangerous wave heights, including those occurring with storm surge, that could have a devastating impact on lives and property along the shore. The model gives meteorologists and many other users a better understanding of coastal swells and surf conditions, and a better insight on probable effects from hurricane and tropical storm surge.

The models allow NOAA to simulate many different storms in order to understand the risks involved and forecast storm surge.

EMERGENCY MANAGEMENT SOFTWARE

Visual 2.3.24



Key Points

Programs exist to help emergency managers make decisions regarding protective action measures in a hurricane. One example of software is:

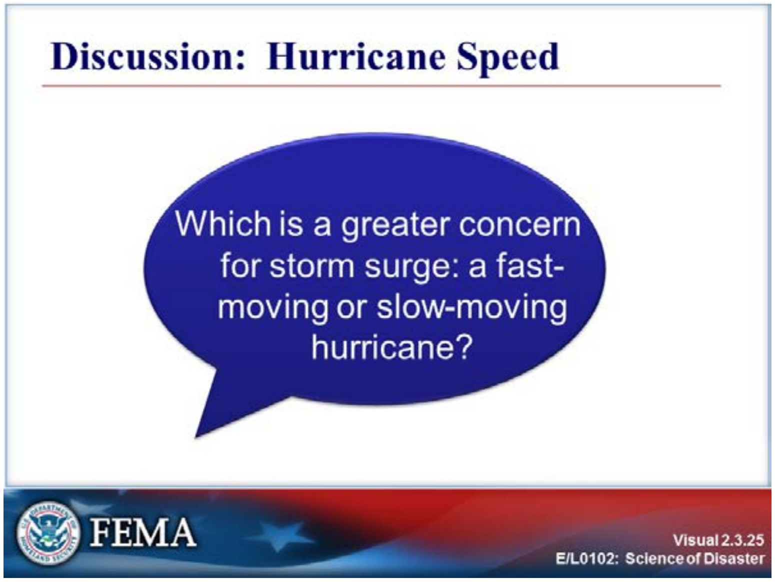
HURREVAC (short for *Hurr*icane *Evac*uation) is a storm tracking and decision support tool. The program combines live feeds of tropical cyclone forecast information with data from various state Hurricane Evacuation Studies (HES) to assist the local emergency manager in determining the most prudent evacuation decision time and the potential for significant storm effects such as wind and storm surge. Many Emergency Operations Centers use HURREVAC as a situational awareness and briefing tool.

Program access is restricted to officials in government emergency management. As a general rule, if you are the Emergency Manager for a county in the hurricane prone states (Texas to Maine), in Puerto Rico or the Virgin Islands, state Emergency Management Agency (EMA), a FEMA office, Corps of Engineers office, or National Weather Service office, you are eligible to use the HURREVAC program (The website can also be accessed at the following URL:http://www.hurrevac.com/about.htm)

The program is distributed free-of-charge to eligible users and also details regular training and exercise opportunities.

STORM SURGE

Visual 2.3.25

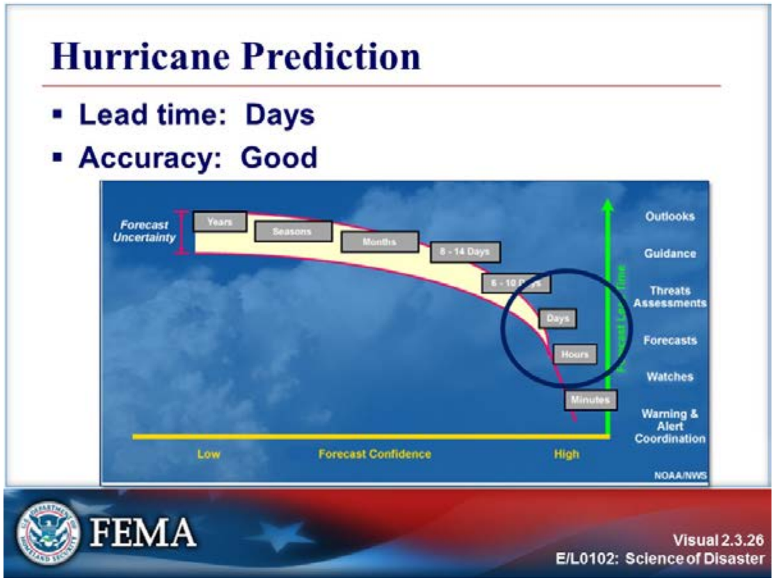


Key Points

<u>Discussion Question</u>: Which storm is a greater concern in terms of storm surge, and why: a fast-moving hurricane, or a slow-moving hurricane?

HURRICANE ANALYSIS AND PREDICTION

Visual 2.3.26



Key Points

We saw in the previous unit that tornadoes are difficult to predict. How well are weather forecasters able to predict hurricanes? The lead time for predicting hurricanes is measured in days, and the accuracy is generally good.

Prediction tools: Forecasters use computer and climate models and satellite imagery to gather information about:

- Hurricane intensity and movement (e.g., preliminary path).
- Large-scale climate factors.
- Atmospheric conditions (e.g., atmospheric pressure).
- Oceanic conditions (e.g., surface water temperatures).
- Cloud top temperatures.
- Moisture levels.
- Typical seasonal activity.

Predictable information: Using this information, forecasters are able to provide information on the storm's:

- Intensity:
  - Wind strength.
  - Central pressure.
  - Amount of precipitation.
- Size.
- Duration.
- Track and cone of uncertainty (probable track of the hurricane based on current information and computer models).

HURRICANE ANALYSIS AND PREDICTION

Visual 2.3.27

Key Points

Introduction: This video discusses the forecasting of Hurricane Katrina using satellite imagery. The narrative is provided on the next page.

HURRICANE ANALYSIS AND PREDICTION

Visual 2.3.27 (Continued)

Transcript: Katrina Retrospective: 5 Years After the Storm

August 29, 2005. After passing over the Caribbean, Hurricane Katrina made landfall along the Gulf of Mexico. By the time the skies cleared, Katrina had killed more than 1,800 people, caused roughly $125 billion in damages, and went down as one of the strongest storms to hit the U.S. in a century.

Five years later, NASA revisits Katrina as captured by NASA satellites. While these images can't tell the whole story of the hurricane and its impacts, they remind us of the power and destructive nature of tropical cyclones.

In the weeks leading up to Katrina, NASA's Aqua satellite captures sea surface temperatures with the AMSR-E instrument. Warm ocean temperatures, indicated in red, provide energy to fuel the growing storm. As Katrina moves, it leaves a trail of cooler water in its wake, stirred up from below.

Two days before landfall... NASA's MISR instrument on the Terra satellite witnesses growing cloud tops as the storm gathers strength.

Just before landfall... the TRMM satellite looks inside the hurricane at "hot towers"—powerful thunderstorms that help propel Katrina to category 5 strength. The same satellite reveals heavy rains. Green means at least a half inch of rain is falling per hour. Yellow, an inch. Red, over two inches per hour.

As the hurricane sweeps through, TRMM's multi-satellite analysis reveals where the hurricane delivered the heaviest rains, shown here in yellows and reds.

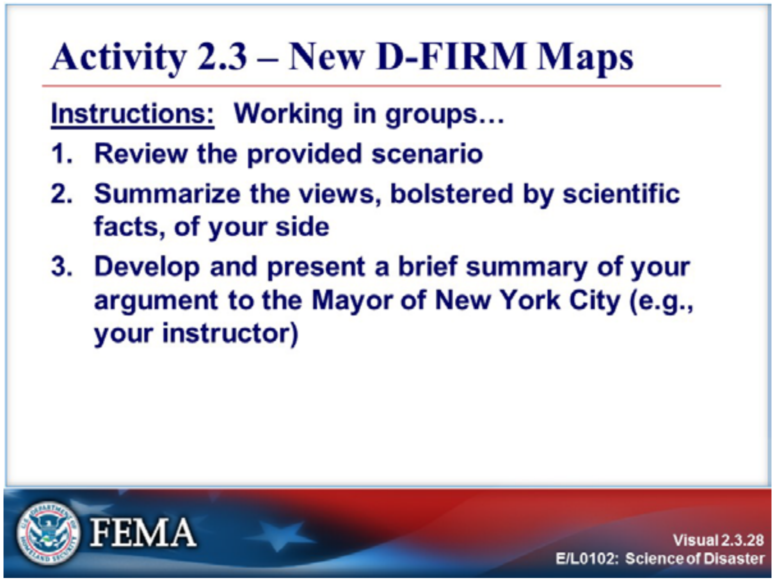
Finally, Landsat satellite imagery shows us the extent of flooding in New Orleans. First, the city before the storm with Lake Pontchartrain to the north. Two days after the storm made landfall, much of the city is flooded by the catastrophic levee failures.

Today, Landsat sees a city still rebuilding from the storm. NASA satellites continue to provide detailed observations of tropical cyclones around the world—to better understand how they work, and so we can prepare for those yet to come.

(Credit: NASA/Goddard Space Flight Center)

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28



Key Points

Instructions: Working in groups…

1. Review the provided scenario.
2. Summarize the views, bolstered by scientific facts, of your side.
3. Develop and present a brief summary of your argument to the Mayor of New York City (i.e., your instructor).

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

Activity 2.4 - Hurricane Sandy Fact Sheet

- Deaths – at least 149
  - New York – 42
  - New Jersey – 12
  - Maryland – 9
  - Pennsylvania – 6
  - West Virginia – 5
  - Connecticut – 4
  - Virginia – 2
  - North Carolina – 1
  - Canada – 1
  - Caribbean - 67
- Landfall Statistics:
  - Dates: 10/29/2012 – 11/1/2012
  - Location: near Atlantic City, NJ
- Complicating Factors & Their Results:
  - Full moon made high tides 20% higher.
    - Seawater flooded highways, low-lying streets, tunnels, subway stations hampering transportation
    - Electrical substations were flooded leading to power outages to 8.5 million people at its worst
    - Tanker ship ran aground
  - High winds made skyscrapers sway and brought down a crane
  - Failure to evacuate so boats were needed to rescue the stranded
  - Fires – one fire in Queens destroyed 80 homes
  - Gas stations were flooded, lost power, or had supplies depleted
- Records:
  - Atmospheric Central Pressure: 940 millibars (27.76”). Was a record low barometric pressure for an Atlantic storm north of Cape Hatteras, NC
  - Record surf in New York Harbor – 32.5’ wave
- Costs:
  - $20 billion in property damage
  - $10 - $30 billion in lost business
  - $19 billion – losses to New York City
  - $9.8 billion – aid request to FEMA for uninsured losses

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 1

NYC Challenges Accuracy of FEMA Flood Maps

by Emily Manley

Flooding caused by Hurricane Sandy on East 91st Street in the Rockaways.
Photo credit: Dakine Kane via Creative Commons

City officials announced last Friday they will challenge new FEMA maps that greatly expand flood zones in New York City.

The federal maps, set to go into effect in 2016, would nearly triple the number of properties included in official flood zones, and affect more than 400,000 citizens. Alternative maps proposed by the de Blasio administration would reduce the number of buildings in the proposed FEMA flood zones by nearly half. This could have a profound impact on the flood insurance burdens faced by residents.

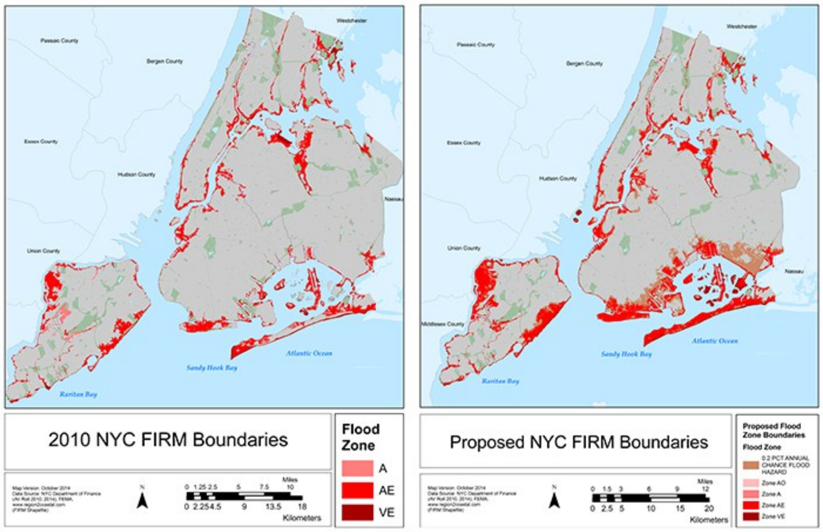
But questions also linger about the wisdom of reducing flood zones in a post-Sandy era—and some climate experts wonder whether the FEMA maps actually go far enough.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 1 (Continued)

Whose Maps are Inaccurate?



FEMA maps with 2010 updates compared to proposed 2016 FEMA maps.

Daily News reports that city officials claim up to 35% of the area FEMA designated as flood-prone is labeled inaccurately. The city argues that federal calculations used a flawed analysis of prior storms, among other reasons.

Many of the homes that would be affected by the new maps are in South Brooklyn (Canarsie), South Queens (Howard Beach, the Rockaways), and Staten Island.

As NYER has reported in the past, these new FEMA maps will have important implications for resiliency projects, human safety, and government policy, but nowhere will the impact be felt more than on individual home flood insurance rates.

Under the proposed FEMA maps, a typical home in the high-risk zones could see premiums increase from around $1,000 in 2014 to nearly $14,500 by 2030.

According to Daily News, the city hired outside engineers to create its own maps. By their estimates, only 230,000 New Yorkers live in flood zones, which include 45,000 buildings. That's 26,500 fewer buildings than the new FEMA maps count, and 170,000 fewer people.

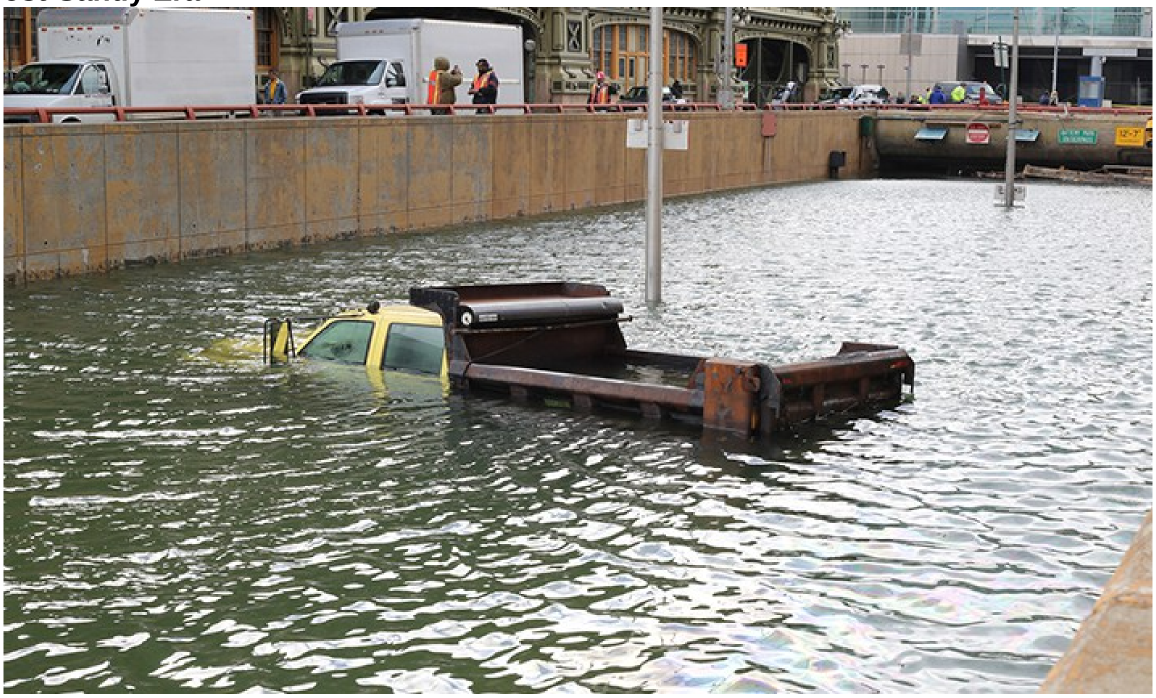
The review process could take more than a year to complete; no insurance changes will be made during that time.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 1 (Continued)

A Post-Sandy Era



Flooded Battery Park Tunnel after Hurricane Sandy. Photo credit: Timothy Krause/Creative Commons.

While many, including U.S Senator Charles Schumer, applaud the city's new calculations, there are others who question the wisdom (and safety) of reducing flood zones in a time of changing climate.

Indeed, there are some who wonder if FEMA's maps actually went far enough.
The Natural Resources Defense Council claims that FEMA's maps are based on outdated data that does not take into account future effects of climate change, including sea level rise that has occurred just in the last 10 years.
In addition, NRDC found FEMA's computer models were not calibrated against data from Hurricane Sandy. As a result "the new 100-year flood zone mapped by FEMA is significantly smaller than the area at risk of flooding assuming 3 feet of sea level rise or the surge from a Category 3 hurricane." By comparison, Sandy was barely a Category 1 storm.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 2

Climate.gov's Brian Kahn interviews Cynthia Rosenzweig, a climate impacts expert at NASA Goddard Institute for Space Studies, co-chair of the New York City Panel on Climate Change, and director of the NOAA-sponsored Consortium for Climate Risk in the Urban Northeast.

Cynthia Rosenzweig, NASA Goddard Institute for Space Studies.

Why should New Yorkers care about sea level rise?

First of all, sea level rise is a big issue for millions of people in the U.S., not just New Yorkers. Twenty-three of the 25 most densely populated U.S. counties are on the coast. In New York, the full brunt of Hurricane Sandy has shown how powerful and damaging the effects of coastal flooding can be for infrastructure and communities.

The storm itself we can't immediately link to climate change, but the flooding damage we can. As sea levels continue to rise, a storm of the same magnitude will cause even greater damages due to storm surges coming in on top of a higher "baseline" water level.

What kind of sea level rise has New York Harbor seen over the past century?

We've had roughly a foot of sea level rise in the New York City area in the past century. That's measured at a tidal gauge near Battery Park just off the southern tip of Manhattan.

The majority of the sea level rise in the New York City region is due to global warming: primarily, because of thermal expansion of ocean water as it warms and secondly, melting of land-based ice sheets.

Land subsidence [sinking] in the New York City area has been roughly 3-4 inches per century, which is primarily due to the Earth's crust rebounding* from being compressed by massive ice sheets that covered Canada and the northern U.S. about 20,000 years ago near the end of the last Ice Age. Local variations in ocean surface elevation associated with the strength of the Gulf Stream has played a small role as well.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 2 (Continued)

How do sea level rise and storm surge interact?

Sea level rise is like a set of stairs. The 12-inch increase in New York Harbor over the last century means we've already gone up one step. When a coastal storm occurs, the surge caused by the storm's winds already has a step up, literally. For Sandy, that meant greater coastal flooding in New York and the surrounding region than we would have experienced a century ago. Continuing to climb the staircase of sea level rise means we'll see greater extent and greater frequency of coastal flooding from storms, even if storms don't get any stronger.

How does sea level rise in New York Harbor compare to other parts of the U.S.? What about the global average?

Sea level isn't rising evenly throughout the world. On average, global sea level has risen about eight inches since 1880. So, the New York rate of sea level rise of nearly one foot is higher than the global average rate. In the U.S., rates of change vary. For example, Grand Isle, Louisiana near New Orleans has seen sea level increase by 23 inches since 1947 whereas Seattle, Washington, has only seen about six inches over that same period. Local factors such as land subsidence are primarily responsible for the differences.

What's the range of sea level rise we can expect to see in the future for the New York region?

We've created two sets of sea level rise projections for the region by downscaling global climate models for local conditions. Using a similar approach to the last IPCC [Intergovernmental Panel on Climate Change] report, we project 12-23 inches by the 2080s.

We also developed a rapid-ice-melt scenario, based on the same greenhouse gas concentrations, but factoring in observations of accelerated ice sheet melt and paleoclimate data from ice cores, tree rings, and other sources. That projection gives a higher end of 41-55 inches in the 2080s.

Why are there sets of ranges?

Not only is there uncertainty about future rates of ice melt, there is also uncertainty about the pace of greenhouse gas emissions. There is also uncertainty in how the Earth's climate system will respond to greenhouse gas forcings. We use sets of scenarios to cover these ranges.

What infrastructure in New York is most threatened by sea level rise? What are some specific impacts?

In 2001, I worked with colleagues at Columbia University, New York University, and NASA on a report called the Metropolitan East Coast Report: Climate Change and a Global City, which examined climate change impacts in New York. In that report, we identified flooding of the tunnels into and out of Manhattan, flooding of the subway, energy infrastructure, and inundation of coastal communities as key vulnerabilities.

More recently, I've worked with colleagues to look at the telecommunications infrastructure, which hasn't really been highlighted before. Hurricane Sandy exhibited all of these impacts.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 2 (Continued)

It's important to note that these systems don't act in isolation; they are incredibly interdependent. For example, when the power goes down then you can't charge your cell phone. These interdependencies are compounding the impacts that people are experiencing in the New York region from Hurricane Sandy.

What about social vulnerabilities?

All of these infrastructure vulnerabilities feed directly into societal ones. In the New York region, many lower-income communities are located in the coastal flood zone. With Sandy, there has been tremendous damage across many of those communities.

In addition, the elderly, the very young, and the ill are also highly vulnerable. It's much harder for them to evacuate, which in turn puts them at greater risk to infrastructure failure. Just look at the challenges hospitals in Lower Manhattan faced when the back-up generators failed.

Did Sandy reveal any previously unforeseen weaknesses?

We're going to be looking at the impacts of Hurricane Sandy very carefully. Many of the impacts that occurred have been included in previous studies, but we're certainly going to go back and evaluate them so we can better inform planning around extreme weather and climate events. We can always learn more and continue to be better prepared. One thing we do want to look at is the fires that occurred in some of the coastal communities, and the gasoline shortages that persisted throughout parts of the region.

What actions has the city undertaken to help infrastructure and residents deal with sea level rise and attendant impacts from storm surge prior to Sandy?

Hurricane Sandy is a wake up call, no, a shout, that going forward we have to do more to prepare for these kinds of events. That said, the city has done a great deal to prepare. The city government has a flood evacuation plan, and they implemented it. The Metropolitan Transit Authority (MTA) had a plan to close the subway, and they did it early enough. The loss of life could have been much higher.

There have been some other important initiatives New York has taken. For example, the Mayor's Office has planted vegetation in over 300 places to absorb storm water. It's called the Greenstreets Program. They're also raising the pumps at the Rockaway Wastewater Treatment Plant in response to sea level rise projections. In addition, the MTA has raised some of the subway grates and air vents on the sidewalks as part of a pilot program.

These programs are informed by the work of the New York City Panel on Climate Change (NPCC), an expert panel convened by Mayor Bloomberg to advise the city on climate science and risk management. The NPCC published an extensive, peer-reviewed report about climate change and its impacts on New York. The New York City Council has passed a resolution to have the NPCC write a report on the order of once every three years to ensure the city is using climate research when it comes to planning.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 2 (Continued)

Can you talk about what the Consortium for Climate Risk in the Urban Northeast (CCRUN), one of your newer initiatives, has done?

CCRUN does stakeholder-driven research on climate variability and change in the urban Northeast from Boston to Philadelphia. It has provided regional climate change projections, and we're working with stakeholders in the region to develop resilience.

We're working with mayors' offices in each of the major cities, metropolitan water utilities, health departments, and disaster managers to provide actionable climate information.

Our focus areas are coasts, water, and health. We're developing a focus on green infrastructure as an adaptation strategy. Stakeholders indicated that these were the important sectors for us to work on together.

When scientists talk about sea level rise in coming decades, you generally hear them say "projections" rather than "predictions." What's the difference?

There's uncertainty about climate change. Not that it's happening, but as to its future rate of change and magnitude. The term "projection" is better because it includes uncertainty more clearly. "Prediction" implies more certainty, a perspective that doesn't take into account that there's still emerging science around climate change, that the climate system is continually evolving, and that there will be updates to future climate and sea level rise scenarios as a result.

If projections are uncertain, why use them?

Despite the range of projections, there is enough knowledge for stakeholders and decision-makers to improve climate resilience. It's clear that people and agencies that are responsible for critical infrastructure and community preparedness need to take the potential impacts of a changing climate into account, rather than assuming that what has happened in the past will not change in the future. It's all about risk management. You don't need complete certainty to be able to plan for better climate protection.

[*Editor's note: Like a giant placing its finger on one end of a seesaw, northern ice sheets compressed the Earth below them, and land beyond the edge of the ice sheet—including the New York area—rose like the other end of the seesaw. With the ice sheets gone, the seesaw is gradually returning to "level:" once-glaciated areas are rising, while adjacent, non-glaciated areas are sinking.—added Nov. 13, in response to a reader's request for clarification.]

Reviewed by Cynthia Rosenzweig, Somayya Ali, and Daniel Bader, all at the NASA Goddard Institute for Space Studies.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 3

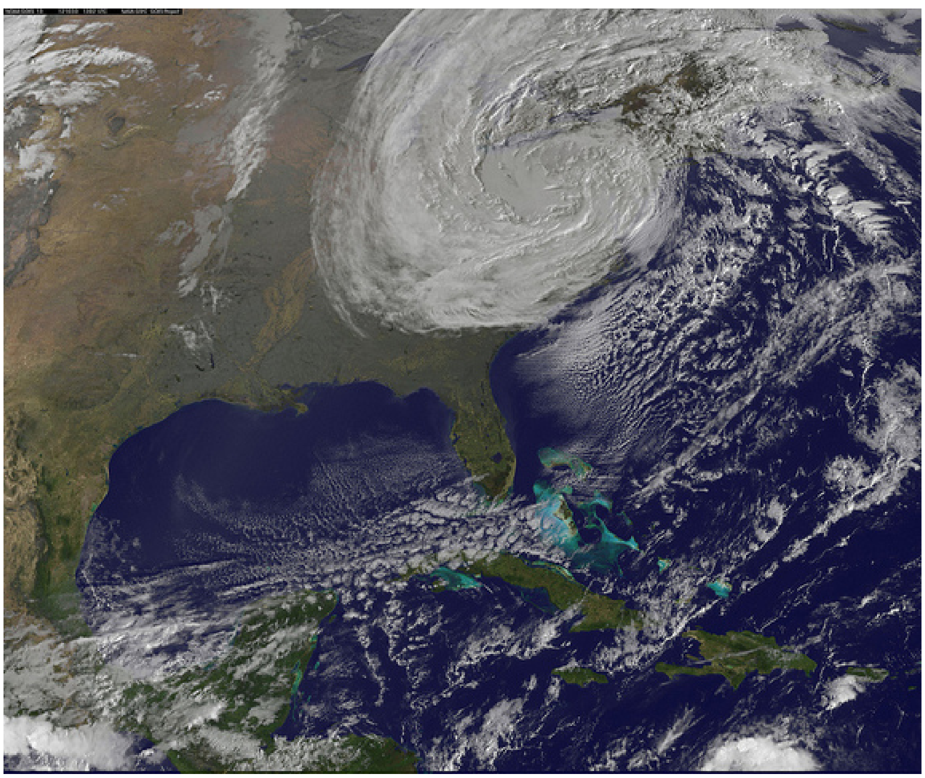
Superstorm Sandy: Facts About the Frankenstorm

By Tim Sharp, LiveScience Reference Editor | November 27, 2012 10:50am ET

Hurricane Sandy, a late-season post-tropical cyclone, swept through the Caribbean and up the East Coast of the United States in late October 2012. The storm left dozens dead, thousands homeless and millions without power. Total damage is expected to be in the billions of dollars.

Death toll

The death toll from Sandy as of Nov. 1 was at least 149. The confirmed deaths include 42 in New York; 12 in New Jersey; nine in Maryland; six in Pennsylvania; five in West Virginia; four in Connecticut; two in Virginia; and one in North Carolina. One person died in Canada, and at least 67 people were killed in the Caribbean, including 54 in Haiti.

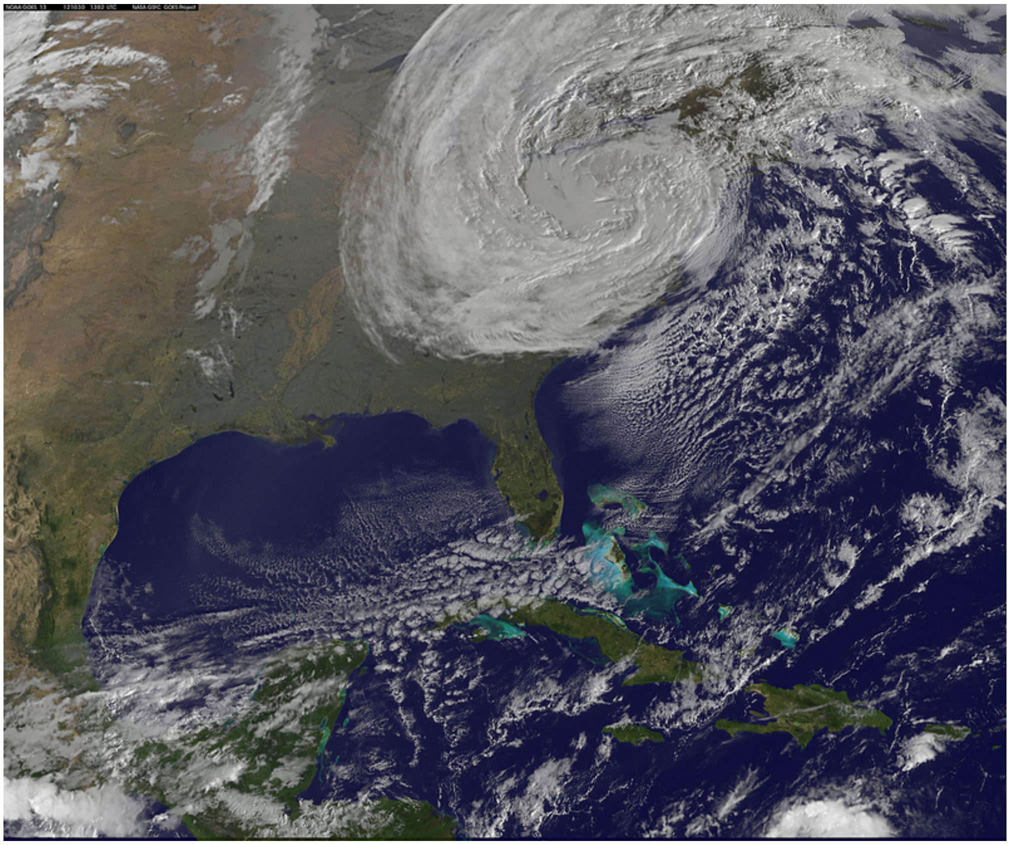


To view this graphic at the following URL:
http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=79553

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 3 (Continued)



To view this graphic at the following URL:
http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=79553

NOAA GOES-13 image of Sandy at 6:02 a.m. EDT Tuesday (Oct. 30).

Credit: NOAA/NASA GOES Project

Origin of storm

Sandy began as a tropical wave in the Caribbean on Oct. 19. It quickly developed, becoming a tropical depression and then a tropical storm in just six hours. Tropical Storm Sandy was the 18th named storm of the 2012 Atlantic hurricane season. It was upgraded to a hurricane on Oct. 24 when its maximum sustained winds reached 74 mph (119 kph).

Sandy tore through the Caribbean, making landfall at Jamaica on Oct. 24. After leaving that island, the storm gained strength over open water and became a Category 2. The storm hit Cuba early Oct. 25, then weakened to a Category 1. On Oct. 26, it swept across the Bahamas. Sandy briefly weakened to a tropical storm on Oct. 27, then gained strength again to become a Category 1 hurricane before turning north toward the U.S. coast.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 3 (Continued)

Sandy slams Jersey shore

Hurricane Sandy made landfall in the United States about 8 p.m. EDT Oct. 29, striking near Atlantic City, N.J., with winds of 80 mph. A full moon made high tides 20 percent higher than normal and amplified Sandy's storm surge. Streets were flooded, trees and power lines knocked down and the city's famed boardwalk was ripped apart. Along the Jersey shore, people were left stranded in their homes and waited for rescue teams in boats to rescue them. More than 80 homes were destroyed in one fire in Queens. Several other fires were started throughout the New York metro area.

Seawater surged over Lower Manhattan's seawalls and highways and into low-lying streets. The water inundated tunnels, subway stations and the electrical system that powers Wall Street and sent hospital patients and tourists scrambling for safety. Skyscrapers swayed and creaked in winds that partially toppled a crane 74 stories above Midtown. A large tanker ship ran aground on the city's Staten Island.

As of Nov. 1, about 4.7 million people in 15 states were without electricity, down from nearly 8.5 million a day earlier. Subway tunnels in Lower Manhattan remained flooded, but some lines had resumed service. Airlines, which had canceled more than 15,000 flights around the world, were returning to normal schedules. Most gas stations in New York City and New Jersey were closed because of power shortages and depleted fuel supplies. Long lines formed at gas stations that were expected to open.

Sandy will end up causing about $20 billion in property damage and $10 billion to $30 billion more in lost business, making it one of the costliest natural disasters on record in the United States, according to IHS Global Insight, a forecasting firm. The New York City mayor's office in late November estimated total losses to the city to be $19 billion and asked the federal government for $9.8 billion in aid for costs not covered by insurance or FEMA.

By Nov. 1, Sandy had dissipated. The National Weather Service reported that "multiple remnants" were circulating across the lower Great Lakes region and moving into Canada. Some areas were getting residual rain and snow showers. Tides were back down to less than a foot above normal.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

ACTIVITY 2.4 – Job Aid 3 (Continued)

Frankenstorm

Sandy, the 10th hurricane of the 2012 Atlantic hurricane season, earned the nickname "Frankenstorm," as well as other descriptive appellations, such as "Blizzacane" and "Snor-eastercane." The National Hurricane Center's official name for the storm is "Post Tropical Cyclone Sandy." Many media outlets started calling it "Superstorm Sandy" after the storm made landfall, weakened and was downgraded from hurricane status.

At one point, Sandy's hurricane-force winds (at least 74 mph) extended up to 175 miles (280 kilometers) from its center and tropical storm-force winds (39 mph) out to 485 miles (780 km). Even so, according to the NHC, Sandy was still only the second-largest Atlantic tropical cyclone on record. Hurricane Olga, another late-in-the-year storm, set the record in 2001, with tropical-force winds extending 600 miles (965 km).

Sandy set other records, however, CNN reported. When hurricane hunter aircraft measured its central pressure at 940 millibars — 27.76 inches — Monday afternoon (Oct. 29), it was the lowest barometric reading ever recorded for an Atlantic storm to make landfall north of Cape Hatteras, N.C. The previous record holder was the 1938 "Long Island Express" Hurricane, which dropped as low as 946 millibars.
Sandy's strength and angle of approach combined to produce a record storm surge of water into New York City. The surge level at Battery Park topped 13.88 feet at 9:24 p.m. Monday, surpassing the 10.02 feet record water level set by Hurricane Donna in 1960.
New York Harbor's surf also reached a record level when a buoy measured a 32.5-foot wave Monday. That wave was 6.5 feet taller than a 25-foot wave churned up by Hurricane Irene in 2011

Presidential campaign interrupted

President Barack Obama joined New Jersey Gov. Chris Christie on Oct. 31 to inspect the devastation, flying over flooded neighborhoods along the New Jersey coastline. He declared states of emergency in New York and New Jersey to allow federal aid to start flowing into damaged areas.

ACTIVITY 2.4 – NEW D-FIRM MAPS

Visual 2.3.28 (Continued)

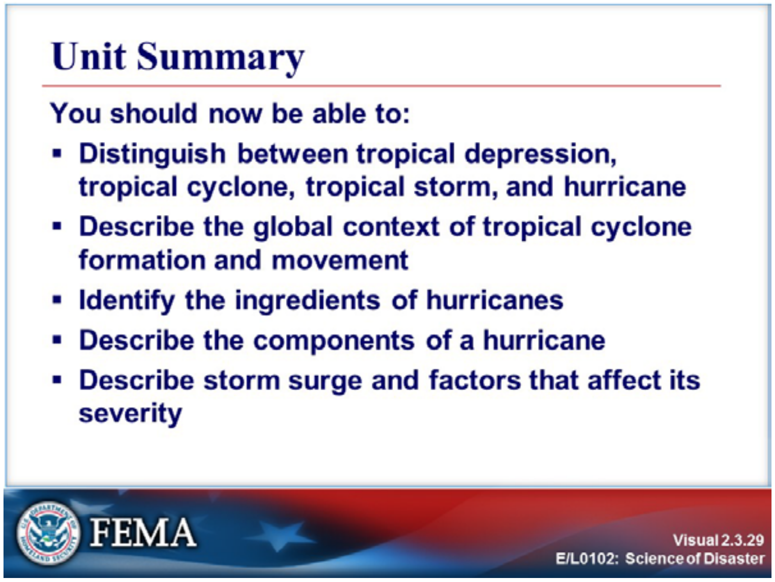
ACTIVITY 2.4 – Job Aid 3 (Continued)

Republican Mitt Romney canceled political rallies on Oct. 29 and 30, turning one campaign appearance into a "storm relief" event. He gave brief non-political remarks and spent less than an hour collecting hurricane relief donations and loading them into a truck. Romney resumed his campaign on Oct. 31, using a Florida campaign stop to criticize the president's record. Obama resumed campaign appearances on Nov. 1.

The storm's political impact is still unknown. Concrete effects on Election Day are yet to be tallied: how many early voting days lost, how many voters who don't make it to the polls because of power outages, damaged homes or cleanup duties, whether any polling places or election equipment are damaged. Parts of four states seen as pivotal to this election were hit — North Carolina, Virginia, Ohio and New Hampshire.

UNIT SUMMARY

Visual 2.3.29



Alt Text for Visual 2.3.29
Unit Summary
You should now be able to:

- Distinguish between tropical depression, tropical cyclone, tropical storm, and hurricane
- Describe the global context of tropical cyclone formation and movement
- Identify the ingredients of hurricanes
- Describe the components of a hurricane
- Describe storm surge and factors that affect its severity

Key Points

Do you have any questions about the material covered in this unit?

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UNIT 4. OTHER HAZARDOUS WEATHER

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INTRODUCTION

Visual 2.4.1

Key Points

This unit will discuss the hazards presented by various other types of weather events, including nor'easters, winter storms, extreme temperatures, and droughts, as well as the science behind their formation and prediction.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Nor'easters • Activity 2.5 – The Perfect Storm Case Study	45 minutes
Winter Storms	20 minutes
Extreme Cold	15 minutes
Unit Summary • Activity 2.6 – Long-Term Power Outage	15 minutes
Total Time	**1 hour 40 minutes**

INTRODUCTION

Visual 2.4.2

Alt Text for Visual 2.4.2
Unit Objectives

- Compare and contrast nor'easters and hurricanes
- Identify the ingredients of nor'easters, winter storms, extreme cold temperatures
- Explain the scientific differences between various types of frozen precipitation
- Indicate the predictability of nor'easters, winter storms, extreme cold temperatures

Key Points

Review the unit objectives as listed on the visual.

NOR'EASTERS

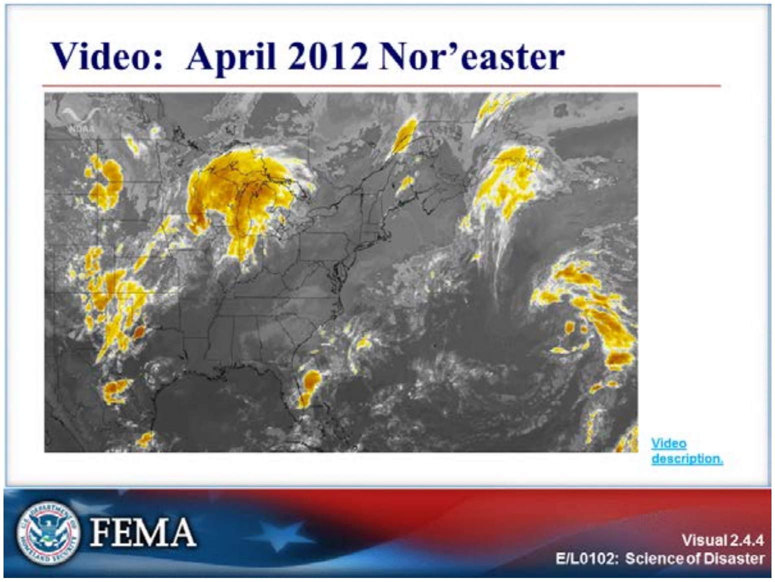
Visual 2.4.3

Key Points

The first section of this unit will present key points about the science of nor'easters.

NOR'EASTERS

Visual 2.4.4



Key Points

This time-lapse animation made using infrared imagery from a NOAA satellite shows a nor'easter forming in April of 2012. There is no audio.

NOR’EASTERS

Visual 2.4.5

Alt Text for Visual 2.4.5
What Is a Nor’easter?

- Low-pressure system
- Moves along east coast
- Counter-clockwise rotation
- Named after northeasterly winds blowing ahead
- Can occur any month (peak September to April)

Types:

- Offshore forming: More catastrophic, heavy snow
- Onshore forming: Less catastrophic, mostly rain

Key Points

Characteristics of a nor’easter: A nor’easter:

- Is a strong, low-pressure system that moves along the east coast of the United States with a counter-clockwise rotation
- Gets its name from the strong, northeasterly winds that blow in from the ocean ahead of the storm and over coastal areas
- Can occur any month of the year, but is strongest (and occurs most frequently) between September and April. They are less common in summer because the jet stream is usually missing (farther north)

A nor’easter normally develops within 100 miles of the coastline between Georgia and New Jersey and moves north or northeastward from there. However, a nor’easter can form over the land of the east coast, or out over the Atlantic coastal waters. This difference constitutes the two types of nor’easters.

NOR'EASTERS

Visual 2.4.5 (Continued)

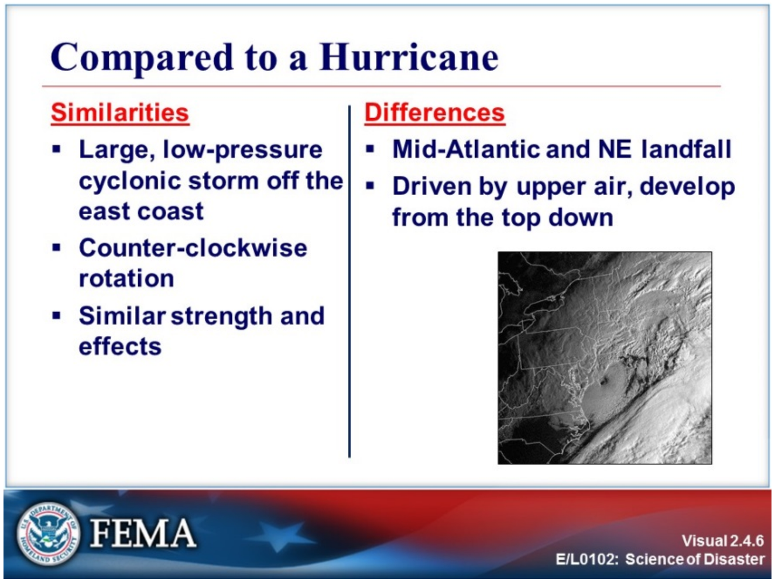
Types of nor'easters:

- **Offshore forming:** These nor'easters are normally more catastrophic and news-worthy. After forming over the Atlantic waters, these storms will dump heavy snow onto cities like Washington, DC, New York City, and Boston.

- **Onshore forming:** These nor'easters are normally much less catastrophic or news-worthy. They tend to move west of most east coast cities, act like average storms, and mostly produce just rain and wind.

NOR'EASTERS

Visual 2.4.6



Alt Text for Visual 2.4.6
Compared to a Hurricane
Similarities
- Large, low-pressure cyclonic storm off the east coast
- Counter-clockwise rotation
- Similar strength and effects

Differences
- Mid-Atlantic and NE landfall
- Driven by upper air, develop from top down

Image of a map with a large storm off of the east coast of the US.

Key Points

When compared to a hurricane, a nor'easter is similar in several key ways:

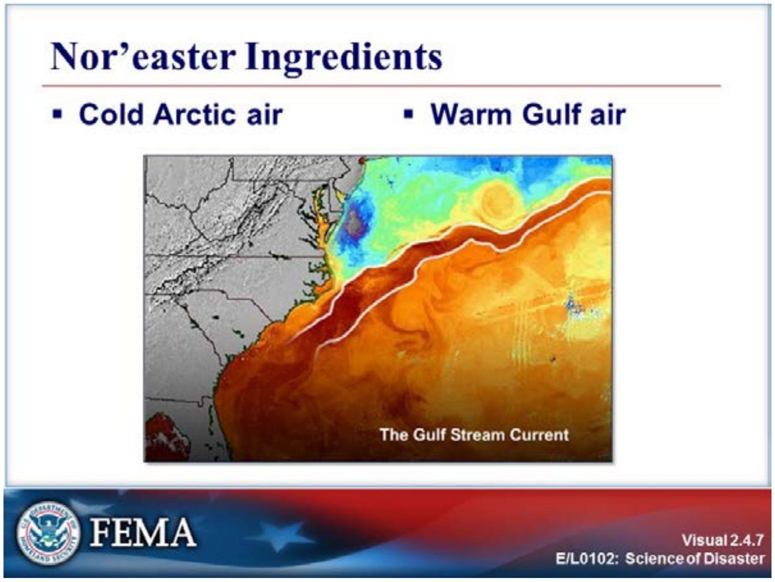
- Both hurricanes and nor'easters are large, low-pressure cyclonic storms that normally have a center of rotation just off the east coast.
- Both are counter-clockwise rotating systems in the Northern Hemisphere.
- Nor'easters can reach the strength of moderate or even strong hurricanes and can produce similar effects.
- Occasionally, a strong nor'easter will form a hurricane-like eye at its center. For example, this visual shows a satellite image of an intense nor'easter with a hurricane-like eye in February 2006.

However, there are also a few key differences:

- Hurricanes normally make landfall in the southern States, while nor'easters typically afflict the mid-Atlantic and northeast States.
- Hurricanes develop from the bottom up, whereas nor'easters are driven by upper air and develop from the top down.

NOR'EASTERS

Visual 2.4.7



Key Points

Nor'easters form as a result of a few key ingredients:

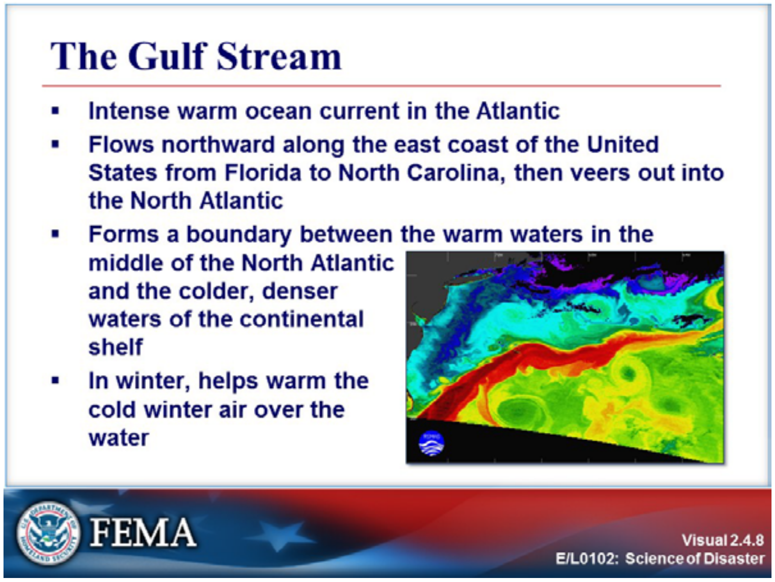
- **Cold Arctic air:** During the winter, the polar jet stream moves cold Arctic air eastward toward the Atlantic Ocean and southward across Canada and the United States.

- **Warm Gulf air:** Meanwhile, subtropical air from the Gulf of Mexico moves northward and interacts with the cold, Arctic air off the east coast.

The interaction of these two systems—the cold, Arctic air over the land fed by the warm, moist Gulf air over the water—can result in the sudden and explosive development of a nor'easter. Any time you have pressure contrasts, there is the potential for wind development.

NOR'EASTERS

Visual 2.4.8



Alt Text for Visual 2.4.8

The Gulf Stream

- Intense warm ocean current in the Atlantic
- Flows northward along the east coast of the United States from Florida to North Carolina, then veers out into the North Atlantic
- Forms a boundary between the warm waters in the middle of the North Atlantic and the colder, denser waters of the continental shelf
- In winter, helps warm the cold winter air over the water

Image of a map with the warm and cold air currents displayed.

Key Points

Impact of the Gulf Stream: The Gulf Stream plays an important part in the formation of nor'easters. The Gulf Stream is an intense warm ocean current in the Atlantic that flows northward along the east coast of the United States from Florida to North Carolina and then veers out into the North Atlantic near Cape Hatteras, North Carolina.

The Gulf Stream:

- Forms a boundary between the warm waters in the middle of the North Atlantic and the colder, denser waters of the continental shelf. The current loops and bends as it veers away from the United
- States. coast, so its exact position is variable.
- Influences the climate of the east coast of Florida, keeping temperatures warmer in the winter and cooler than the other southeastern states in the summer. Because it also extends toward Europe, it warms western European countries as well.
- Helps keep the coastal waters relatively mild during the winter which, in turn, helps warm the cold winter air over the water.

NOR'EASTERS

Visual 2.4.8 (Continued)

The following video will present a case study that examines in greater detail how these ingredients interact.

The infrared image shows the Gulf Stream as it departs from the coast at Cape Hatteras. The coldest waters are shown as purple, with blue, green, yellow, and red representing progressively warmer water. Temperatures range from about 45-72 °F (7-22 °C).

NOR'EASTERS

Visual 2.4.9

Key Points

Introduction: This video presents a case study that examines in greater detail how the Gulf Stream and other ingredients interact to create a nor'easter.

Video Transcript:

The Tropics provide a steady stream of clouds and storms that generally move east to west. In mid-latitudes, weather moves west to east with some twists and turns due to Earth's rotation. An important kind of storm moves north and east along the United States' east coast, especially in winter. People in the New England States call these "nor'easters," and they usually bring snow, rain, and driving wind. In late April, an unusual, post-winter nor'easter brought much-needed rain to an especially dry eastern United States.

To understand the climate connections driving nor'easters, here are satellite loops that track the storm through late April.

A low-pressure system developed off the coast of Florida on April 21 as light, warm moist air rose from the warm ocean surface. Warm water is a climate characteristic of the Gulf, the Caribbean, and the Gulf Stream which warms the entire east coast before heading off towards northern Europe. Earth's rotation interacts with the prevailing movement of air from west to east to spin these storms up and along the east coast.

NOR'EASTERS

Visual 2.4.9 (Continued)

The difference in temperature between land, which is cold, and the ocean, which is warm, fuels driving rains. The ocean in this part of the world stays warm due to the Gulf Stream. The land is especially cold when Arctic air plunges southward. During winter, this temperature difference is more common, but notice how the polar jet stream dipped south of the Great Lakes on April 22.

The east coast has been drier than normal so far this year, in part because winter didn't bring any major nor'easters. This map shows rainfall differences from average for January through April. The brown areas were drier than normal for this time of year.

Farmers are often the first to feel water shortages. In Maryland, some farmers lost their spinach crops and had to delay soy and corn planting because the soil was so dry. Farmers and residents in Delaware-Maryland-Virginia, Connecticut, Rhode Island, and Massachusetts have all delayed their spring planting and have been conserving water.

This springtime storm made up for most of April's rainfall deficit in a single event, dumping over 2 inches along much of the Atlantic coast and between 4 and 6 inches in parts of Maine. Unfortunately, the year-to-date through April was still well below average, not only for the Mid-Atlantic and New England, but much of the United States.

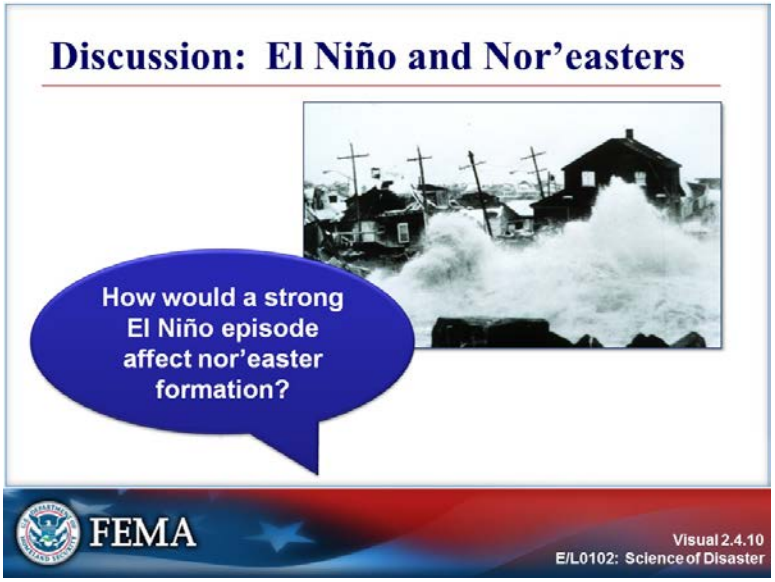
Recapping the climate connections for a nor'easter: warm ocean water fuels a low-pressure system with moisture; Earth's rotation moves that air mass in a counter-clockwise motion along the east coast, and cold air from the North drives toward the storm's center. That was the climate story for one strange nor'easter after Easter.

For climate.gov, I'm Ned Gardiner.

(Source: NOAA Climate.gov)

NOR'EASTERS

Visual 2.4.10

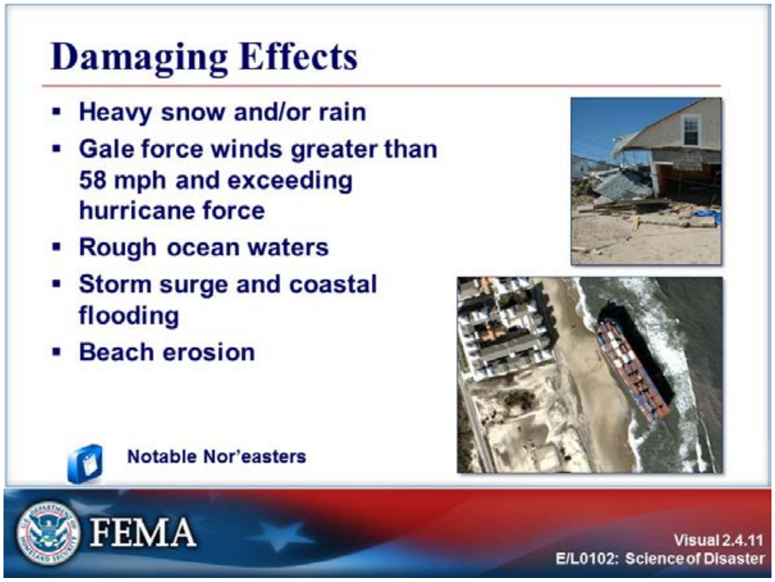


Key Points

<u>Discussion Question</u>: How do you think a strong El Niño episode would affect the formation of nor'easters (if at all)?

NOR’EASTERS

Visual 2.4.11



Alt Text for Visual 2.4.11
Damaging Effects
- Heavy snow and/or rain
- Gale force winds greater than 58 mph and exceeding hurricane force
- Rough ocean waters
- Storm surge and coastal flooding
- Beach erosion

An image of a house damaged by a nor’easter, and an image overhead image of rough ocean waters surging on a residential area

Key Points

Damaging effects of nor’easters can include:

- Heavy snow and/or rain
- Gale force winds with a speed greater than 58 mph and exceeding hurricane force in intensity
- Rough ocean waters
- Coastal flooding and beach erosion

The bottom image on the slide shows an area off the coast of Virginia where storm surge resulting from a nor’easter grounded a barge on shore.

One of the biggest concerns is the huge amounts of snow dumped on east coast cities. For example, a nor’easter in February 2006 brought more than 26 inches of snow to Central Park in New York City.

On the next page are descriptions of some of the most notable nor’easters in terms of damage.

NOR’EASTERS

Visual 2.4.11 (Continued)

Notable Nor’easters

- **Post-Christmas Storm of 2010:** This late-December nor’easter was initially a low-pressure system from the Gulf but exploded into a nor’easter off the mid-Atlantic coast. It brought heavy snow, thunderstorms, and strong winds of up to 40 mph throughout the Northeast.

- **Blizzard of 1996:** This nor’easter developed in the Gulf, intensified along the mid-Atlantic, and brought heavy snow and wind gusts to the mid-Atlantic and much of the Northeast. Local accumulations in West Virginia were as high as 4 feet, and Philadelphia received 30.7 inches—its highest accumulation on record. After this nor’easter, the same general area was hit with a warmer rainstorm that contributed to widespread melting and flooding.

- **1993 Super storm:** This storm was named for its wide area of impact (New England to Florida). It took a more inland track rather than moving up the coast. In the Mid-Atlantic States, there was severe flooding and snowfall; in Florida, the super storm resulted in storm surges of 9 to 12 feet.

- **1992 Great Nor'easter or “The Downslope Nor'easter”:** The effects of this December storm were felt most strongly in the northeast and the mid-Atlantic coasts, which were battered with high winds and waves. There was moderate flooding in Maryland and storm surges of 10 to 12 feet in New Jersey, Delaware, and New York City.

- **Blizzard of 1978:** This February nor’easter was historic due to its long-duration snowfall and hurricane-force winds (gusts of 80–90 mph in eastern Massachusetts) resulting from a strong high-pressure system off the coast of New England. The Northeast was hit the hardest, and Boston and Providence were buried under record snowstorm totals (27.1 inches and 27.6 inches, respectively).

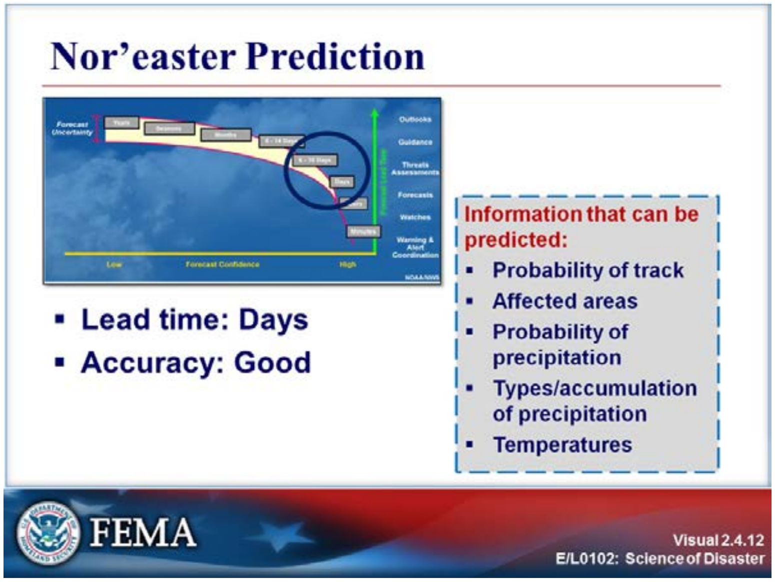
- **1962 Ash Wednesday Storm:** Perhaps the strongest nor’easter of the century, this monstrous March storm resulted in major coastal erosion from New York to North Carolina. As a result of the massive storm surge in Virginia, entire islands off the coast (Chincoteague, Assateague) were completely flooded, and winds as high as 70 mph built up 40-foot waves in the ocean.

- **1956 Nor'easter:** This storm resulted in significant damage from high tides in Virginia. For example, there was a 4.6-foot rise in water levels in Hampton Roads, and a 6.32-foot rise in Norfolk. The storm flooded thousands of homes and washed two ships on shore.

- **Blizzard of 1888:** This massive March nor’easter:
    - Brought devastating amounts of snowfall from Virginia to Maine
    - Paralyzed Washington, D.C., Philadelphia, Boston, and New York City
    - Dumped up to 50 inches of snow in multiple New England States with snow drifts as high as 40 to 50 feet
    - Resulted in 200 sunken ships and 400 fatalities

NOR'EASTERS

Visual 2.4.12



Alt Text for Visual 2.4.12
Nor'easter Prediction

- Lead time: Days
- Accuracy: Good

Information that can be predicted:

- Probability of track
- Affected areas
- Probability of precipitation
- Types/accumulation of precipitation
- Temperatures

Image: a weather chart showing the movement of a forecast of a nor'easter

Key Points

Accuracy of prediction: The lead time for predicting nor'easters is measured in days, and the accuracy is generally good.

Challenges: However, as with all weather, there is a degree of unpredictability that continually poses challenges to forecasters. Dr. Louis Uccellini, Director of the National Centers for Environmental Prediction (NCEP), said in 2002 that "the rare and episodic nature of nor'easters adds a challenge for meteorologists who have to forecast these storms with the confidence and reliability required so that proper precautions can be taken in advance of their occurrence."

For example, in early March of 2001, forecasters were able to predict that a nor'easter would hit the east coast 7 to 3 days in advance, with great accuracy. However, 1 day before the storm, the slow-moving storm stalled, taking almost a full day longer to fully develop, and producing the heaviest snow much farther north than the models had predicted (i.e., Albany and western Massachusetts, instead of large east coast cities, such as New York City and Boston).

NOR'EASTERS

Visual 2.4.12 (Continued)

Informational sources: To predict nor'easters, forecasters rely on many of the same informational sources we have discussed, including:

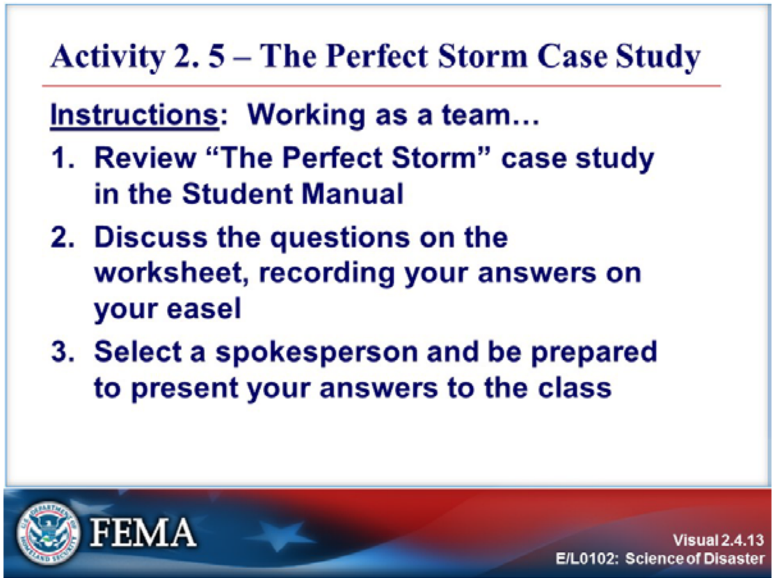
- Surface observations (e.g., balloon-launched temperature, moisture, and wind measurements)
- Statistical models
- Coordination with Federal, State, and local emergency managers

With the necessary information gathered from these sources, forecasters are able to predict:

- Probability of the nor'easter's track and affected areas
- The probability of precipitation
- Types and accumulation of precipitation
- Temperatures

ACTIVITY 2.5 – THE PERFECT STORM CASE STUDY

Visual 2.4.13



Key Points

Instructions: Working as a team:

1. Review the case study about "The Perfect Storm" on the following page of your Student Manual.
2. Discuss the questions that follow, and record your answers on your easel.
3. Select a spokesperson and be prepared to present your answers to the class.

ACTIVITY 2.5 – THE PERFECT STORM CASE STUDY

Visual 2.4.13 (Continued)

Activity 2.5 Job Aid

Case Study:

From October 28th to November 4th, much of the United States was affected by the Halloween Nor’easter of 1991, or “The Perfect Storm.” (A book and popular film of the same name chronicle the experience of fishermen caught in the nor’easter.)

Meteorologist Bob Case, who is credited with coining the term “The Perfect Storm,” explained the unique set of conditions this way:

> It was an unprecedented set of circumstances. A strong disturbance associated with a cold front moved along the U.S.-Canadian border on October 27 and passed through New England pretty much without incident. At the same time, a huge high-pressure system was forecast to build over southeast Canada. When a low-pressure system along the front moved into the Maritimes southeast of Nova Scotia, it began to intensify due to the cold dry air introduced from the north. These circumstances alone could have created a strong storm, but then, like throwing gasoline on a fire, a dying hurricane Grace delivered immeasurable tropical energy to create the perfect storm.

Another interesting feature of the storm was its motion—despite never making United States landfall, it moved toward the New England coast, rather than away from it. The weather was also remarkably fair prior to the storm. “There was a certain amount of skepticism to our warnings of what turned out to be one of the North Atlantic’s most powerful storms,” Case added. “Not too many people could fathom—or believe—100-foot waves and hurricane force winds, 70-80 mph plus, in a storm that was heading from east to west. You were looking at a set of meteorological circumstances that come together maybe every 50-to-100 years."

ACTIVITY 2.5 – THE PERFECT STORM CASE STUDY

Visual 2.4.13 (Continued)

Activity 2.5 Worksheet

1. **What scientific ingredients or conditions made this nor'easter "The Perfect Storm?"**

2. **We know that our ability to predict extreme weather is getting better but, that in disaster after disaster, people do not heed the messages of personal preparedness and of imminent warnings to take protective actions. What do you think causes this?**

3. **How can/does your community combat this?**

WINTER STORMS

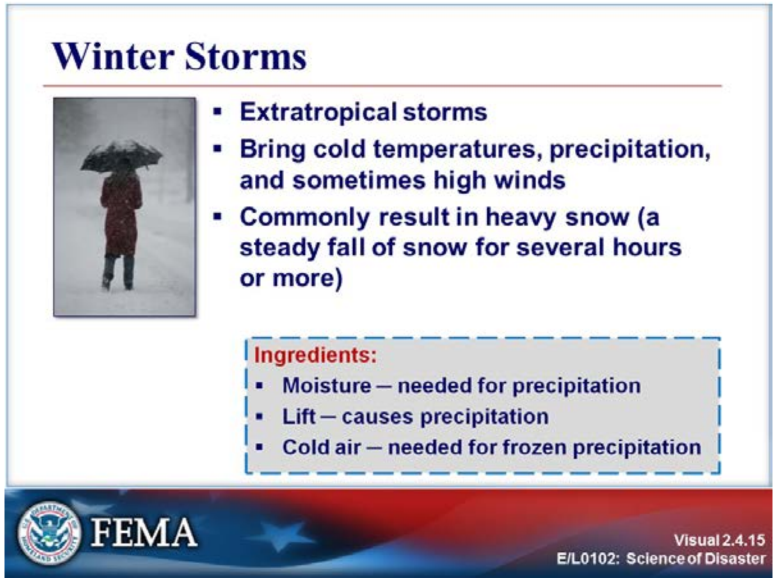
Visual 2.4.14

Key Points

The next section of this unit will present key points about the science of winter storms, which are related to nor'easters in their effects, but they are somewhat different in their causation.

WINTER STORMS

Visual 2.4.15



Alt Text for Visual 2.4.15
Winter Storms

- Extratropical storms
- Bring cold temperstures, precipitation, and sometimes high winds
- Commonly result in heavy snow (a steady fall of snow for several hours or more)

Ingredients:

- Moisture – needed for precipitation
- Lift – causes precipitation
- Cold air – needed for frozen precipitation

Image of a person standing in a snowy area with an umbrella

Key Points

Description: Winter storms are extratropical storms that bring cold temperatures, precipitation, and sometimes high winds. Heavy snow is a common component of winter storms and is defined as a steady fall of snow for several hours or more.

The accumulations and timeframes for defining heavy snow depend on region and elevation, but are generally defined as:

- Snowfall accumulating to 4 inches (10 cm) or more in 12 hours or less
- Snowfall accumulating to 6 inches (15 cm) or more in 24 hours or less

Ingredients: The development of a winter storm requires three ingredients:

- **Moisture:** The air must contain moisture in order to form clouds and precipitation. As you learned in earlier units, air blowing across a body of water, such as a large lake or an ocean, is an excellent source of moisture.

WINTER STORMS

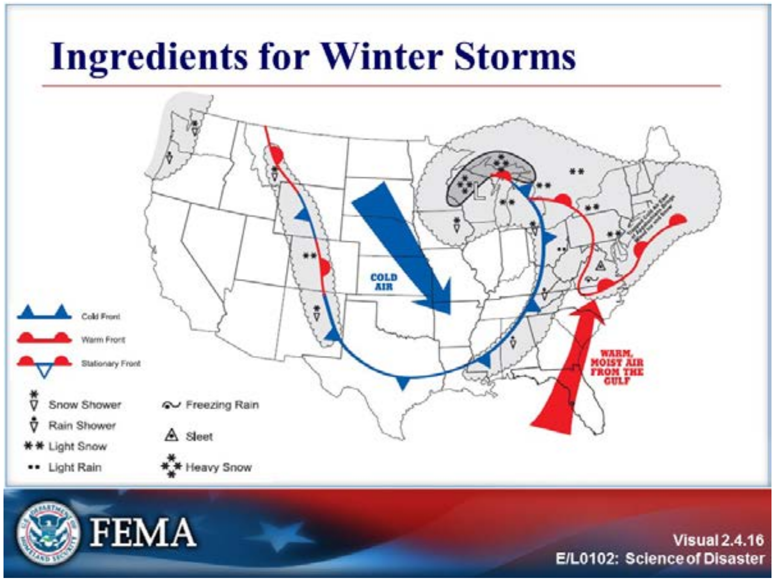
Visual 2.4.15 (Continued)

- **Lift:** A mechanism to raise the moist air to form the clouds and cause precipitation must also be present. Lift can be provided by any or all of the following:
  - Orographic flow, i.e., the flow of air up a mountainside
  - Fronts, where warm air collides with cold air and rises over the cold dome
  - Upper-level low pressure troughs

- **Cold air:** Cold air generally refers to subfreezing temperatures (below 32 °F) in the clouds and/or near the ground needed to make snow and/or ice.

WINTER STORMS

Visual 2.4.16



Alt Text for Visual 2.4.15
Ingredients for Winter Storms
A map displaying cold fronts, warm fronts, and stationary fronts across the US. An arrow shows the cold air flowing south and warm, moist air from the gulf flowing north. Additional markings show showers, rain, sleet and heavy snow.

Key Points

This visual illustrates the three ingredients needed for winter storm formation interacting on a national scale. Note that:

- A front of cold air is represented by the blue line with triangles
- A front of warm, moist air from the Gulf is represented by the red line with half-circles
- A stationary front (i.e., a front between warm and cold air masses that is moving very slowly or not at all) is represented as a combination of the two lines

In this scenario, the three ingredients necessary for winter storm formation—moisture, lift, and cold air—are all present.

WINTER STORMS

Visual 2.4.17

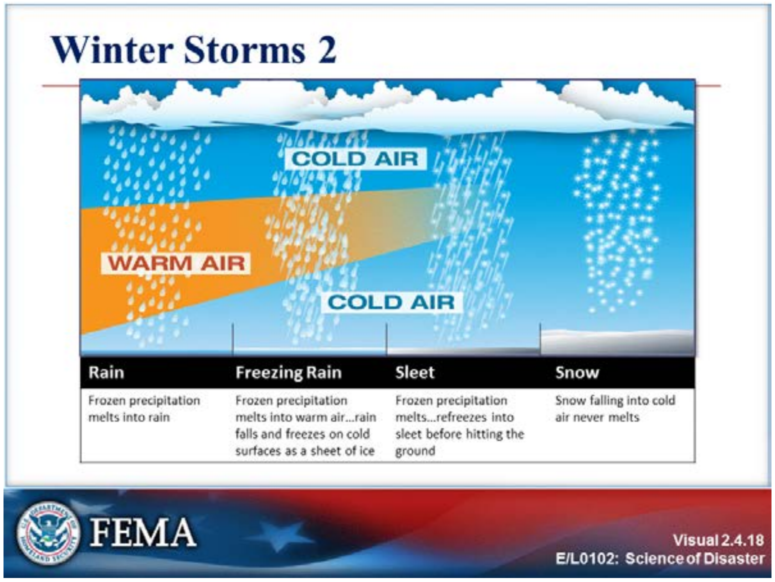
Key Points

Often, the general public uses the words snow, sleet, and freezing rain interchangeably. However, these are all distinct types of frozen precipitation with different scientific definitions.

<u>Discussion Question</u>: What is the scientific difference between snow, sleet, freezing rain, and hail? (Consider how the precipitation forms and falls.)

WINTER STORMS

Visual 2.4.18



Alt Text for Visual 2.4.18

Winter Storms

Warm Air – Rain – Frozen precipitation melts into rain

Cold Air – Freezing Rain – Frozen precipitation melts into warm air… rain falls and freezes on cold surfaces as a sheet of ice

Cold Air – Sleet – Frozen precipitation melts… refreezes before into sleet before hitting the ground

Cold Air – Snow – Snow falling into cold air never melts

Key Points

Winter Storm Terminology

- **Blizzard:** A winter storm with strong winds >35 mph, visibility of ¼ mile or less, and large amounts of snow prevailing for 3 hours or longer
- **Blowing snow:** Snow lifted from the ground by wind
- **Drifting snow:** Falling snow caught by surface winds and accumulated into drifts
- **Freezing rain:** Precipitation that falls as very cold rain and freezes when it touches the ground
- **Hail:** Frozen precipitation that originates in a cloud, starts falling, gets caught by an air current in the cloud, and is propelled up through the cloud again. This process may repeat several times. Each time the frozen droplet accumulates more ice until it is heavy enough to overcome the air currents and fall to the ground. (Hail can even occur in summer thunderstorms.)

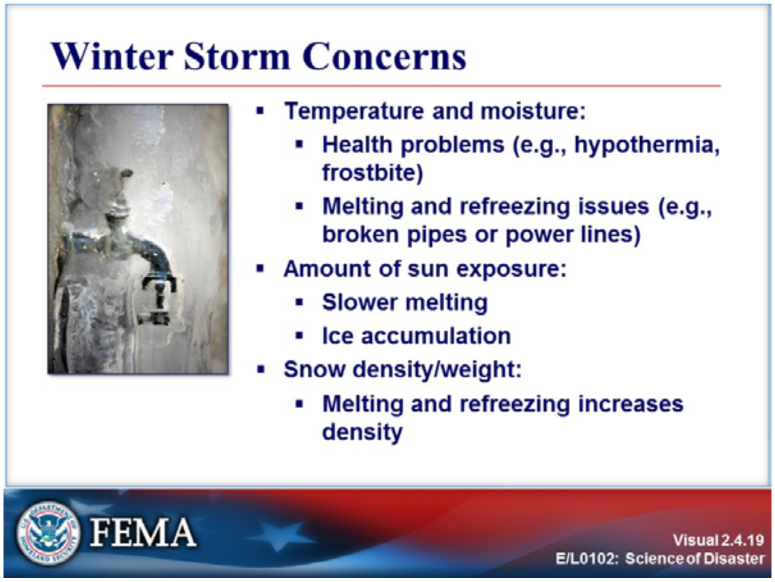
WINTER STORMS

Visual 2.4.18 (Continued)

- **Sleet:** Precipitation that originates from a cloud as frozen precipitation, falls through a warm layer of air and starts to melt, then falls through a layer of freezing air and refreezes as it falls to the ground
- **Snow:** Precipitation in the form of ice crystals, mainly of intricately branched, hexagonal form and often agglomerated into snowflakes, formed directly from the freezing (deposition) of the water vapor in the air. Snow is a solid form of frozen precipitation that has never melted, from the time it originates from a cloud until it falls to the ground.
- **Snow flurry:** Light snowfall of short duration with no measurable accumulation
- **Snow shower:** Moderate snowfall for a short period
- **Snow squall:** Moderate-to-heavy snowfall for limited time, with strong surface winds and possibly lightning
- **White-out:** Reduction of visibility due to strong winds blowing falling snow or snow falling at rapid rates. (Note that a white-out is a condition; blizzard, drifting snow, and blowing snow are phenomena that can lead to a white-out.)

WINTER STORMS

Visual 2.4.19



Alt Text for Visual 2.4.19
Winter Storm Concerns
Temperature and moisture:

- Health problems (e.g., hypothermia, frostbite)
- Melting and freezing issues (e.g., broken pipes or power lines)

Amount of sun exposure:

- Slower melting
- Ice accumulation
- Snow density/weight:
- Melting and refreezing increases density

Image of frozen water piquet

Key Points

There are multiple concerns about winter storms rooted in scientific factors.

Temperature and moisture: Chronic freezing or subfreezing temperatures can lead to health problems from extreme cold, including hypothermia, frostbite, and lowered tolerance. Another concern is that large temperature fluctuations between daytime and nighttime can result in dangerous melting and refreezing. Water that freezes into ice expands and can cause cracks or breaks in pipes and snap power lines, usually during extended periods of below-freezing temperatures.

Sun exposure: Another concern is the amount of sun exposure in an area hit with a winter storm. For example, north-facing areas get less sun exposure in the winter and will have slower melting snow. Ice accumulation will also be greater in areas facing north.

WINTER STORMS

Visual 2.4.19 (Continued)

Snow density: A third concern is snow density, i.e., the weight of snow. The density of snow depends on the amount of moisture it contains. Newly fallen snow is lighter than accumulated snow, and certain areas get less dense, more powdery snow (e.g., Colorado) than other areas (e.g., the east coast, which gets denser, wetter snow).

As snow accumulates, it melts a bit and refreezes, and the density increases. The densest snow (i.e., packed snow) is snow that has been sitting for days without melting.

WINTER STORMS

Visual 2.4.20

Alt Text for Visual 2.4.20
Winter Storm Hazards
In what parts of the country is annual snowfall the highest?

- Alaska – heavy snow, strong winds/blizzards, coastal flooding, extreme cold, avalanches, ice jams, and ice fog
- Midwest and Plains – heavy snow, strong winds/blizzard, extreme wind chill, lake-effect snow, and ice storms
- The West Coast – heavy precipitation, high winds, coastal flooding, and beach erosion
- The Rockies – heavy snow, mountain-effect snow, strong winds, avalanches, extreme cold, and blizzards
- Southeast and Gulf Coast – ice storms, crop-killing freezes, and occasional snow
- Mid-Atlantic to New England – heavy snow, ice storms, strong winds, coastal flooding, beach erosion, and extreme cold

Job Aid: Handout 2.4.1: Winter Storm Hazards in the US

Key Points

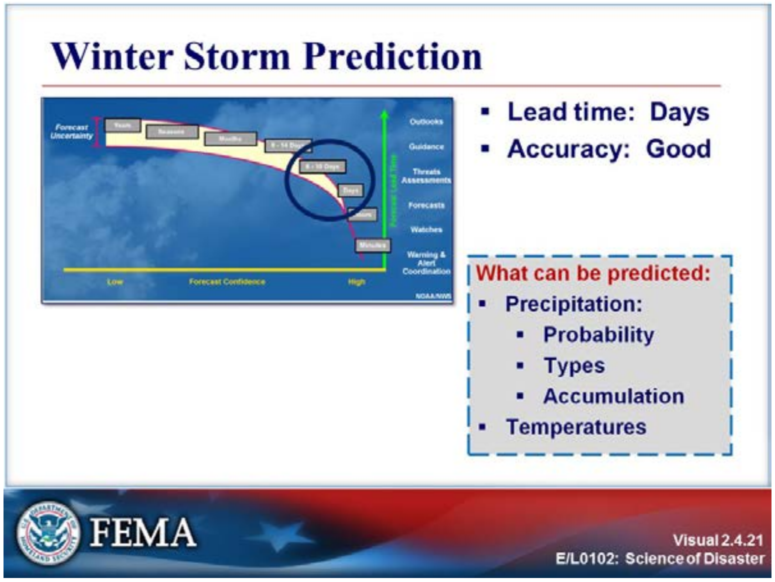
This map shows the annual mean snowfall across the United States and indicates which areas are at a greater risk for damaging winter storms.

<u>Discussion Question</u>: In what parts of the country is annual snowfall the highest?

See color Handout 2.4.1: Winter Storm Hazards in the US

WINTER STORMS

Visual 2.4.21



Alt Text for Visual 2.4.21
A chart showing that the lead time for predicting winter storms is measured in days, and the accuracy is generally good.
Winter Storm Prediction

- Lead time: Days
- Accuracy: Good

What can be predicted:

- Precipitation: probability, types, accumulation
- Temperatures

Key Points

Gathering information: In order to predict winter storms, forecasters rely on many of the same technologies mentioned in previous units, including radar, surface observation, satellites, and computer models. In the process, they gather information about:

- Air, ground, and cloud top temperatures
- Wind direction.
- Cold fronts
- Moisture
- Type and heaviness of precipitation
- Comma clouds, i.e., synoptic scale cloud patterns with a characteristic comma-like shape that are associated with large and intense low-pressure systems.

What's predictable: With this information, forecasters are able to predict the probability, types, and accumulation of precipitation, along with expected temperatures. The lead time for predicting winter storms is days, and the accuracy is generally good.

WINTER STORMS

Visual 2.4.21 (Continued)

Challenges: Forecasts for winter storms are improving but still involve certain challenges. For example, heavy snow often appears as small bands on larger resolution models that are harder to pick up; conversely, extremely light snow can go undetected because of its low moisture and high air content. Also, the boundary line between rain and snow is defined by a very small temperature disparity.

EXTREME COLD

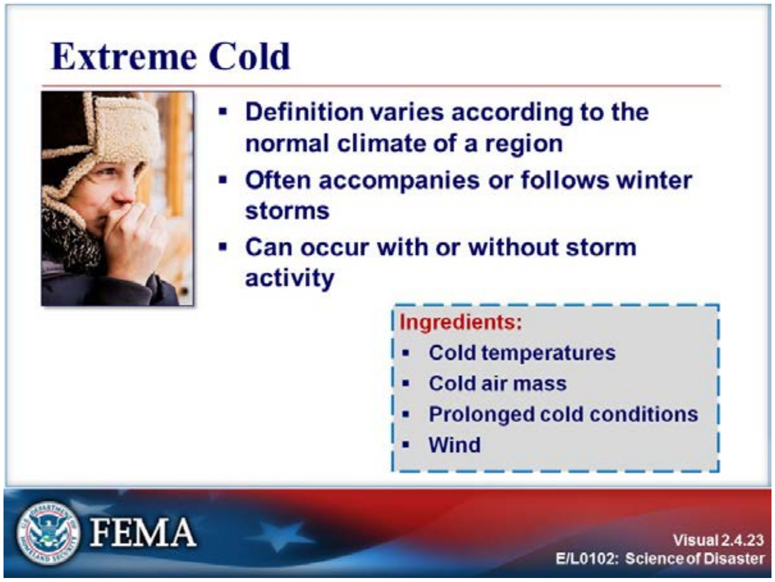
Visual 2.4.22

Key Points

The next section of this unit will present key points about the science of extreme cold temperatures.

EXTREME COLD

Visual 2.4.23



Alt Text for Visual 2.4.23
Extreme Cold

- Definition varies according to the normal client of a region
- Often accompanies or follows winter storms
- Can occur with or without storm activity

Ingredients: Cold temperatures, cold air mass, prolonged cold-conditions, wind

Key Points

Definition: The criterion for extreme cold varies according to the normal climate of a region. For example, in a relatively warm climate, temperatures just below or at freezing can be hazardous; in the north, temperatures below zero may be considered extreme.

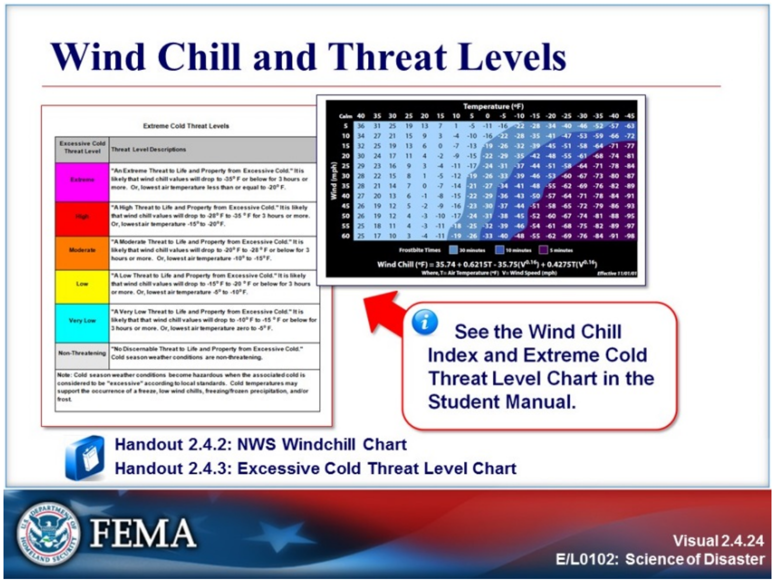
Excessive cold often accompanies or follows winter storms, but it can also occur without storm activity.

Ingredients: The ingredients necessary for extreme cold are:

- **Cold temperatures:** Remember, the temperature boundary of “extreme” varies by region.
- **Cold air mass:** An invasion of arctic air mass (pulled down by the jet stream) is also a necessary ingredient for extreme cold.
- **Prolonged cold conditions:** A prolonged period of cold—even if above-freezing—temperatures can result in the extreme cold that causes hypothermia.
- **Wind:** Extreme cold can be particularly dangerous when accompanied by wind, creating an effect known as wind chill.

EXTREME COLD

Visual 2.4.24



Key Points

As we all know, “cold” is not just a matter of temperature; it’s also wind chill. Wind chill is based on the rate of heat loss from exposed skin caused by the combined effects of wind and cold. As the wind increases, heat is carried away from the body at an accelerated rate, driving down the body temperature.

Wind chill index: Forecasters use a wind -hill index as a guide to heat loss resulting from given temperatures and wind speeds.

Excessive cold threat level: Just as storms can be evaluated in terms of threat level, there is an Excessive Cold Threat Level scale that helps forecasters determine the severity of the threat of extreme cold, from nonthreatening to extremely threatening.

Review the NWS Wind Chill Index and the Excessive Cold Threat Level chart on the following pages. On the Wind Chill Index, note that the purple area is the most dangerous for frostbite; the combined low temperatures and high winds can result in a frostbite time of only 5 minutes.

See color:

- Handout 2.4.2: NWS Windchill Chart
- Handout 2.4.3: Excessive Cold Threat Level Chart

Excessive Cold Threat Level Chart

Excessive Cold Threat Level	Threat Level Descriptions
Extreme	"An Extreme Threat to Life and Property from Excessive Cold." It is likely that wind chill values will drop to -35 °F or below for 3 hours or more, or, the lowest air temperature is less than or equal to -20 °F.
High	"A High Threat to Life and Property from Excessive Cold." It is likely that wind chill values will drop to -28 °F to -35 °F for 3 hours or more, or the, lowest air temperature is -15° to -20 °F.
Moderate	"A Moderate Threat to Life and Property from Excessive Cold." It is likely that wind chill values will drop to -20 °F to -28 °F or below for 3 hours or more. Or, lowest air temperature -10° to -15 °F.
Low	"A Low Threat to Life and Property from Excessive Cold." It is likely that wind chill values will drop to -15 °F to -20 °F or below for 3 hours or more, or the lowest air temperature is -5° to -10 °F.
Very Low	"A Very Low Threat to Life and Property from Excessive Cold." It is likely that that wind chill values will drop to -10 °F to -15 °F or below for 3 hours or more, or the lowest air temperature is zero to -5 °F.
Non-Threatening	"No Discernible Threat to Life and Property from Excessive Cold." Cold season weather conditions are not threatening.

Note: Cold season weather conditions become hazardous when the associated cold is considered to be "excessive" according to local standards. Cold temperatures may support the occurrence of a freeze, low wind chills, freezing/frozen precipitation, and/or frost.

NWS WINDCHILL CHART

Temperature (°F)

Wind (mph) / Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times 30 minutes 10 minutes 5 minutes

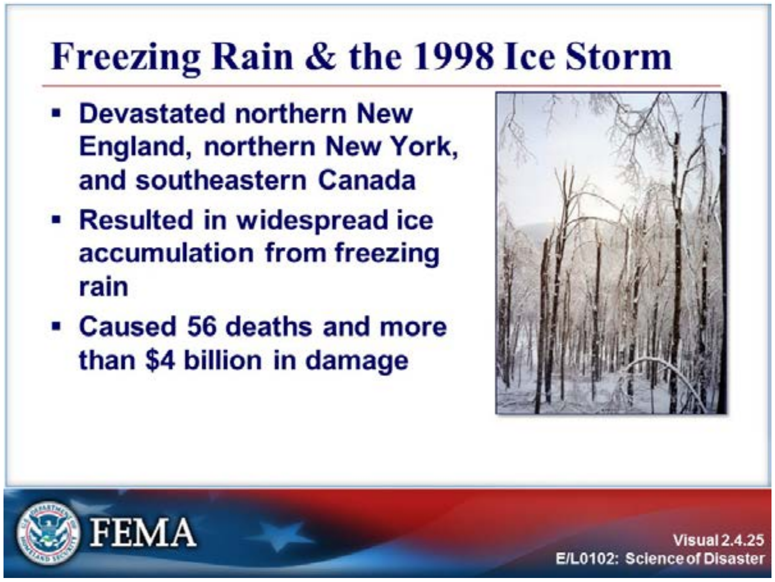
$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01

WINTER STORM CONCERNS

Visual 2.4.25



Alt Text for Visual 2.4.25
Freezing Rain & the 1998 Ice Storm

- Devastated northern New England, northern New York, and southeastern Canada
- Resulted in widespread ice accumulation from freezing rain
- Caused 56 deaths and more than $4 billion in damage

Image of a forest covered in ice.

Key Points

Storm description: In January 1998, a massive ice storm devastated major parts of northern New England, northern New York, and southeastern Canada. The storm resulted in approximately 56 deaths, 4.4 billion dollars in damage, and millions of households losing power, some for several weeks. (Source: NOAA's National Climatic Data Center)

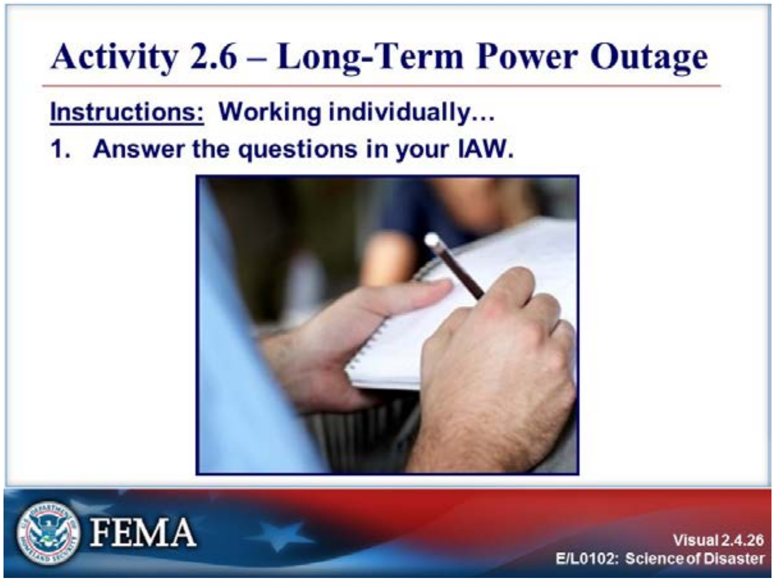
The storm, it is worth noting, was partly the result of a strong El Niño episode influencing weather patterns during the winter of 1997 to 1998.

The most notable aspect of this storm was the widespread ice accumulation resulting from freezing rain. Parts of New York and Canada saw as much as 3 inches of ice accumulation, which brought about devastating and even life-threatening conditions.

Discussion Question: Why is ice accumulation resulting from freezing rain so destructive and life-threatening, as was the case in January of 1998?

ACTIVITY 2.6 – LONG-TERM POWER OUTAGE

Visual 2.4.26



Key Points

<u>Instructions:</u> Working individually…

1. Answer the questions in your IAW.

UNIT SUMMARY

Visual 2.4.27

Alt Text for Visual 2.4.25
Unit Summary

- Compare/contrast nor'easters/hurricanes
- Identify ingredients of nor'easters/winter storms/extreme cold
- Explain scientific differences: various types of frozen precipitation
- Indicate predictability of nor'easters/winter storms/extreme cold temperatures

Key Points

This was the last unit in the Storms module. **Do you have any questions about material covered in this module?**

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MODULE 3. FLOODS

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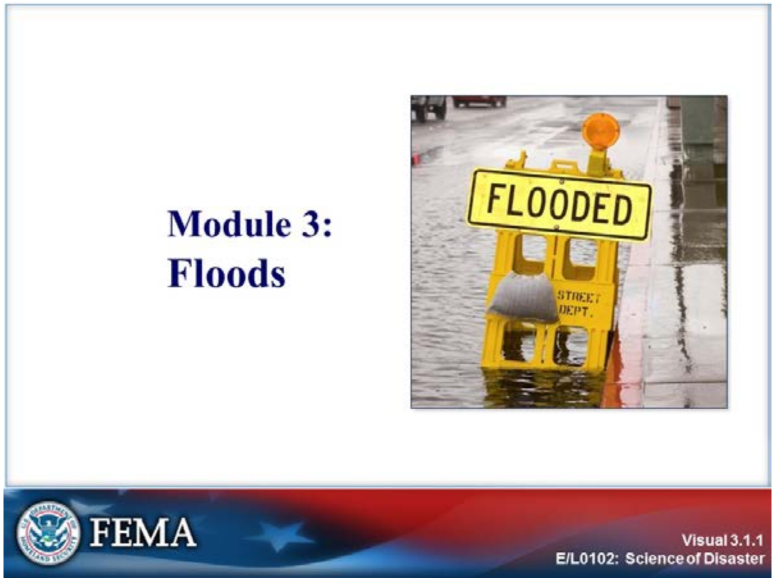
INTRODUCTION

Visual 3.1.1



Key Points

Welcome to Module 3: Floods.

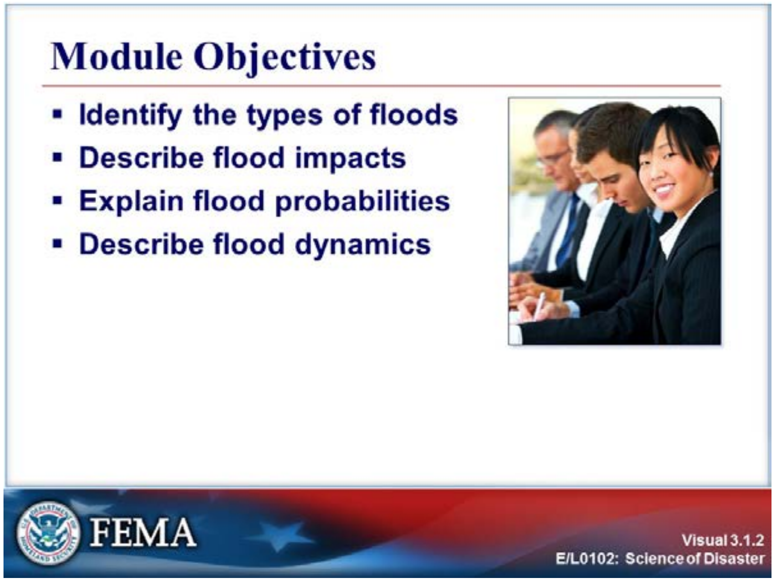
Time Plan

A suggested time plan for this module is shown below.

Topic	Time
Introduction	5 minutes
Flood Types • Activity 3.1 – Floods That Could Affect My Area (Visual 3.1.9)	20 minutes
Flood Factors	15 minutes
Flood Dynamics and Impacts	15 minutes
Flood Probability and Forecasting • Activity 3.2 – Using a Risk Map (Visual 3.1.35)	30 minutes
Unit Summary	5 minutes
Total Time	**1 hour 30 minutes**

INTRODUCTION

Visual 3.1.2

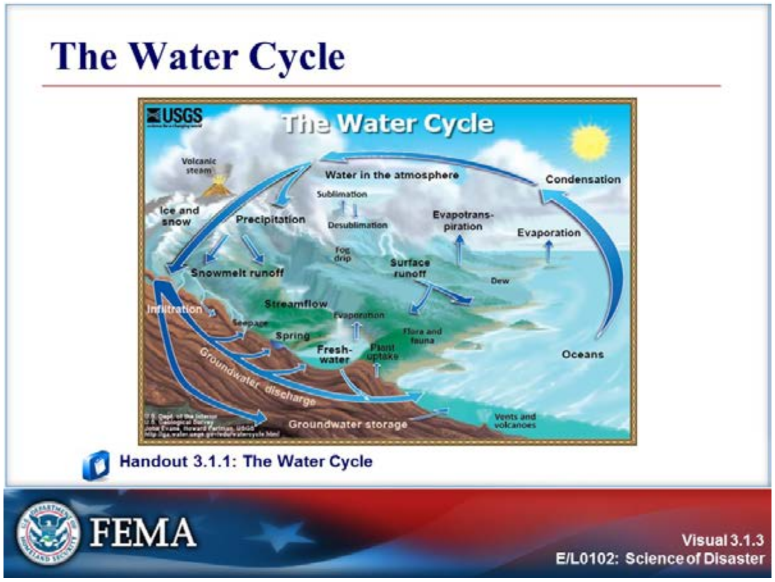


Key Points

Review the module objectives as shown on the visual.

FLOOD FACTORS

Visual 3.1.3



Alt Text for Visual 3.1.3
The Water Cycle
Natural water cycle is the continuous movement of water on, above, and below the surface of the Earth. Water is always changing states between liquid, vapor, and ice, with these processes happening in the blink of an eye and over millions of years.
Handout 3.1.1: The Water Cycle

Key Points

Most floods occur in relation to the:

- Weather
- Water cycle

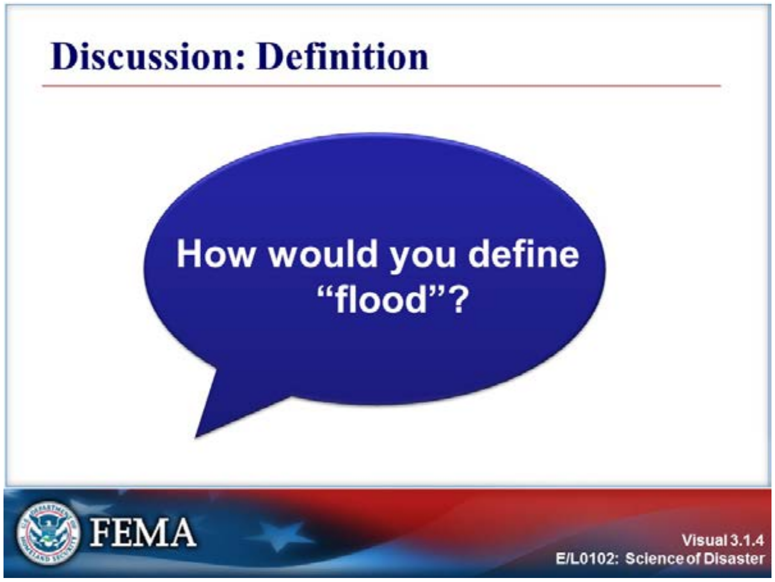
On the surface of our planet, water is always moving and circulating. Gravity moves water downhill, and water moves from ground to ocean to atmosphere through fluctuations in pressure and temperature that change the phases of water from solid to liquid to gas.

Floods occur when water is delivered to a water body (e.g., stream, river, lake) at a rate and in an amount that is greater than normal—or, in other words, when the water cycle cannot keep up with the amount of water to be accommodated at one time at one location.

See Color Handout 3.1.1: The Water Cycle

INTRODUCTION

Visual 3.1.4

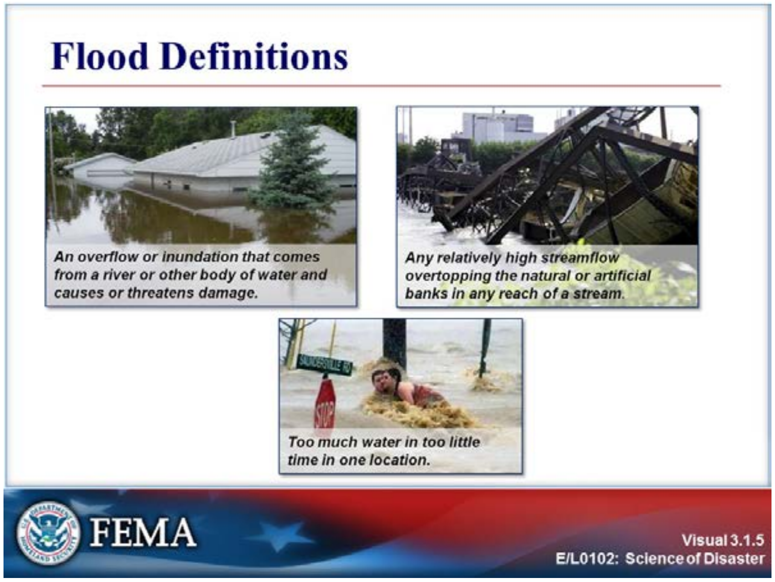


Key Points

<u>Discussion Question</u>: How would you define "flood"?

INTRODUCTION

Visual 3.1.5



Alt Text for Visual 3.1.5
Flood Definitions
An overflow or inundation that comes from a river or other body of water and causes or threatens damage.
Image: a flooded trailer park.
Any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream.
Image: A collapsed bridge.
Too much water in too little time in one location.
Image: Two people holding on to each other in flood waters.

Key Points

There are many technical definitions of a flood that address different aspects of floods.

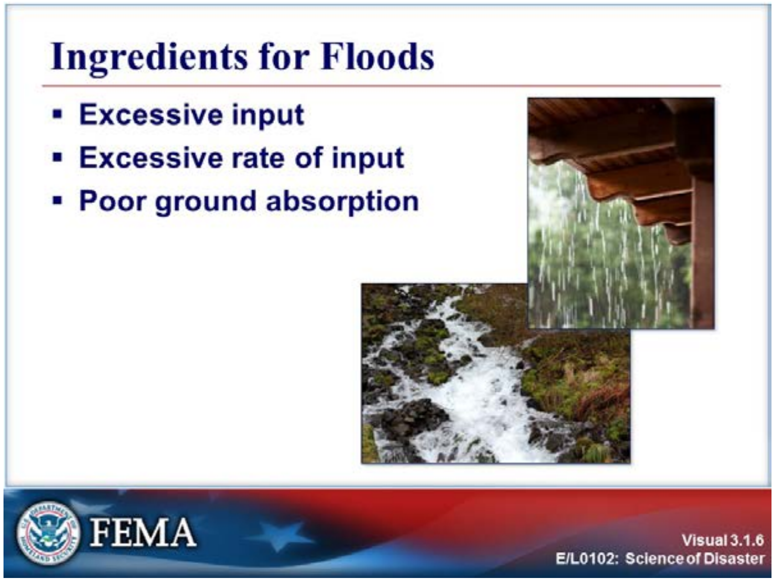
One widely used definition is "an overflow or inundation that comes from a river or other body of water and causes or threatens damage." By this definition, a phenomenon isn't a flood unless it could cause damage. However, it turns out to be useful to distinguish between floods and damaging events, which are **flood disasters.**

Another definition is that a flood is "any relatively high streamflow that overtops the natural or artificial banks in any reach of a stream."

The essential point is that a flood is a condition in which there is too much water accumulating in too little time at a given location.

FLOOD FACTORS

Visual 3.1.6



Key Points

We'll look next at the factors that contribute to flooding. The major ingredients for floods are:

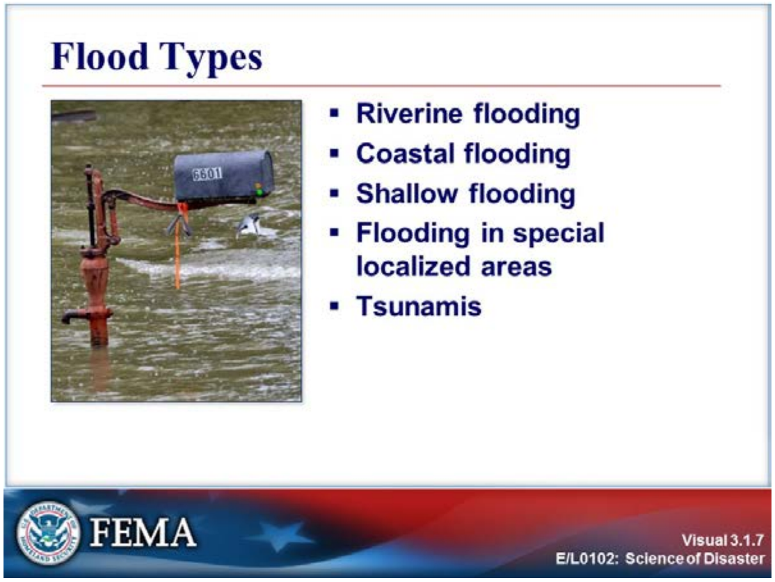
- **Excessive input,** which may result from:
  - Heavy downpours
  - Long-duration constant rainfall

- **Excessive rate of input,** which may result from:
  - Rate of precipitation:
    - Short-duration intense downpours
    - Rapid snowmelt
  - Rate of runoff, caused by:
    - Steep slopes
    - Sparse vegetation
    - Thin soils
  - Failure of flood protection structures:
    - Levee break
    - Dam failure

- **Poor ground absorption,** which may result from:
  - Poor-quality soils, caused by:
- Sparse vegetation (often from deforestation)
- Thin soils (often from deforestation)
  - Ground saturation
  - Urban landscapes
  - Closely spaced bodies of water
  - Time of year (e.g., rainfall on frozen ground in winter)

FLOOD TYPES

Visual 3.1.7



Key Points

Floods can be grouped in various ways, but for the purposes of this course, the types recognized by the National Flood Insurance Program (NFIP) will be used. These types are:

- **Riverine flooding**
  - **Riverine overbank flooding** is the most common type of flooding in the United States. This type of flooding occurs when excess water from storms, snowmelt, or blockages due to debris or ice jams overloads the stream channel. When the stream channel is overloaded, excess floodwaters flow onto the adjacent land, called the floodplain. (floodplain concepts will be covered later in this unit). The extent of riverine overbank flooding in a particular area depends on many factors, including topography, size of the river basin, development in the river basin, and geographical location, to name a few.

  - **Flash floods** are characterized by floodwaters that rise and end quickly. Areas with steep slopes and narrow stream valleys, such as mountainous areas, are especially susceptible to flash flooding. These floods can cause extensive damage and loss of life, especially in recreation areas such as campgrounds. Flash floods are the leading cause of flood-related deaths in the United States, primarily because they can strike with little warning, giving little or no time to evacuate

FLOOD TYPES

Visual 3.1.7 (Continued)

- **Coastal flooding**
  - **Coastal flooding** involves the inundation of land along any coastal area of the United States. The variation in our coastal areas means that the factors contributing to coastal flooding also vary.

  - Coastal storms include:
    - Hurricanes, which typically occur on the East Coast and Gulf Coast between June and November
    - Nor'easters, which form off the East Coast at any time of year
    - Pacific Coast rainy season, which usually occurs between November and April each year

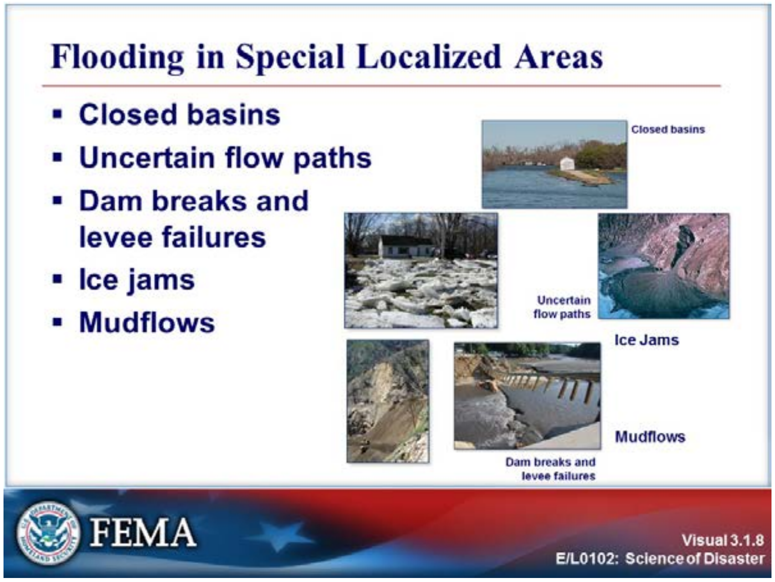
    These storms can produce extremely heavy rainfall, resulting in flooding of coastal areas and nearby rivers and streams.
- **Shallow flooding**
  - **Sheet flow** consists of shallow-depth, slow-velocity flow. An example of sheet flow can be found in the Florida Everglades shown in the visual (photo credit: U.S. Geological Survey).

  - **Ponding** usually occurs in areas with little variation in topography. These generally flat areas don't allow rainfall runoff to drain; instead, the water gradually seeps into the soil, evaporates, or is pumped out. Ponding can be found in depressions caused by glaciation, in areas where sinkholes and caves are found, and in developed areas where structures such as railroads or inadequate culverts restrict the flow of water.

  - **Urban drainage** consists of various types of man-made structures intended to divert water from areas in the built environment. Storm drains, retention ponds, ditches, and storm sewers are examples of urban drainage systems. These systems are typically designed for lower storm flows, such as the kind expected to occur on average once every 10 years. However, severe flooding of neighborhoods, commercial areas, and other developed areas can occur when larger storm events overwhelm these systems

FLOOD TYPES

Visual 3.1.8



Key Points

The National Flood Insurance Program (NFIP) recognizes other types of flooding as "special localized flooding." These special situations include closed-basin lakes, areas with uncertain flow paths, dam breaks and levee failures, ice jams, and mudflows.

Closed basins are lakes that formed after the glaciers retreated, primarily from areas in the northern United States. Because these lakes are closed basins, they have no way of draining. As a result, they frequently flood nearby areas as they expand outward. Devils Lake, North Dakota, is an example of a closed-basin lake.

Uncertain flow paths describe areas primarily in mountainous locations, where high-velocity floodwaters spread out as they reach the valleys below. As the floodwater slows, it seeks various channels in a fanlike pattern. The channels may differ with each successive flood event, and are therefore less predictable than riverine floods that occur in a defined channel. These fanlike features are called **alluvial fans** because of the large amount of sediment and debris deposited by floodwaters as they approach the valley floor.

Dam breaks and levee failures occur when the structural integrity of a dam or levee is compromised, resulting in leakage, fracture, or complete failure of the dam or breaching of the levee. Many private or locally built dams and levees that are poorly designed or maintained are especially susceptible to failure during extreme flooding conditions.

Ice jams occur when warm air and rain break up frozen rivers and streams, or whenever there is a rapid cycle of freezing and thawing in the stream environment.

Broken ice floats downstream until it is obstructed by any feature, including bridges, tunnels, or shallow areas. The resulting jam is similar to a dam that causes water to flood adjacent land upstream. Ice jams present three types of hazards:

FLOOD TYPES

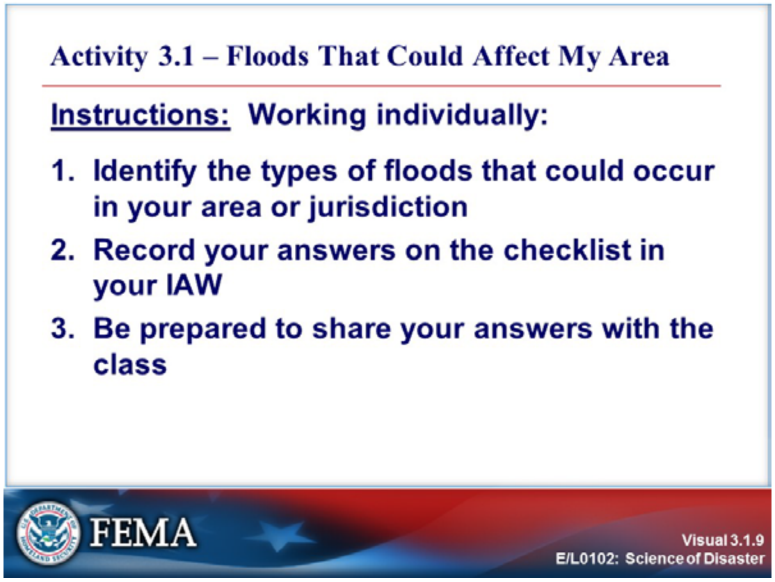
Visual 3.1.8 (Continued)

- Flooding upstream lands
- Movement of broken ice into structures, trees, and other obstacles downstream
- Sudden release of water and ice when the ice jam breaks apart, similar to the failure of a dam

A mudflow is a landslide of saturated soil and debris, usually in hilly or mountainous areas. Mudflow hazards are compounded by the weight and volume of saturated debris that is released onto structures and people in the path of the flow.

ACTIVITY 3.1 – FLOODS THAT COULD AFFECT MY AREA

Visual 3.1.9



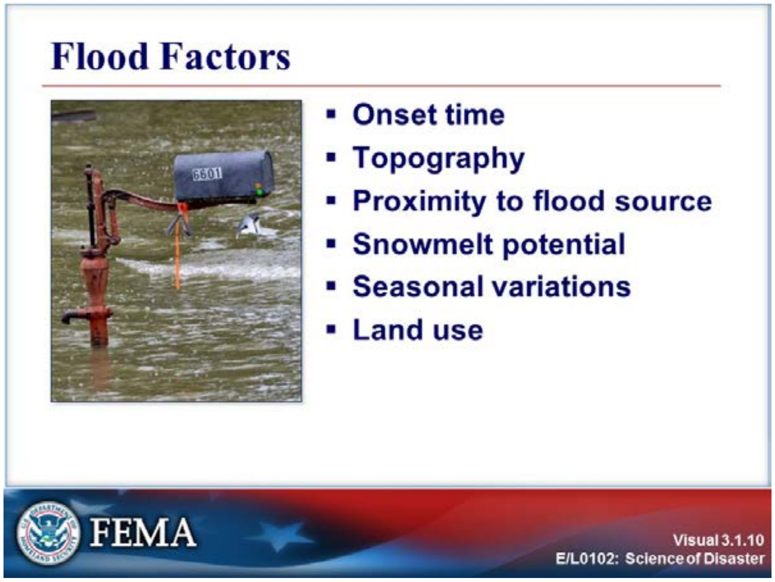
Key Points

Instructions: Working individually:

1. Identify the types of floods that could occur in your area or jurisdiction.
2. Record your answers on the checklist in your IAW.
3. Be prepared to share your answers with the class.

FLOOD FACTORS

Visual 3.1.10



Key Points

What all floods have in common is the presence of water in some phase (whether solid, liquid, or gas) and the force of gravity acting on the water.

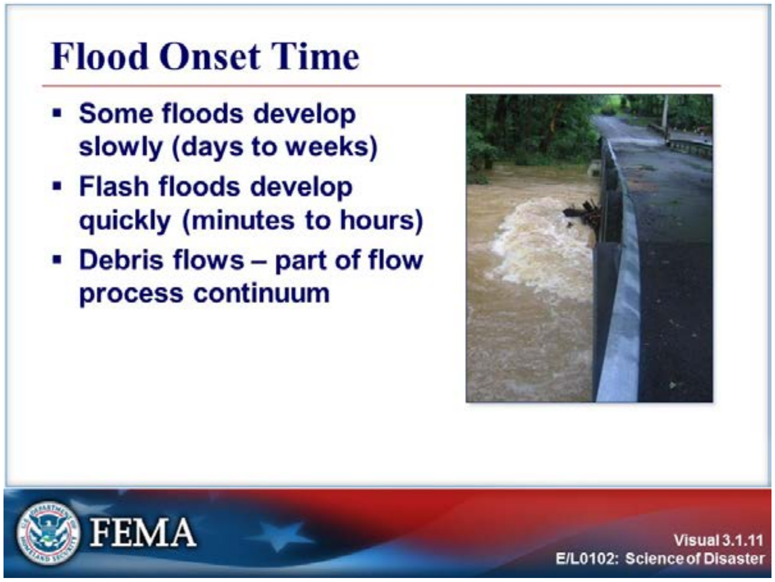
Flood factors describe the conditions associated with different types of floods or under which floods will develop. Although there may be many factors involved, the primary ones are:

- Onset time
- Topography
- Proximity to flood source
- Snowmelt potential
- Seasonal variation
- Land use

These flood factors are described in more detail in the following visuals.

FLOOD FACTORS

Visual 3.1.11



Key Points

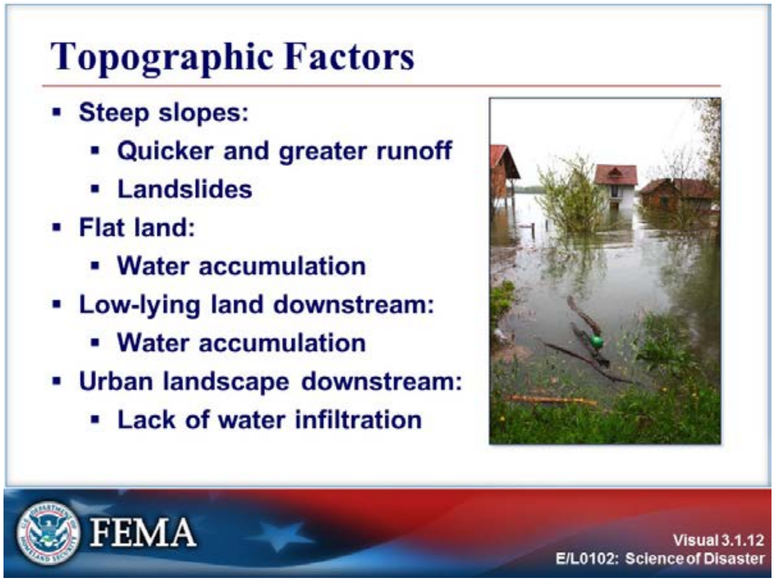
Floods can also be classified based on the time it takes for onset to occur.

Slow-developing: Some floods develop slowly, like those on the Mississippi, causing river water to rise about a foot every other day. These floods tend to linger for a long time.

Fast-developing: By contrast, in a rapid-onset flood (or flash flood), the water can rise 2 or 3 feet in 5 minutes.

FLOOD FACTORS

Visual 3.1.12



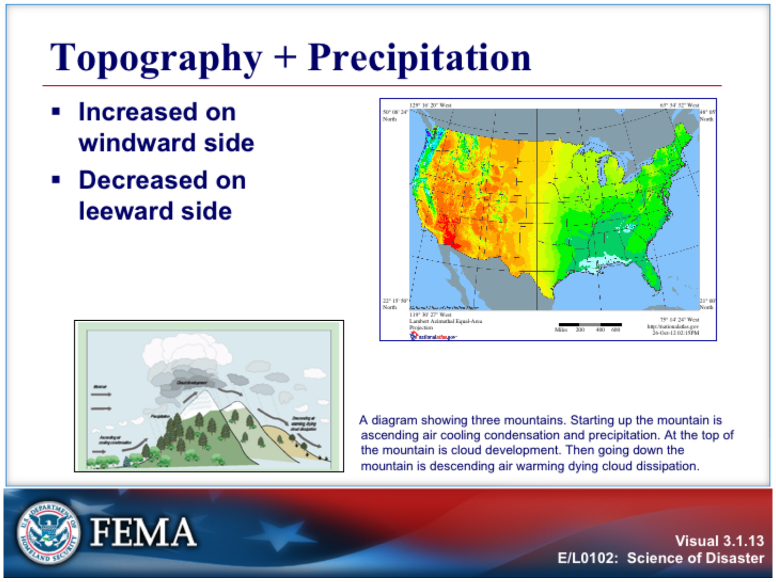
Key Points

There are a number of topographic factors that can contribute to flooding.

- **Steep slopes** may result in quicker and greater runoff or even landslides. Steeper gradients funnel water together to produce more catastrophic floods.
- **Flat land** and low-lying land downstream will facilitate greater water accumulation.
- **Downstream urban landscapes** lack water infiltration.
- In **small river basins** (i.e., the large area of land encompassing the entire river network with the main channel and its tributaries) such as those in mountains, flooding is dominated by precipitation from short-duration, high-intensity, convective thunderstorms.
- In **larger river basins** like the Mississippi, flooding is dominated by longer-duration, widespread rainfall from atmospheric systems like hurricanes that dump a lot of rain over a long period of time.

FLOOD FACTORS

Visual 3.1.13



Alt Text for Visual 3.1.13
Topography + Precipitation
Increased on windward side
Decreased on leeward side
The map on the visual shows the annual mean precipitation throughout the continental United States.
A diagram showing three mountains. Starting up the mountain is ascending air cooling condensation and precipitation. At the top of the mountain is cloud development. Then going down the mountain is descending air warming dying cloud dissipation.

Key Points

The interaction of topography and precipitation is also a major factor in floods. The map on the visual shows the annual mean precipitation throughout the continental United States. Two key factors are at play: proximity to a moisture source and orographic lifting.

- **Proximity to moisture source:** The importance of proximity to a moisture source is evident in the rapid drop-off of precipitation as you move inland from the Pacific to the Gulf of Mexico and the Atlantic.

  Certainly, proximity to moisture source is important—and you can see a lot of points north of the Gulf, which provides large quantities of moisture. But this factor is not sufficient by itself, because otherwise there would be more floods in Florida than there are.

FLOOD FACTORS

Visual 3.1.13 (Continued)

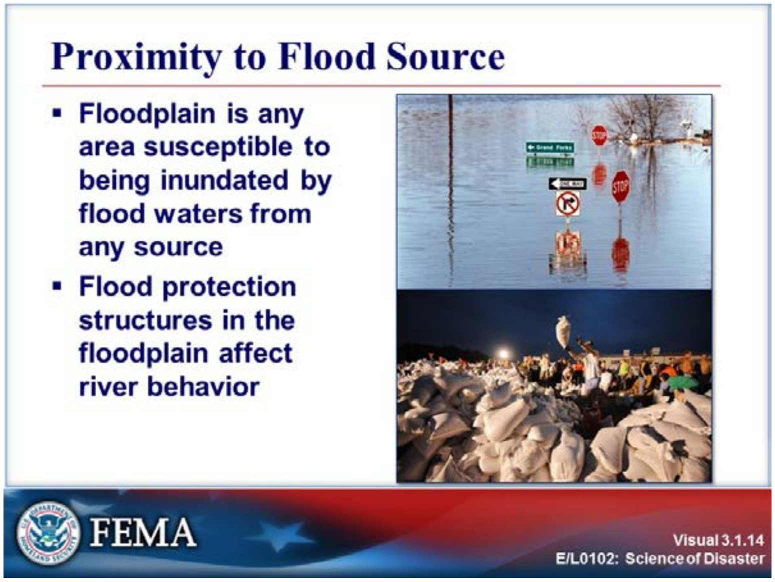
- **Orographic lifting:** In addition, the precipitation map shows areas of higher precipitation due to orographic lifting (shown in the left-hand drawing), a phenomenon that occurs when a mass of air is forced to travel from a lower elevation to a higher elevation over a rising mountain. As masses of air move inland and rise up over the highlands, the air cools. If it cools to its saturation point, the water vapor condenses and a cloud forms.
    - On the windward side of mountains (upwind, the side that is reached first) there is a lot of rain.
    - On the leeward side (downwind) there is substantially less.

All of the major mountain ranges in the United States have “rain shadows”—more arid areas on the lee, or downwind, side.

If not mentioned by the group, cite the Lake Tahoe, California/Nevada area as an example.

FLOOD FACTORS

Visual 3.1.14



Key Points

Proximity to the flood source is another important factor.

Floodplain: According to the NFIP, a floodplain is defined as "any land area susceptible to being inundated by flood waters from any source." During floods, water that normally flows downstream overflows beyond the channel onto the floodplain.

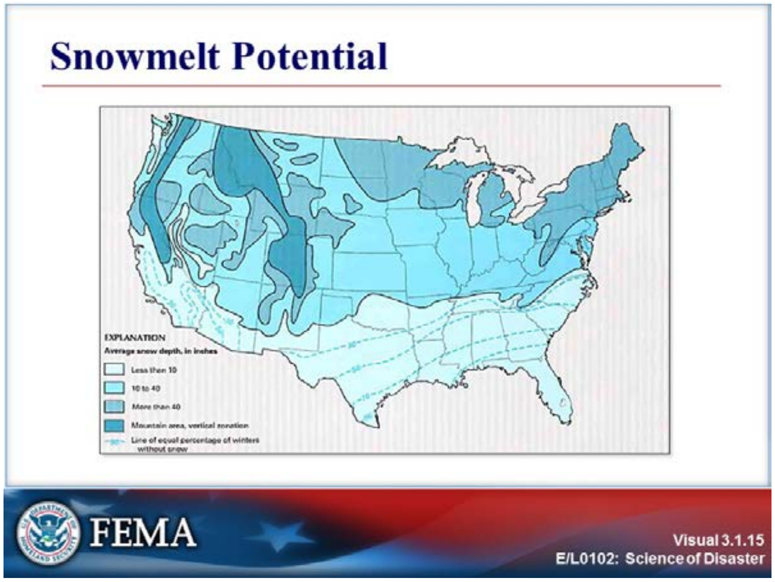
As with other hazards, the choices and actions of humans determine whether the natural phenomenon of the flood will become a disaster. There are 3,800 communities in the United States (communities with at least 2,500 inhabitants) that are located in floodplains.

Flood protection measures: Development in floodplains is sometimes followed by creation of flood protection measures, such as levees or floodwalls. Flood protection structures alter river behavior by:

- Affecting natural deposition process
- Affecting river cresting/water level
- Affecting stream path

FLOOD FACTORS

Visual 3.1.15



Key Points

Another contributor to flooding is snowmelt.

Snow stores a lot of moisture. The moisture content of snow generally varies with the geographical location and time of year.

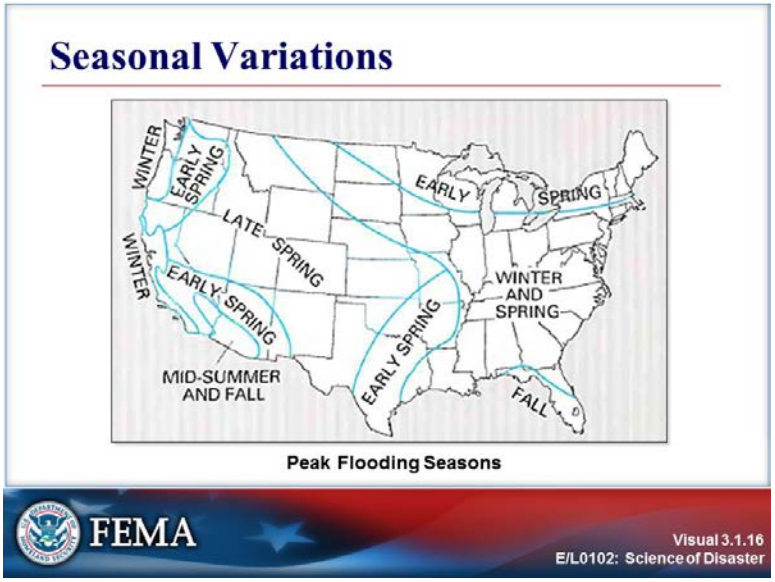
> For example, 10 inches of soft, powdery snow in the Rocky Mountains may have different moisture content than 10 inches of snow in the more humid Appalachian Mountains. Likewise, late-spring snowfalls may have greater moisture content than winter snowfalls. The rate at which snow melts and releases its moisture content can have a significant impact on flooding.

This map shows the snowmelt potential, based on average snowfall. The darker the color, the thicker the average snow depth, and thus the greater the possible contribution of snowmelt to flooding.

See Color Handout 3.1.2: Snow Melt Potential

FLOOD FACTORS

Visual 3.1.16



Alt Text for Visual 3.1.16
A map of the U.S. showing peak flooding seasons. For the eastern states the peak flooding is in Winter and Spring. The North Eastern and Northern states from Maine through North Dakota floods in early spring. Florida floods in fall. The central state flood in late spring, with early spring to the right of Texas, Arkansas and Missouri. Coastal Western states flood in Winter, with mid-Washington and Oregon flooding in Early Spring, and California through Arizona flooding in Early Spring. Flooding in Arizona and California bordering Mexico floods in Mid-Summer and fall.

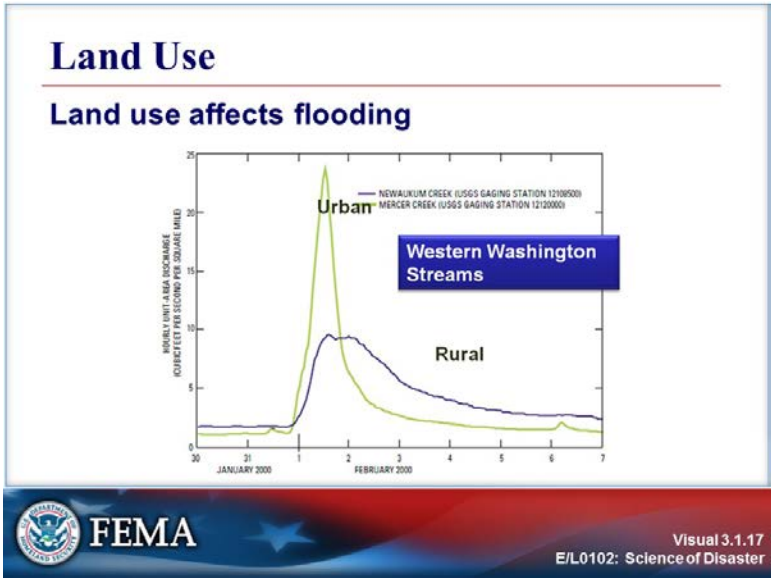
Key Points

The season of the year is another factor that affects flooding; however, typical seasons for the largest annual flood vary by area, as illustrated by this map.

The variation depends on seasonal rainfall patterns and the time it takes snowmelt to reach the region's rivers.

FLOOD FACTORS

Visual 3.1.17



Key Points

Land use affects flooding, especially in terms of the extent of rural use vs. urban use.

Rural land use: In rural areas, there is more opportunity for moisture to soak into the ground.

Urban use: In urban areas, pavement keeps water aboveground. In addition, efforts to control water flow, as it moves from roofs to gutters to streets to drains, deliver more water into rivers more quickly, causing a rapid rise in flood level.

This visual shows two **hydrographs**, from urban and rural gages in Washington State, which depict height of water over time. The tendency for the urban site to show a strong, early pulse of flooding compared to the rural site is a commonly noted difference between urban and rural sites.

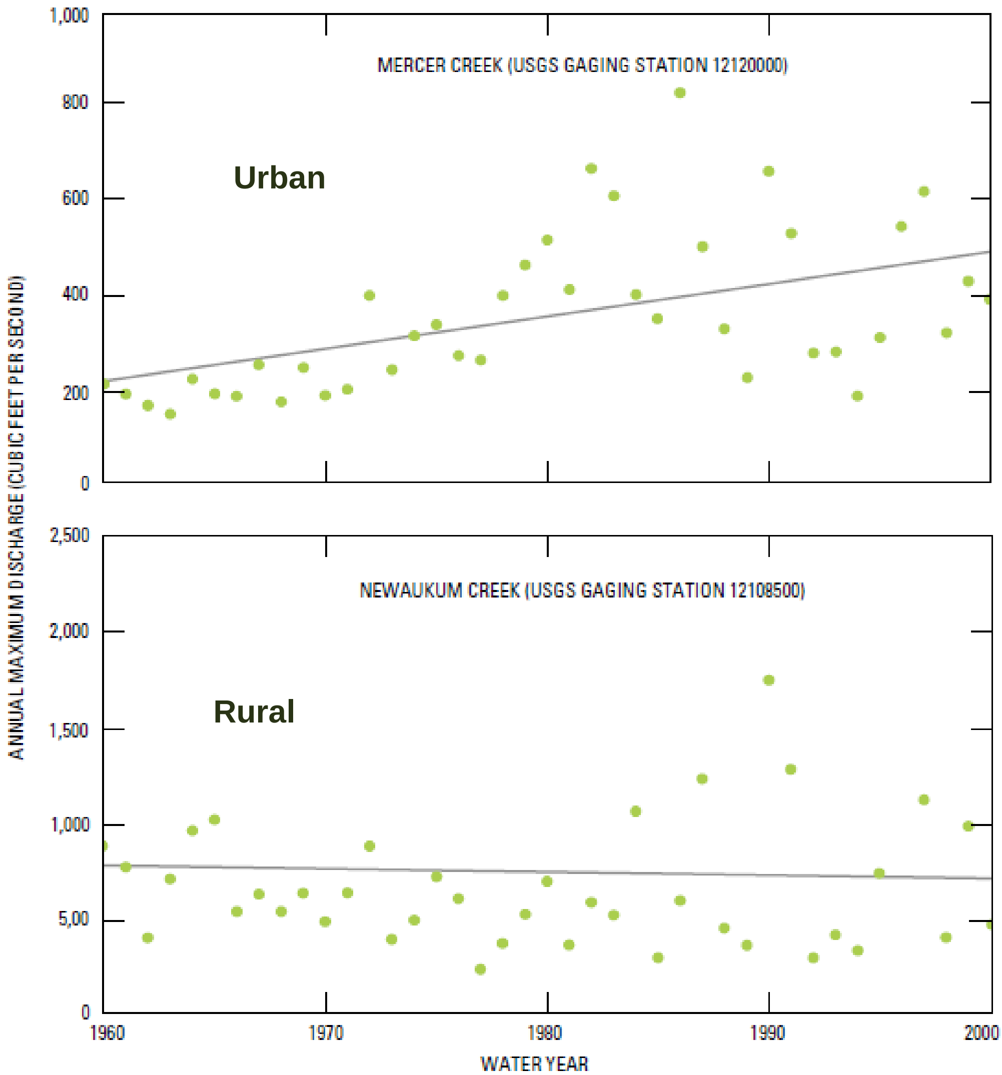
Increase in peak flows over time: Another trend related to urban sites is an increase in peak flows over time. The graph on the next page compares peak flows at the same sites shown in the hydrograph.

FLOOD FACTORS

Visual 3.1.17 (Continued)

The dots represent highest flow level for each year. The rural site shows very little change over the decades. The impact of urbanization at the other site (the top graph) is visible in the general rise in maximum water level as the years advance.

Annual Peak Streamflow (Cubic Feet Per Second)



FLOOD FACTORS

Visual 3.1.18

Key Points

During Hurricane Sandy in 2012, areas of dense urban development in New York and New Jersey experienced severe flooding of underground subway systems, as floodwaters sought the lowest level.

Cleanup and recovery efforts required sophisticated pumping equipment to remove huge volumes of water that natural drainage could not handle.

FLOOD DYNAMICS

Visual 3.1.19

Key Points

Another way of characterizing floods is by the dynamic qualities or forces associated with them.

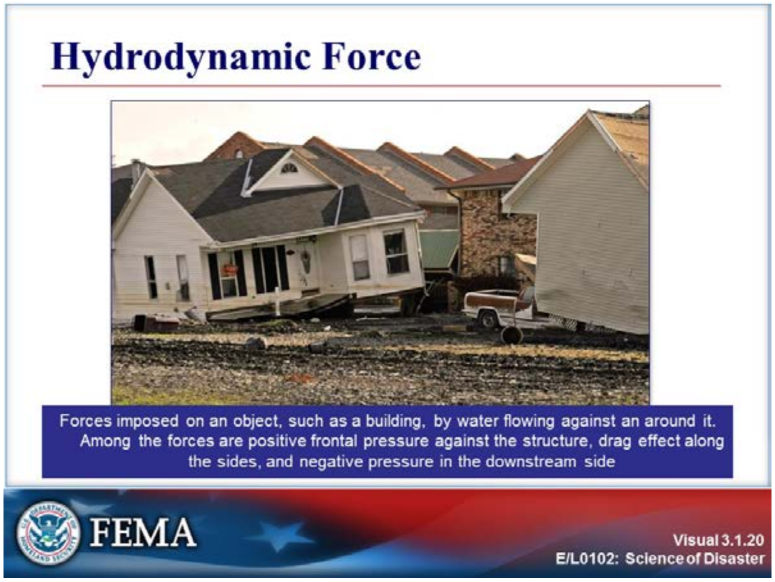
Flood dynamics describes the damage and injury to structures, people, and the environment caused by floodwaters in various stages of formation. The main dynamic forces are:

- Hydrodynamic force
- Hydrostatic force
- Debris impact
- Velocity
- Soaking
- Sediments and contaminants

These forces are explained in the following visuals.

FLOOD DYNAMICS

Visual 3.1.20



Key Points

The NFIP describes hydrodynamic forces as:

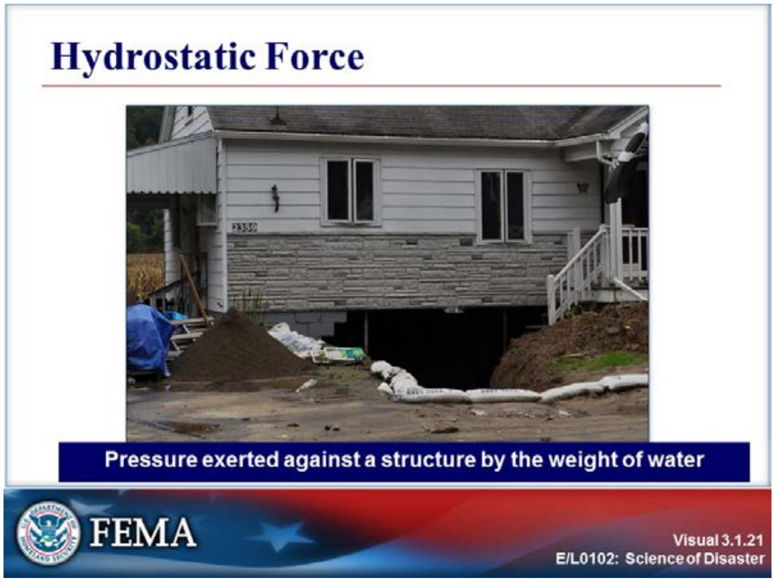
> "…[F]orces imposed on an object, such as a building, by water flowing against and around it. Among the forces are positive frontal pressure against the structure, drag effect along the sides, and negative pressure in the downstream side. Hydrodynamic forces are one of the main causes of flood damage."

The visual shows the effects of hydrodynamic force on a house. In this case, frontal impact resulted from flood waters striking the structure.

Hydrodynamic forces also involve a drag effect as water runs along the sides of a structure, and eddies or negative pressures as water passes the downstream side of the structure.

FLOOD DYNAMICS

Visual 3.1.21



Key Points

Hydrostatic force involves the pressure exerted against a structure by the weight of water. This type of pressure is especially damaging to walls of structures, and studies have shown that 3 feet of standing water can be sufficient to collapse the walls of a frame house.

Basement walls are especially vulnerable to hydrostatic force. In this visual, part of the basement wall has collapsed because of hydrostatic force exerted on it.

FLOOD DYNAMICS

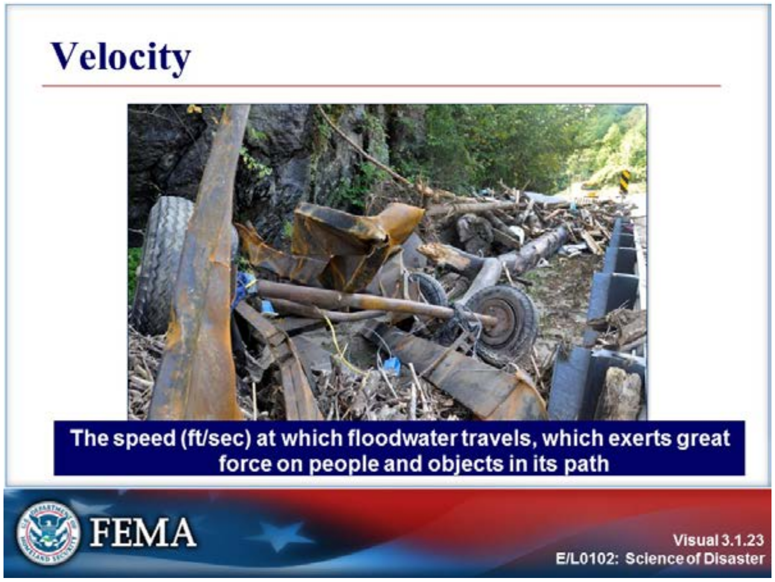
Visual 3.1.22

Key Points

Another dynamic force is debris impact. Floodwaters are powerful and will pick up and move almost anything in their path. Vehicles, lawn furniture, propane tanks, vegetation, and even rocks and boulders can be moved by floodwaters. Such flood debris can cause extensive damage when striking buildings, bridges, or other structures in the flood path.

FLOOD DYNAMICS

Visual 3.1.23



Key Points

Velocity is the speed at which floodwater travels and is measured in feet per second. Floodwaters moving faster than 5 feet per second are considered a high-velocity flood.

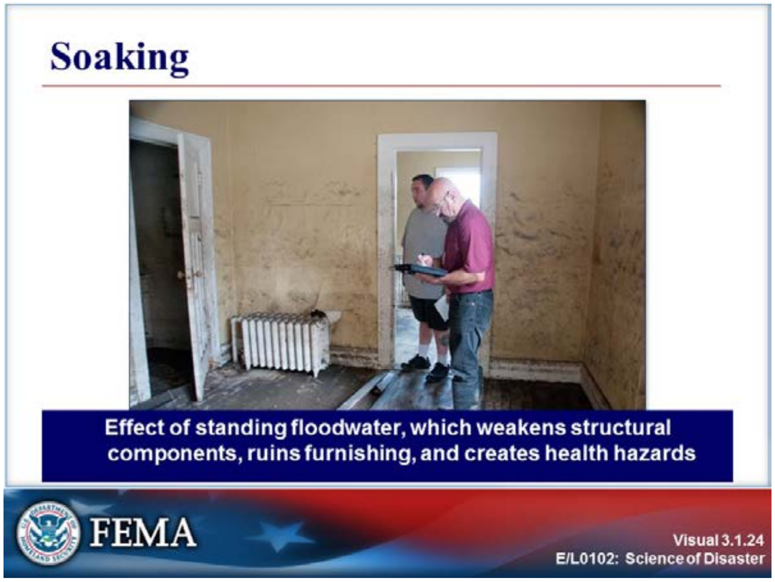
Even shallow floodwater can knock a person down, and it is estimated that water 3 feet deep moving at 3 feet per second is sufficient to do so.

A car will float in only 2 feet of moving water.

These potential impacts of floodwater velocity on people and automobiles make it extremely hazardous to wade or drive into floodwaters.

FLOOD DYNAMICS

Visual 3.1.24



Key Points

Soaking is a major cause of flood damage. Standing floodwaters, especially water standing over a long period of time, will weaken or destroy the structural components of buildings and ruin furnishings. In addition to causing structural damage, soaking also presents health hazards for building occupants.

FLOOD DYNAMICS

Visual 3.1.25

Key Points

The final dynamic force involved in floods is sediments and contaminants. Floodwaters carry many types of sediment, including sand and debris. These sediments permeate structures and the environment and are difficult, if not impossible, to remove.

Contaminants include any type of substance that is harmful to living organisms, including chemicals, sewage, and other toxic material.

Next, we will look at some health hazards associated with contaminants and other flood hazards.

FLOOD IMPACTS

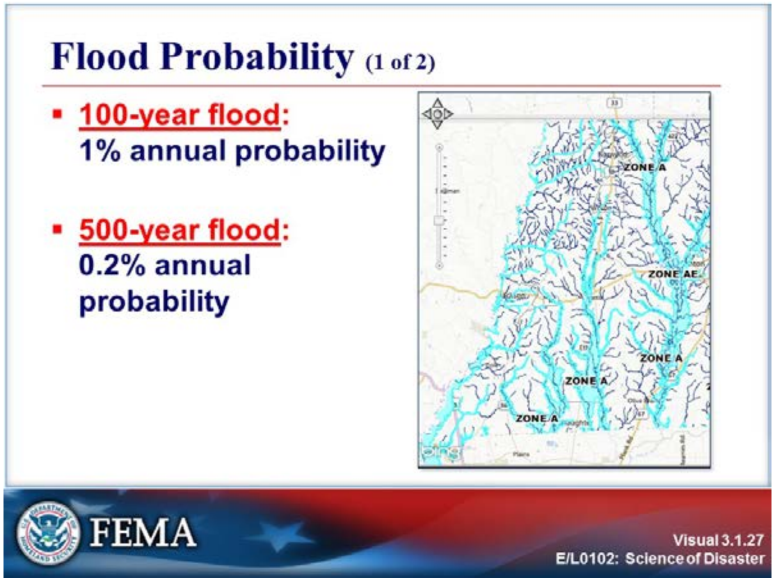
Visual 3.1.26

Key Points

<u>Discussion Question:</u> How can flooding impact health?

FLOOD PROBABILITY

Visual 3.1.27



Key Points

All of the factors we have discussed relate to the probability of flooding in any given area. What do we know about flood probability?

As scientists study river systems over time, patterns emerge:

- Areas that have flooded before will often flood again.
- Some areas will flood in garden-variety storms of the type that occur frequently.
- Other areas will flood much more rarely and only in larger storms.

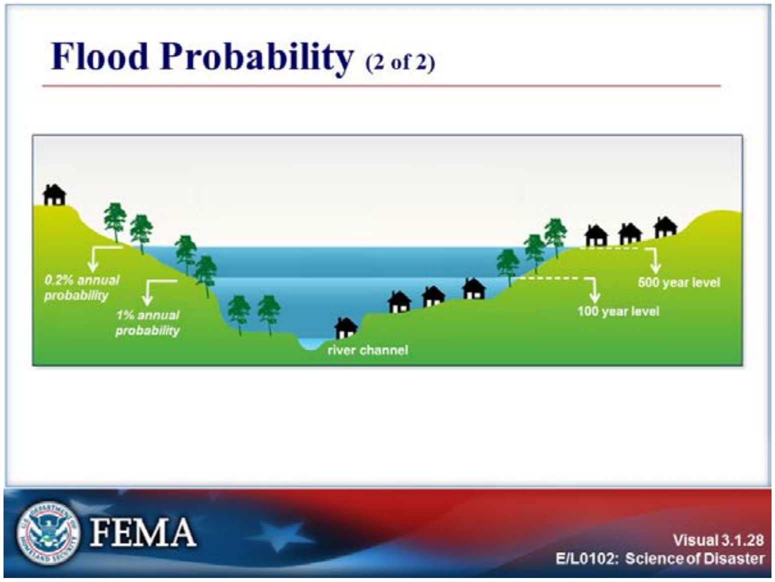
Such patterns give rise to efforts to quantify the chance that a particular area will flood in a certain time span, and that effort to quantify in turn requires a statement of probability.

The image on this visual delineates areas that will be flooded in the Louisiana parish of East Feliciana. The bright blue areas have a 1 percent chance of being flooded in any year. These areas are thus, by definition, in a “**100-year floodplain.**”

Many communities also have **500-year floodplains.** Any site in a 500-year floodplain has a 0.2 percent chance of being flooded in any given year.

FLOOD PROBABILITY

Visual 3.1.28



Key Points

The 100-year flood is the national standard adopted by the NFIP and used by all Federal agencies.

A 100-year flood is a flood that has a 1 percent chance of occurring in any given year.

The graphic illustrates the difference between a 100-year floodplain and a 500-year floodplain, and the relative percentage of probability.

See Color Handout 3.1.3: Flood Probability Probabilities

FLOOD PROBABILITY

Visual 3.1.29

Key Points

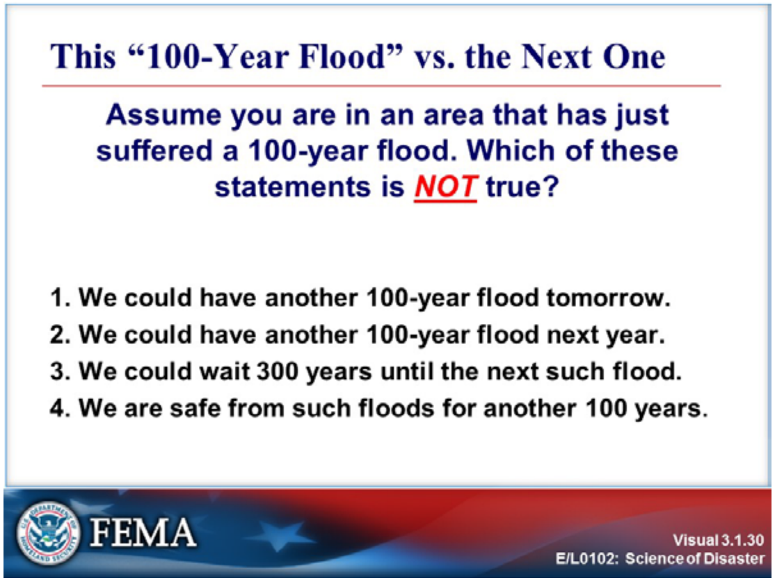
Hydrologists have identified a different flood hazard area for coastal regions. The Coastal High-Hazard Area that extends from offshore to the inland limit of a primary frontal dune along an open coast, and any other areas subject to high-velocity wave action, are designated Velocity Zones (V Zones).

The flood hazard area landward of the V Zone may be affected by flooding associated with astronomical tides, storm surges, seiches, or tsunamis.

See Color Handout 3.1.3: Flood Probability

FLOOD PROBABILITY

Visual 3.1.30



Alt Text for Visual 3.1.30
This "100-Year Flood" vs. the Next One
Assume you are in an area that has just suffered a 100-year flood. Which of these statements is ***NOT*** true?

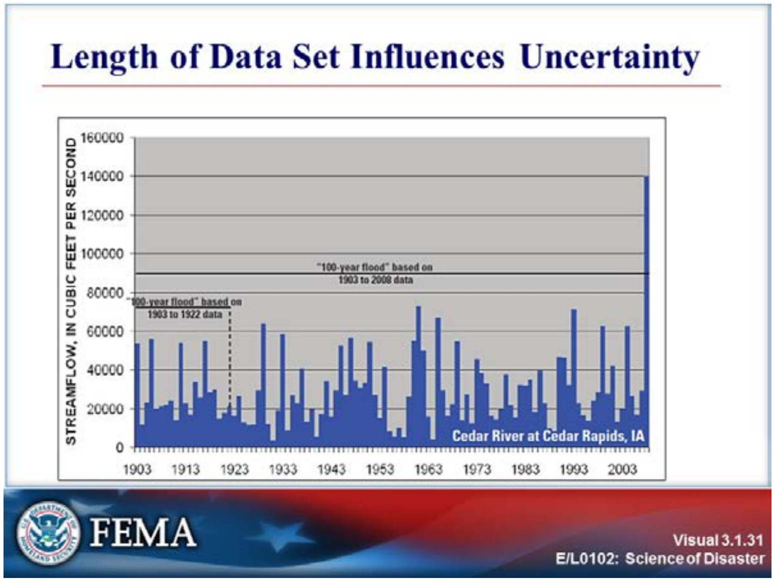
1. We could have another 100-year flood tomorrow.
2. We could have another 100-year flood next year.
3. We could wait 300 years until the next such flood.
4. We are safe from such floods for another 100 years.

Key Points

Discussion Question: Assume you are in an area that has just suffered a 100-year flood. Which of these statements is NOT true?

FLOOD PROBABILITY

Visual 3.1.31



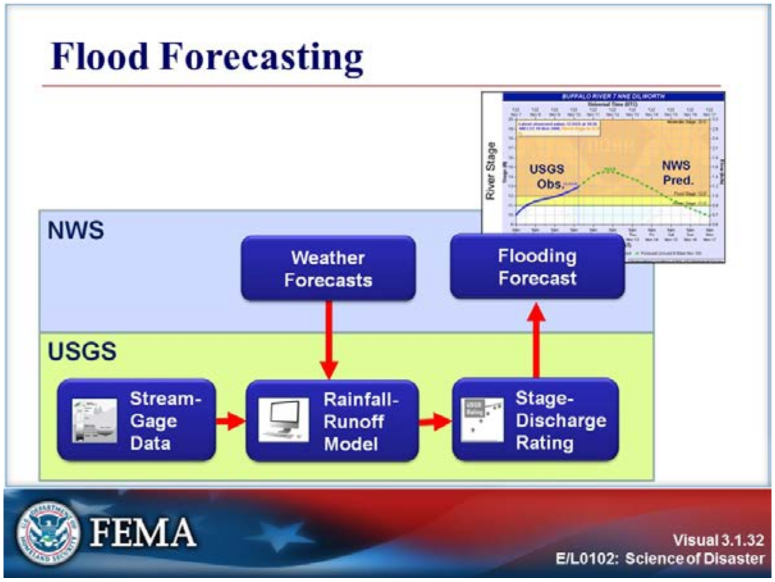
Key Points

It is also important to note that the longer the record of data, the better the chances are that scientists will successfully interpret patterns. This graph of streamflow data from Cedar Rapids, Iowa shows highest flood levels from 1903 to 2011. (The blue line at the far right of the graph is the 2011 flood level.)

<u>Discussion Question:</u> Look at the data set from 1963–1983. How high would you build a levee to protect against a 100-year flood? Now look at the data set from 1963–2011. How does that change your 100-year flood level?

FLOOD FORECASTING

Visual 3.1.32



Key Points

Given the hazards associated with flooding, Emergency Managers need to have reliable flood forecast information available in order to be prepared for flood emergencies that arise. What kinds of forecast information are available?

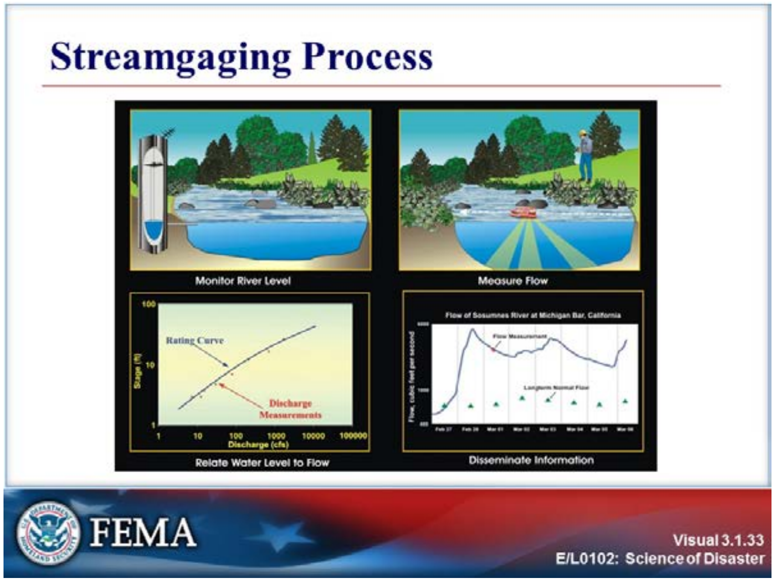
Flood forecasting: For rivers around the country, flood forecasts are available that show where and when the river is going to **crest** (reach its highest level). Forecasts can be made four (4) to five (5) days in advance of the event and can be crucial in decisions such as evacuation and emergency levee-building. The National Weather Service (NWS) and U.S. Geological Survey (USGS) partner to make and improve flood forecasts.

Streamgages: Forecasts are based in part on data from streamgages, along with NWS rainfall predictions. Streamgages are devices located beside a river that measure and record the water level in the river. The streamgages reveal what is actually happening on the river and are essential to calibrate flood models and make more accurate forecasts of flood parameters.

USGS operates more than 7,800 streamgages around the Nation.

FLOOD FORECASTING

Visual 3.1.33



Key Points

Streamgaging is based on two key factors—water elevation and volumetric streamflow.

- **Water elevation:** Sensors like the one on the upper left sense the water elevation at all hours and at varying frequencies. But water elevation, while important, is not enough information alone.

- **Streamflow:** To assess floods, volumetric streamflow (which only occasionally gets measured) must also be factored in. Based on those occasional measurements, scientists can estimate the flow at a site when the water is at different elevations. Thus, elevation becomes a surrogate for volumetric flow.

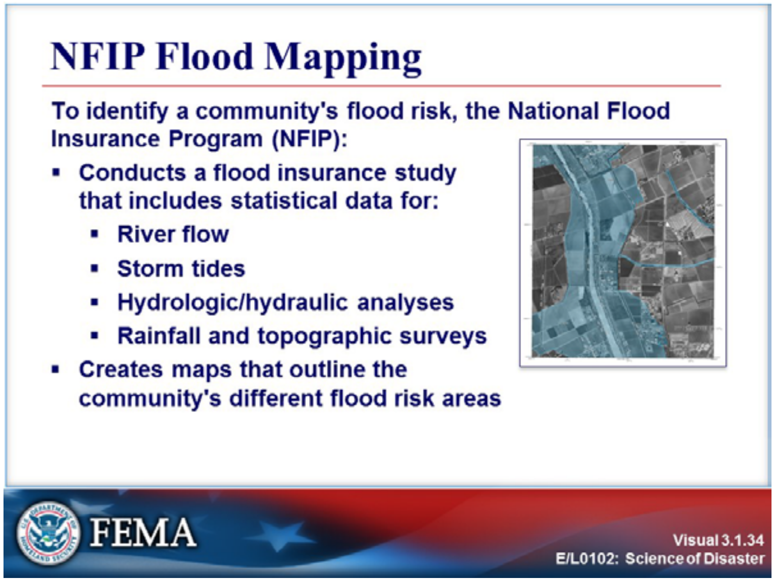
- **Rating curve:** As the sensors continually gather observations of water elevation, these elevations get converted to estimates of gallons per minute of volumetric streamflow through what is called a rating curve (stage/discharge rating). The “stage” is synonymous with elevation. In the sample rating curve shown on the lower left, red dots are discrete observations made by a human being. The rest of the curve is estimated.

- **Hydrograph:** A product of this measurement and estimation process is a hydrograph (bottom right). Some hydrographs show the water stage; others, like this one, show **discharge** (the volume of water passing a point per unit time, often measured in cubic feet per second, or CFS). Again, the red dots indicate discrete measurements.

These data are the basic tools of flood forecasting, and these products are available online almost immediately.

FLOOD MAPPING

Visual 3.1.34



Alt Text for Visual 3.1.34
NFIP Flood Mapping
To identify a community's flood risk, the National Flood Insurance Program (NFIP):

- Conducts a flood insurance study
  that includes statistical data for:
  - River flow
  - Storm tides
  - Hydrologic/hydraulic analyses
  - Rainfall and topographic surveys
- Creates maps that outline the community's different flood risk areas

Key Points

To identify a community's flood risk, the NFIP conducts a flood insurance study that includes statistical data for:

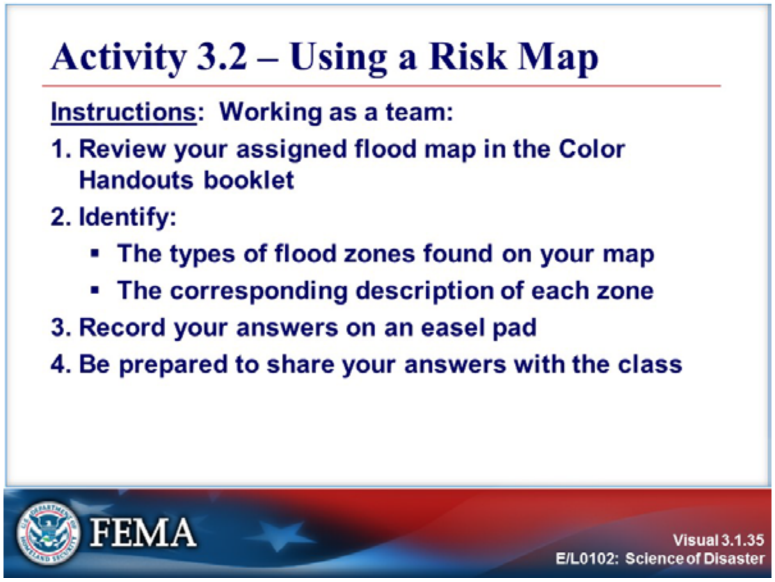
- River flow
- Storm tides
- Hydrologic/hydraulic analyses
- Rainfall and topographic surveys

These data are used to create maps that outline the community’s different flood risk areas.

Almost 100,000 Flood Insurance Rate Maps (FIRMs, or DFIRMs, if digitized) have been published and are currently being updated.

ACTIVITY 3.2 – USING A RISK MAP

Visual 3.1.35



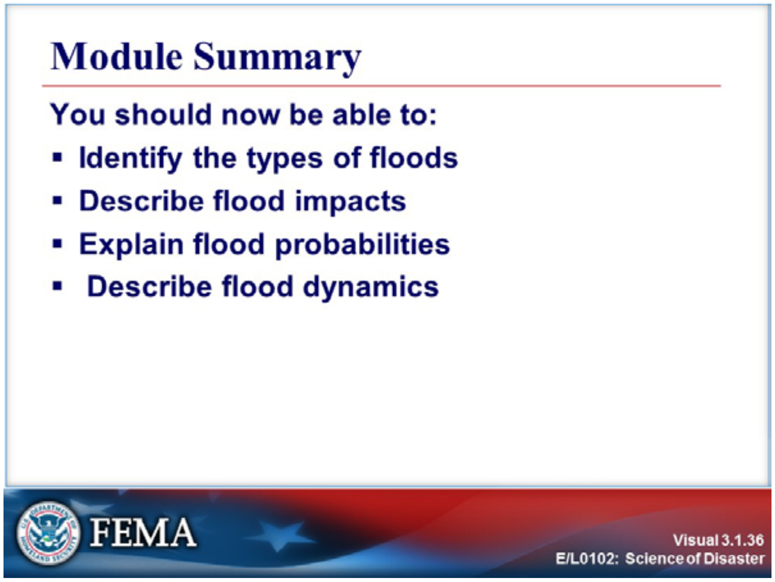
Key Points

Instructions: Working as a team:

1. Review your assigned flood map in the Color Handouts booklet.
2. Identify:
   - The types of flood zones found on your map
   - The corresponding description of each zone
3. Record your answers on an easel pad.
4. Be prepared to share your answers with the class.

MODULE SUMMARY

Visual 3.1.36



Key Points

Do you have any questions about the material covered in this module?

MODULE 4. EXTREME HEAT, DROUGHTS, AND WILDFIRES

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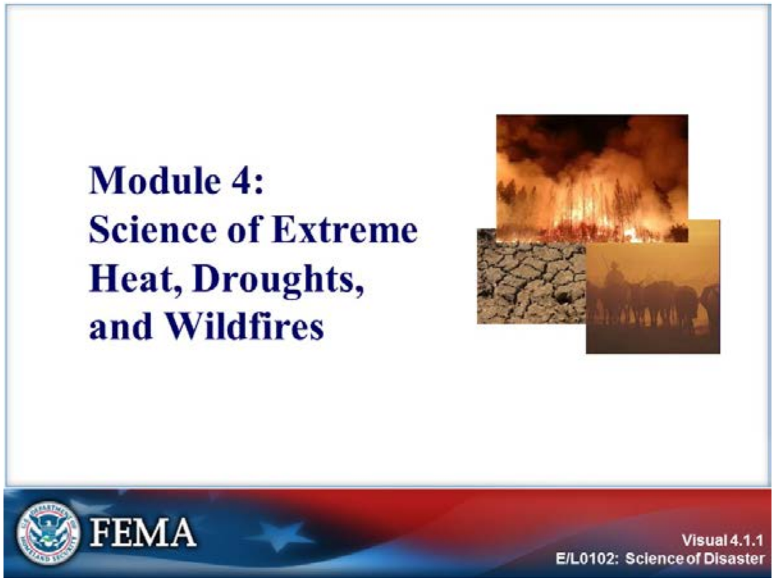
INTRODUCTION

Visual 4.1.1



Key Points

This module will discuss the discuss the science of extreme heat, droughts, and wildfires.

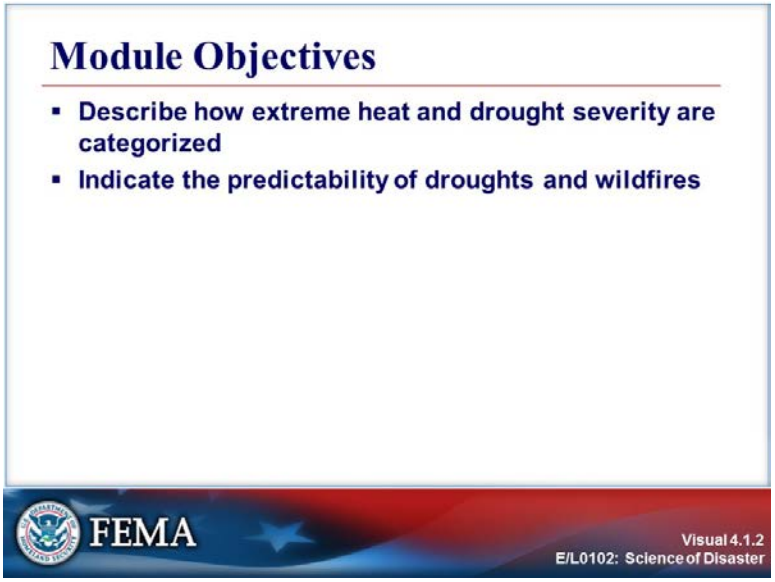
Time Plan

A suggested time plan for this module is shown below.

Topic	Time
Introduction	5 minutes
Extreme Temperatures	10 minutes
Extreme Temperature Predictions	5 minutes
Droughts	10 minutes
Droughts and Wildfires	5 minutes
Module Summary	5 minutes
Total Module Time:	**40 minutes**

INTRODUCTION

Visual 4.1.2

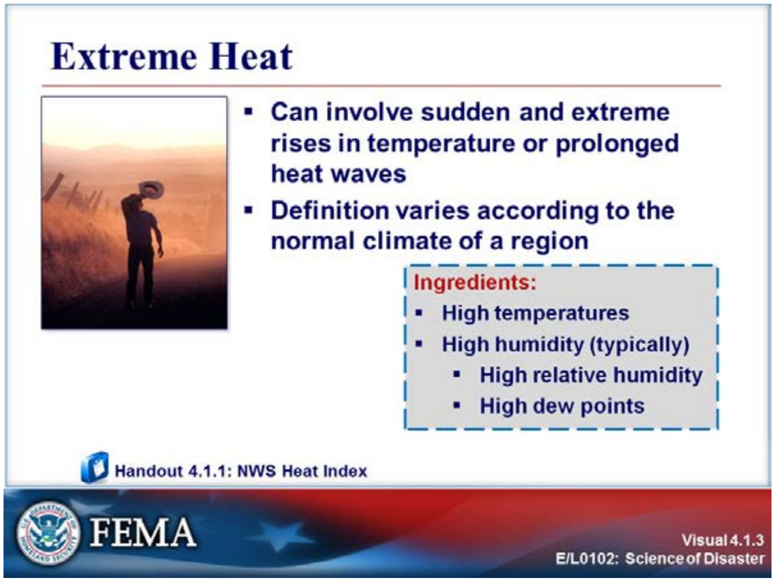


Key Points

Review the module objectives as shown on the visual.

EXTREME TEMPERATURES

Visual 4.1.3



Alt Text for Visual 4.1.3
Extreme Heat
- Can involve sudden and extreme rises in temperature or prolonged heat waves
- Definition varies according to the normal climate of a region

Ingredients:
- High Temperatures
- High Humidity (typically)
  - High relative humidity
  - High dew points

Handout 4.1.1: NWS Heat Index

Key Points

Definition: Extreme heat can involve sudden rises in temperature to extreme levels (taking away people's chance to acclimate) or prolonged heat waves. Either of these cases can cause heat-related fatalities.

As with extreme cold, the exact definition of "extreme heat" varies according to the normal climate of a region. For example, what is considered extreme heat in Seattle would differ from extreme heat in Tucson.

Ingredients: Heat waves and extreme heat are caused by:

- **High temperatures:** Remember that, as with extreme cold, what is considered "extreme" varies by region.

EXTREME TEMPERATURES

Visual 4.1.3 (Continued)

- **High humidity:** This includes:
  - **High relative humidity:** Relative humidity is a function of both moisture content and temperature. Relative humidity refers to how much moisture is in the air compared to the maximum amount the air can hold before the moisture is precipitated out, and is measured by a percentage (higher number = more humidity). Relative humidity is relative; by itself it does not directly indicate the actual amount of atmospheric moisture present. For example, Colorado has relative humidity of about 20 percent, which is dry compared to 97 percent in Washington, DC.

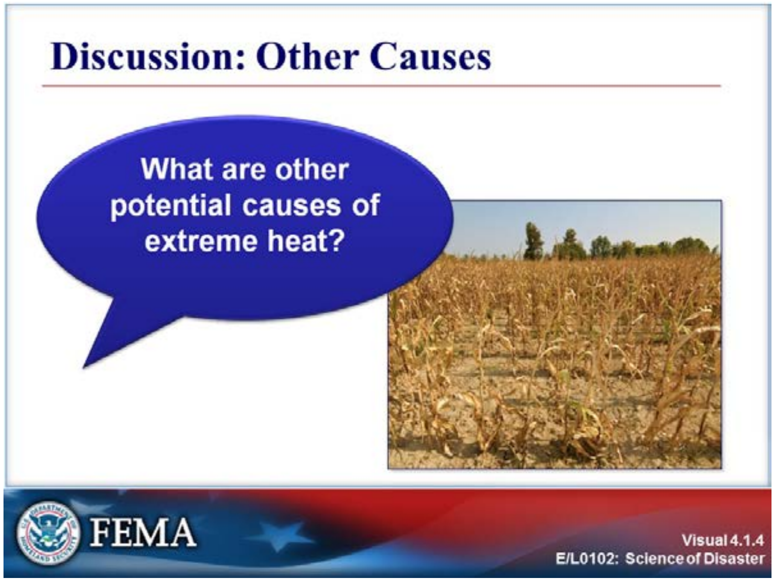
  - **High dew points:** Dew point is a measure of atmospheric moisture. It is the temperature to which air must be cooled in order to reach saturation (assuming air pressure and moisture content are constant). A higher dew point indicates more moisture present in the air. It is sometimes referred to as Dew Point Temperature, and sometimes written as one word (Dewpoint).

- **Heat index:** Just as the combined forces of wind speed and temperature are measured in wind chill, the combined forces of humidity and temperature are measured by the heat index (HI), shown below. What wind chill is to cold waves, heat index is to heat waves—it indicates apparent temperature.

See Color Handout 4.1.1: NWS Heat Index

EXTREME TEMPERATURES

Visual 4.1.4

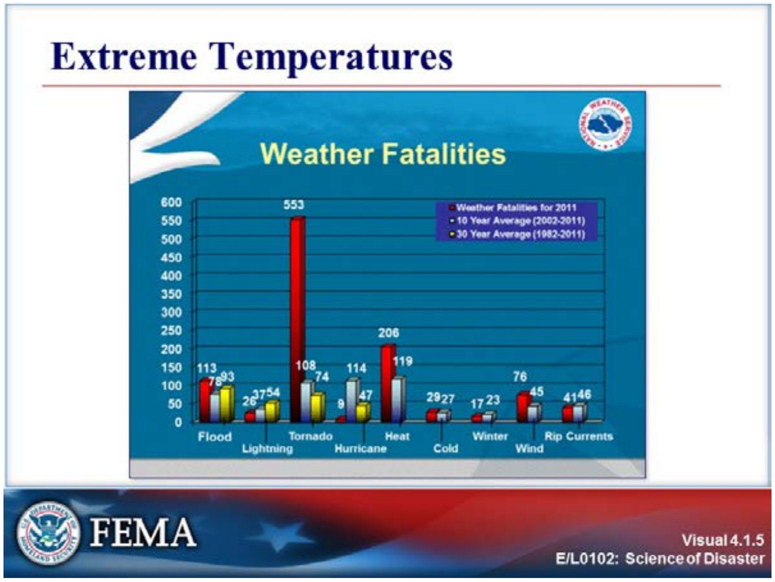


Key Points

<u>Discussion Question</u>: What are other potential causes of extreme heat?

EXTREME TEMPERATURES

Visual 4.1.5



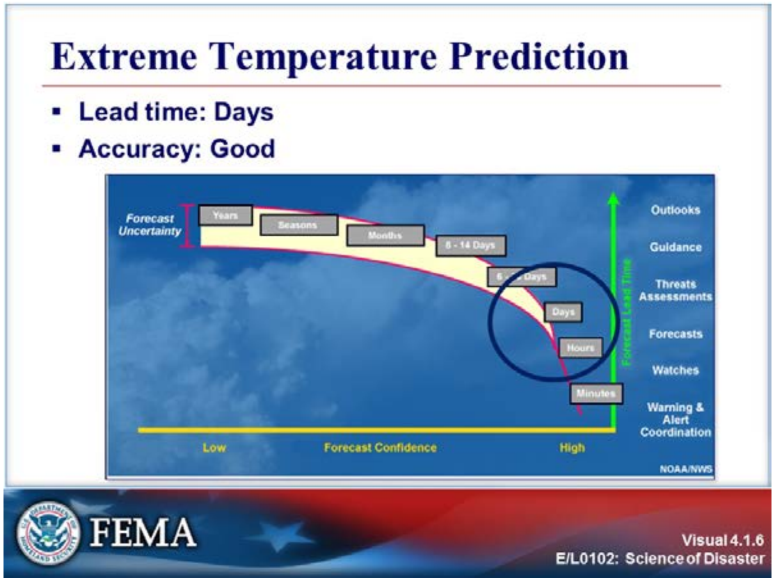
Key Points

Although extreme cold can be dangerous, the greatest weather-related hazard to life safety has historically been extreme heat.

Notice in the visual, that excessive heat was second highest in 2011 weather fatalities and has the **highest 10-year average fatality count.**

EXTREME TEMPERATURE PREDICTION

Visual 4.1.6



Key Points

Like winter storms, the lead time for predicting extreme temperatures is days, and the accuracy is generally good.

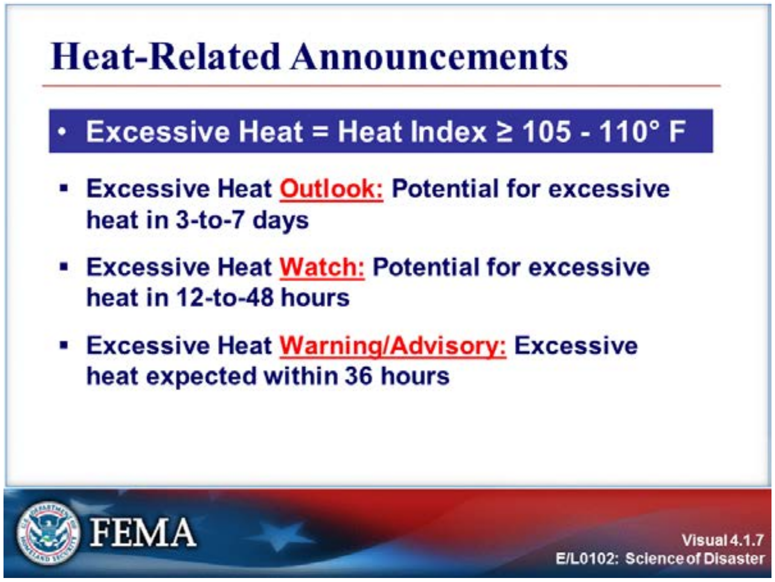
To predict cold waves and heat waves, forecasters gather information about:

- High/low temperatures
- Humidity (heat waves)
- Winds (cold waves)

With this information, forecasters are generally able to predict the duration of the system and expected temperatures.

EXTREME TEMPERATURE PREDICTION

Visual 4.1.7



Alt Text for Visual 4.1.7
Heat-Related Announcements
Excessive Heat = Heat Index ≥ 105 - 110° F

- Excessive Heat Outlook: Potential for excessive heat in 3-to-7 days
- Excessive Heat Watch: Potential for excessive heat in 12-to-48 hours
- Excessive Heat Warning/Advisory: Excessive heat expected within 36 hours

Key Points

Heat-related announcements are the equivalent of storm-related announcements. However, note that the timeframe in which the extreme heat is expected to occur is the differential between the different types of announcements:

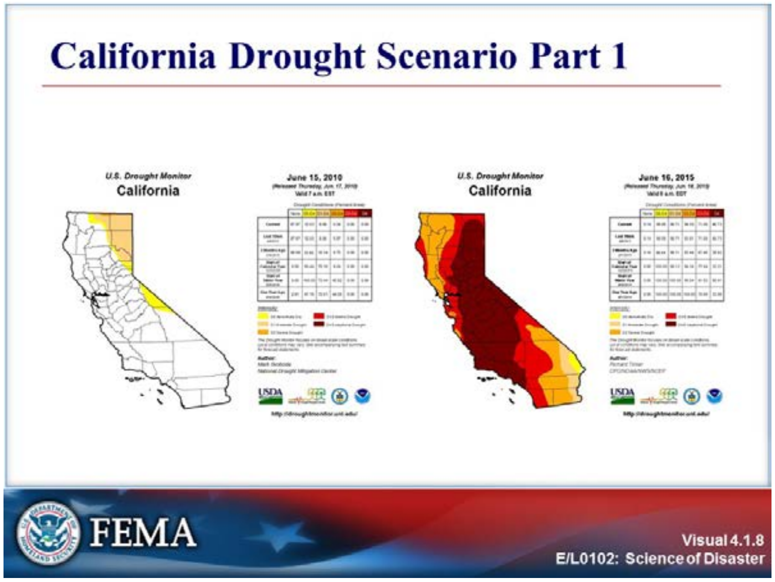
- Excessive Heat Outlook: Potential for excessive heat to occur in the next 3 to 7 days
- Excessive Heat Watch: Potential for excessive heat to occur in the next 12 to 48 hours
- Excessive Heat Warning/Advisory: Excessive heat expected to occur within 36 hours

Although absolute values for extreme heat are also defined regionally, extreme heat is considered to be "officially" a heat index ≥ 105–110 °F.

A daytime heat index reaching these temperature levels for two consecutive days, with nighttime lows at or above 80 °F, may significantly impact public safety. The local NWS office will generally issue an advisory or warning for these conditions.

CALIFORNIA DROUGHT SCENARIO

Visual 4.1.8

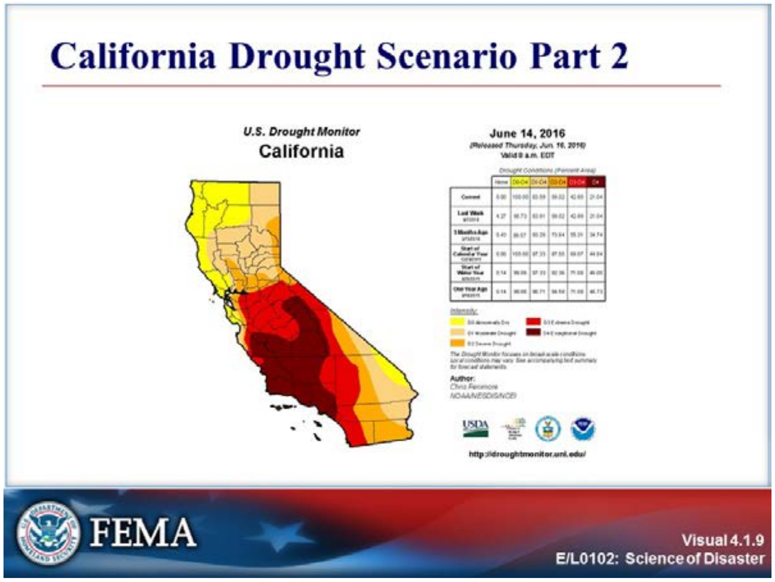


Key Points

Scenario Part 1:
California is currently (2016) in its fifth year of severe drought, the primary cause of which is a persistent high-pressure ridge that developed in the western Pacific during the 2011 La Niña. This high pressure failed to dissipate and has resulted in extreme temperatures and reduced precipitation throughout the Southwest. In the third year of the drought, on January 17, 2014, Governor Brown declared a Drought State of Emergency.

CALIFORNIA DROUGHT SCENARIO

Visual 4.1.9

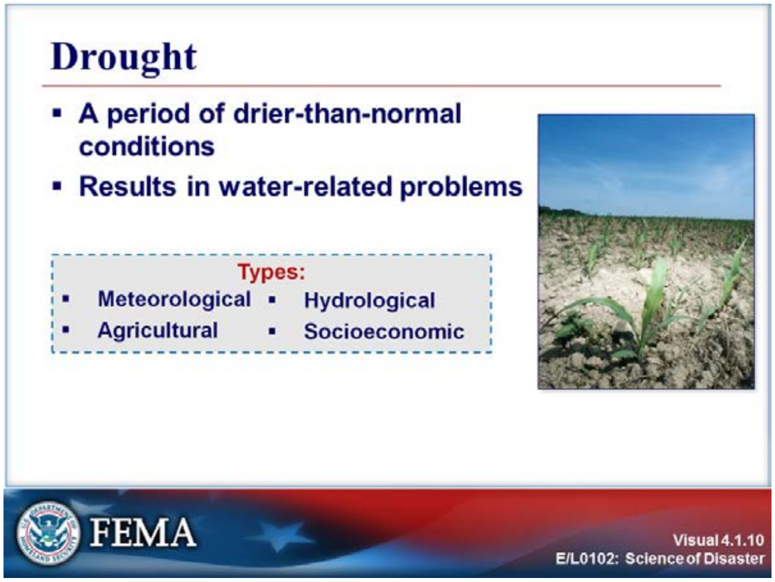


Key Points

Scenario Part 2:
While the 2015 El Niño event helped to reduce drought conditions, more than 55 percent of California remains in extreme drought. Snowpack in the Sierras is a primary water source for California and in 2016 levels in the Sierras were at 87 percent of normal. This is a significant improvement over the 5 percent of average snowpack levels measured in April 2015. Even with greater precipitation in the 2016 Water Year, drought conditions are still much more widespread than they were before the drought began in 2011.

DROUGHTS

Visual 4.1.10



Key Points

Description: The USGS defines drought as a period of drier than normal conditions that results in water-related problems. Thus, **there is no universally accepted quantitative definition of drought.**

Instead, a drought is most often defined by its impacts, which are typically economic, environmental, or societal in nature. For example, an agricultural drought is identified when crop production is adversely affected, while a hydrological drought is linked to a very substantial and potentially damaging reduction in water supplies.

Types: In general, there are four types of droughts:

- **Meteorological:** A drought in which there is a measure of departure from the normal level of precipitation. Due to climatic differences, what might be considered a drought in one location of the country may not be a drought in another location
- **Agricultural:** A drought in which the amount of moisture in the soil no longer meets the needs of a particular crop
- **Hydrological:** A drought in which surface and subsurface water supplies are below normal
- **Socioeconomic:** A drought in which physical water shortages begin to affect people

DROUGHTS

Visual 4.1.10 (Continued)

Beginning and end: The onset of any drought is slow, making it difficult to determine start and end times. Often, the onset of drought is not recognized until the impacts of the event have been ongoing for some time. Likewise, the end of a drought is not always ascertained until the event has already passed.

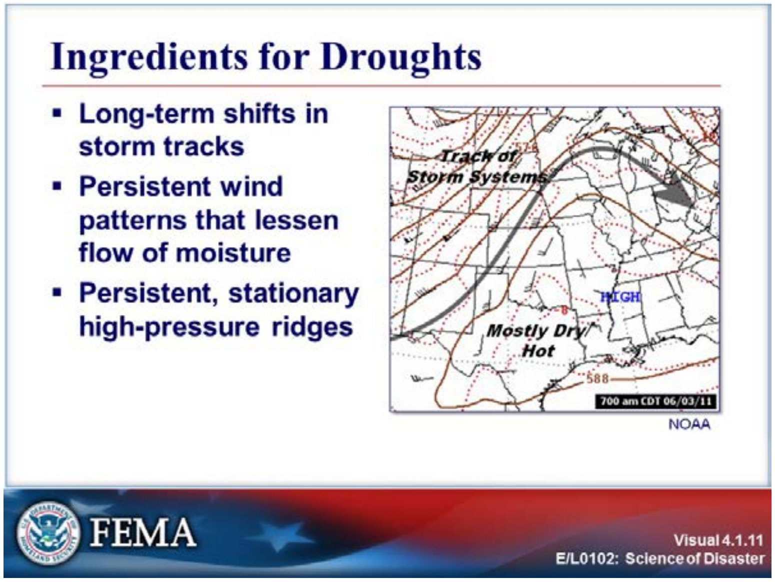
Droughts can span a range of timescales, from monthly or seasonal durations affecting agriculture to multi-year or multi-decade or even century-long events that dramatically change water quantities.

Geographic span: Droughts can also span very large spatial areas, encompassing large parts of the country at a given time.

Science helps in planning for drought and in making day-to-day management decisions regarding competing demands for water.

DROUGHTS

Visual 4.1.11



Alt Text for Visual 4.1.11
Ingredients for Droughts

- Long-term shifts in storm tracks
- Persistent wind patterns that lessen flow of moisture
- Persistent, stationary high-pressure ridges

A weather map that shows a high-pressure ridge ("HIGH") over Arkansas. The tracks of storm systems are driven around the ridge and well to the north. This ridge persisted from June to August, resulting in a hotter, drier climate in the region.

Key Points

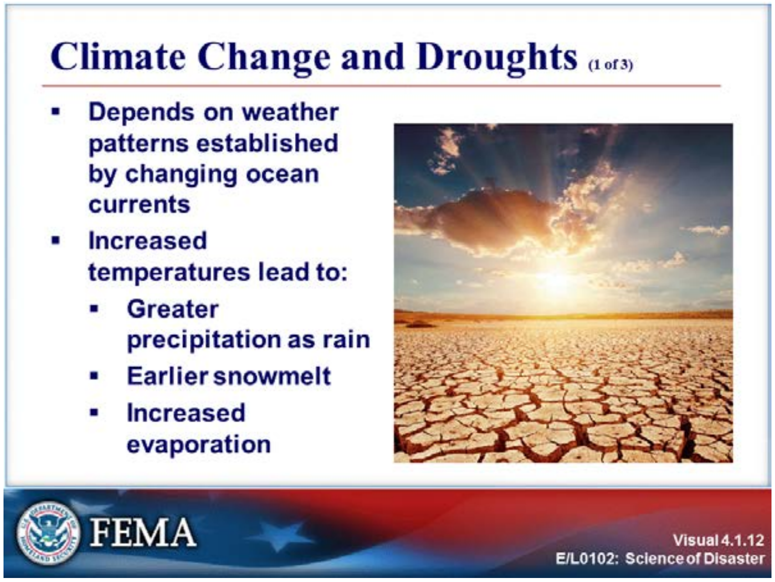
Droughts depend on weather factors including temperature, precipitation, wind speed, and solar radiation, which vary with time of year, local environment, and regional climate.

In general, the specific ingredients that result in the suppression of precipitation and droughts are:

- Long-term shifts in the storm tracks away from the affected region (for example, recall from the climatology unit that La Niña affects the jet streams, which in turn affects the storm tracks, potentially depriving certain regions of much-needed precipitation)
- Persistent wind patterns that lessen the flow of moisture into a region
- "Blocking weather patterns" that are composed of persistent, stationary high-pressure ridges
  - The California drought began in 2011 after a La Niña-induced weather pattern failed to subside. A high-pressure ridge off the California coast effectively blocked precipitation from falling in California. This ridge did not begin to subside until the 2015 El Niño. This seems to be a fairly consistent pattern for ENSO (El Niño Southern Oscillation) circulation with persistent drier conditions two to three years after the end of La Niña

DROUGHTS

Visual 4.1.12



Key Points

How does climate change affect drought?

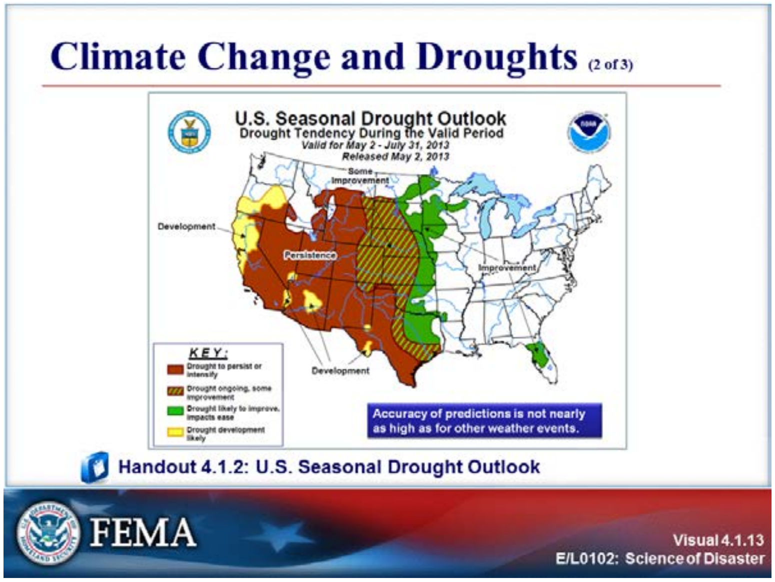
Depends on the weather patterns established by changing ocean currents. Some regions will experience greater rainfall, whereas others will experience less. Most models indicate that the American Southwest will be at greater risk of drought.

Increased temperatures lead to

- Greater precipitation as rain rather than snow, reducing snowpack
- Earlier snowmelt, causing water supply to be out of sync with water demand
- Increased evaporation and transpiration, increasing the likelihood of agricultural drought

DROUGHTS

Visual 4.1.13



Key Points

The National Oceanic and Atmospheric Administration (NOAA) and the NWS Climate Prediction Center create drought outlook maps. These maps take into account data collected by the USGS, NOAA, and the NWS. However, because droughts result from complex, long-term atmospheric phenomena, the accuracy of drought predictions is not nearly as high as the accuracy of predictions about other weather events.

For example, in this U.S. Seasonal Drought Outlook for September to November 2012, the map is divided into the following categories:

- Drought to persist or intensify
- Drought ongoing, some improvement
- Droughts likely to improve, impacts ease
- Drought development likely

This map “depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts.”

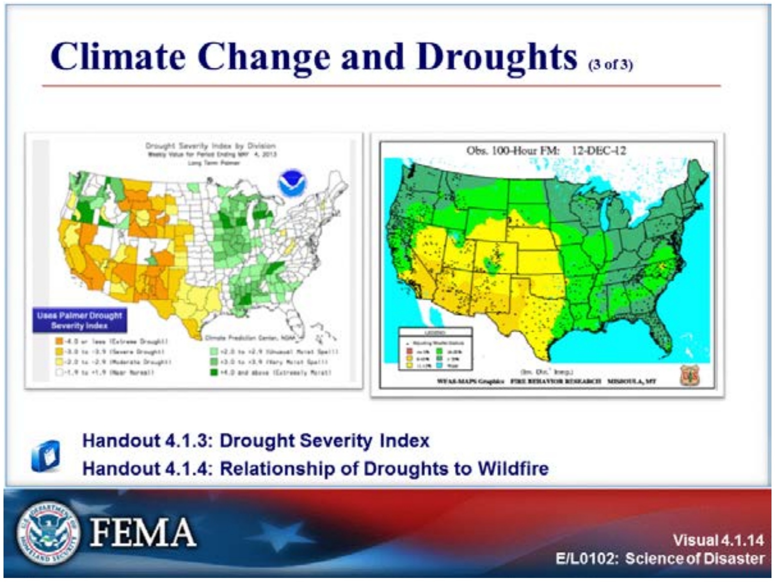
In short, **there are many complications involved in making these predictions, and the confidence in the forecast is necessarily much lower than for predictions of other weather events.**

A more complete version of the map is provided in the color handouts packet.

See Color Handout 4.1.2: U.S. Seasonal Drought Outlook

DROUGHTS AND WILDFIRES

Visual 4.1.14



Alt Text for Visual 4.1.14
Climate Change and Droughts (3 of 3)
Image of Drought Severity Index - -4.0 or less (Extreme Drought)
-3.0 to -3.9 (Severe Drought)
-2.0 to -2.9 (Moderate Drought)
-1.9 to +1.9 (Near Normal)
+2.0 to +2.9 (Unusual Moist Spell)
+3.0 to +3.9 (Very Moist Spell)
+4.0 and above (Extremely Moist)
A map image showing the distribution of dead fuel.
Handout 4.1.3: Drought Severity Index
Handout 4.1.4: Relationship of Droughts to Wildfire

Key Points

Forecasters collect scientific information that evaluates current drought levels. These data are normally expressed with the semi-official Palmer Drought Severity Index (PDSI), a formula developed by Wayne Palmer in the 1960s.

The Palmer Index is effective in using rainfall and temperature information to determine long-term drought (i.e., duration of months). Another advantage to the Palmer Index is that it is standardized according to local climates and can be applied to any region in the country to show the relative drought or rainfall conditions.

DROUGHTS AND WILDFIRES

Visual 4.1.14 (Continued)

This map shows the PDSI for the continental U.S. taken in early May 2013. Note that the index is organized in the following way:

PDSI Level	Description
-4.0 or less	Extreme Drought
-3.0 to -3.9	Severe Drought
-2.0 to -2.9	Moderate Drought
-1.9 to +1.9	Near Normal
+2.0 to +2.9	Unusual Moist Spell
+3.0 to +3.9	Very Moist Spell
+4.0 and above	Extremely Moist

See Color Handouts

- 4.1.3: Drought Severity Index
- 4.1.4: Relationship of Droughts to Wildfire

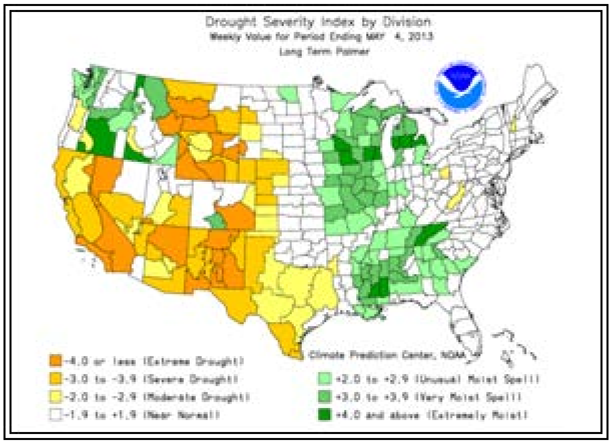
DROUGHTS & WILDFIRES

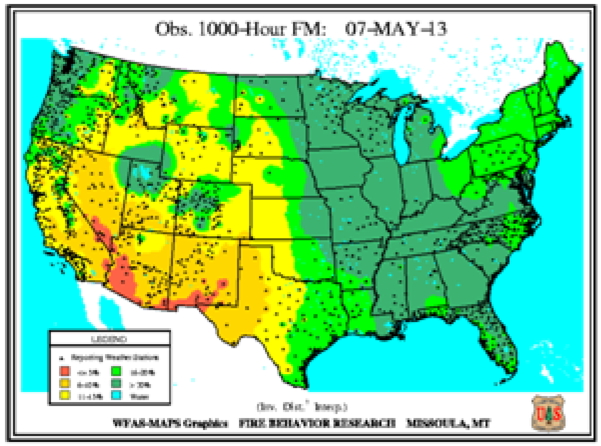
Visual 4.1.14 (Continued)

Relationship of droughts to wildfire: Drought is an important ingredient in wildfires, which may be caused by a combination of:

- Dry or drought conditions
- Wind
- Topography (slopes and changes in elevation enable fire to spread more easily)
- Moisture content of the soil
- Buildup of vegetation—especially dead fuel

In the maps below, note the similarity of the areas affected by drought in the left map, and the distribution of dead fuel in the right map.





Alt Text for map images
The first U.S. map shows drought severity (This link can also be accessed at the following URL: https://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/psi/201303-201305) which affects the mid-west and south west. The second U.S. map shows the dead fuel (This link can also be accessed at the following URL: http://www.wfas.net/index.php/dead-fuel-moisture-moisture--drought-38) that is covering the same areas.

DROUGHTS

Visual 4.1.15

Key Points

Droughts are also sometimes indexed using a D1 to D4 scale used by the U.S. Drought Monitor.

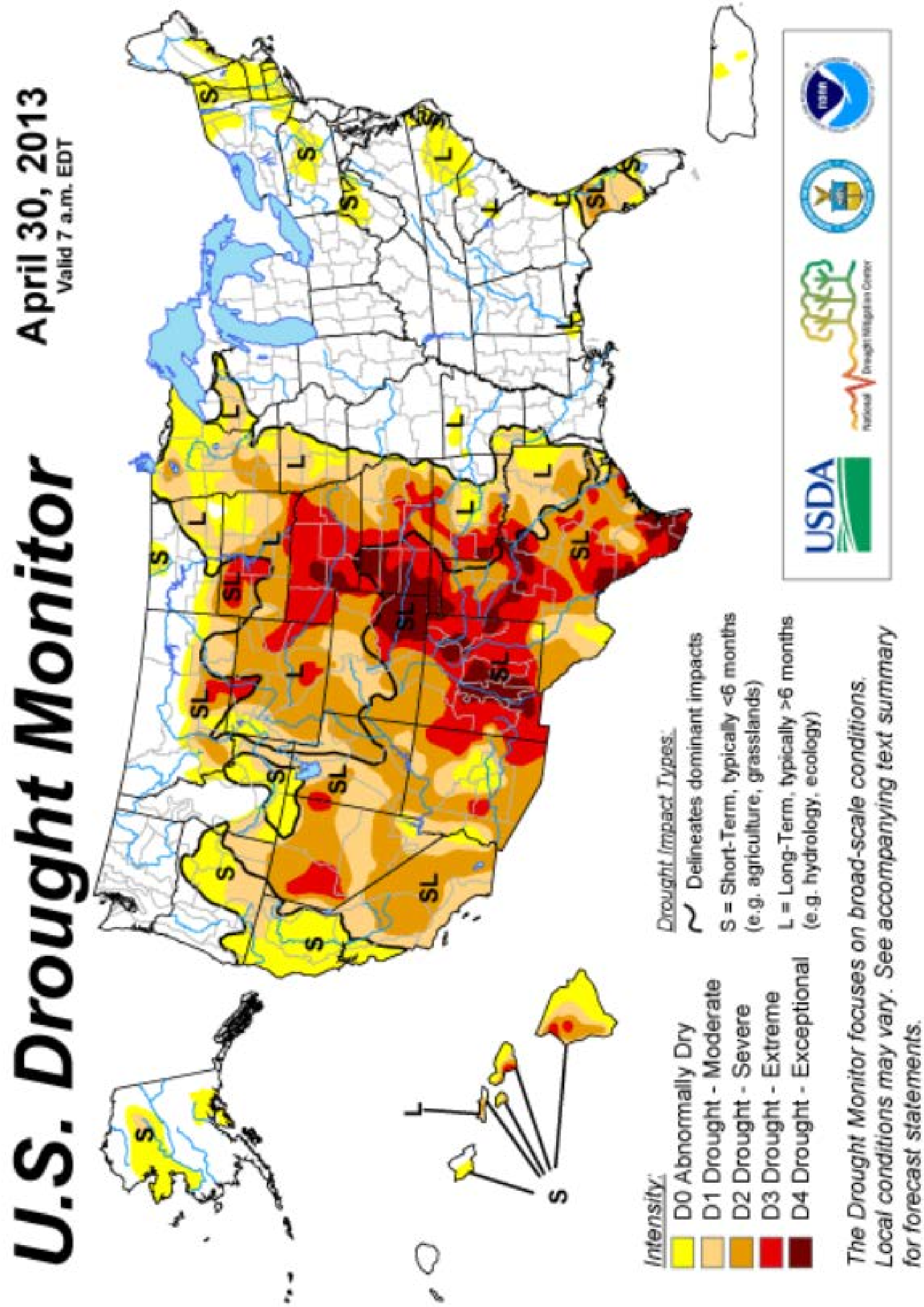
This video shows extended drought conditions across the United States from January to July of 2012. The colors represent four different categories of drought conditions: D1 (the lightest color) is the least intense drought condition (“Moderate” Drought), and D4 (the darkest color) is the most intense (“Exceptional” Drought).

An example of a U.S. Drought Monitor map and scale is provided on the next page.

See Color Handout 4.1.5 Drought Monitor Map

DROUGHTS

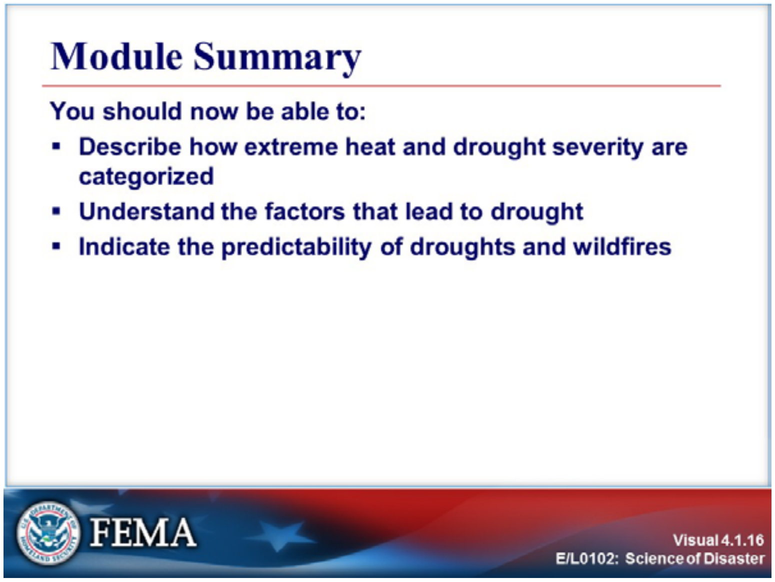
Visual 4.1.15 (Continued)



[U.S. Drought Monitor](https://Www.Ncdc.Noaa.Gov/Temp-And-Precip/Drought/Historical-Palmers/Psi/201304-201304) Map (This Link Can Also Be Accessed At The Following Url: https://Www.Ncdc.Noaa.Gov/Temp-And-Precip/Drought/Historical-Palmers/Psi/201304-201304)

MODULE SUMMARY

Visual 4.1.16



Key Points

Do you have any questions about material covered in this module?

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MODULE 5: SCIENCE OF LANDSLIDES AND SINKHOLES

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INTRODUCTION

Visual 5.1.1

Key Points

Welcome to Module 5: Landslides and Sinkholes. This module will discuss two kinds of ground failure: landslides and sinkholes. These two phenomena are paired because they are both common and destructive forms of mass wasting—e.g., the movement of rocks, sediments, or soils downslope or to lower elevation.

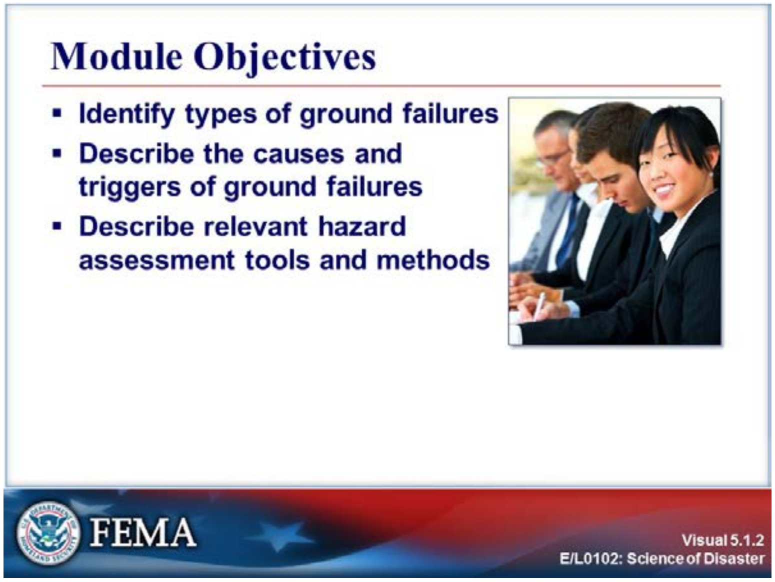
Time Plan

A suggested time plan for this module is shown below.

Topic	Time
Introduction	5 minutes
Landslides • Activity 5.1 – Oso Community Science Brief (Visual 5.1.19)	1 hour
Sinkholes • Activity 5.2 – Karst Terrain and Hazmat Spill (Visual 5.1.29) • Activity 5.3 – Module 5 IAW (Visual 5.1.31)	55 minutes
Module Summary	5 minutes
Total Time	**2 hours, 5 minutes**

INTRODUCTION

Visual 5.1.2



Alt Text for Visual 5.1.2
Module Objectives

- Identify types of ground failures
- Describe the causes and triggers of ground failures
- Describe relevant hazard assessment tools and methods

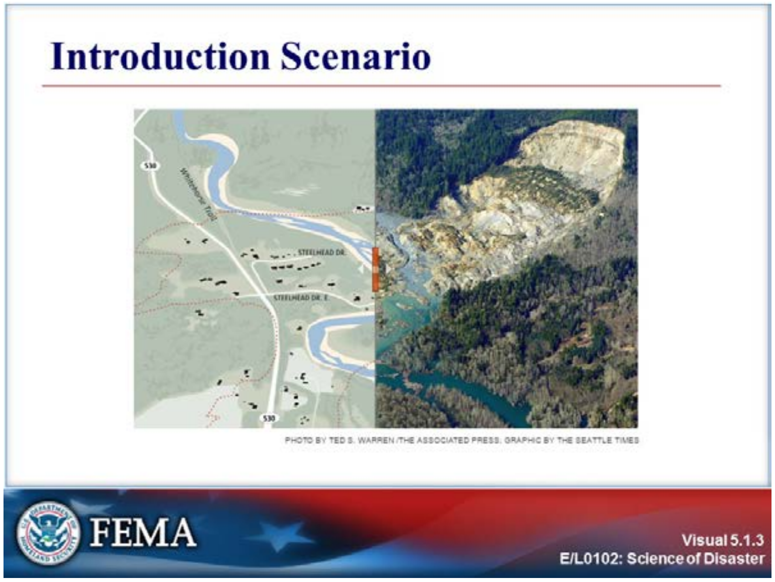
Image of a group of professionals working together

Key Points

Review the module objectives as shown on the visual.

INTRODUCTION SCENARIO

Visual 5.1.3



Key Points

On March 22, 2014, a landslide occurred in the town of Oso, Washington. The SR530 landslide overran a Local neighborhood and killed 43 people. The landslide provides an outstanding opportunity to review what scientists know about landslide potential, the means of preventing and mitigating landslide disaster, and the conflict that can occur between developers and the city and emergency planners.

INTRODUCTION SCENARIO

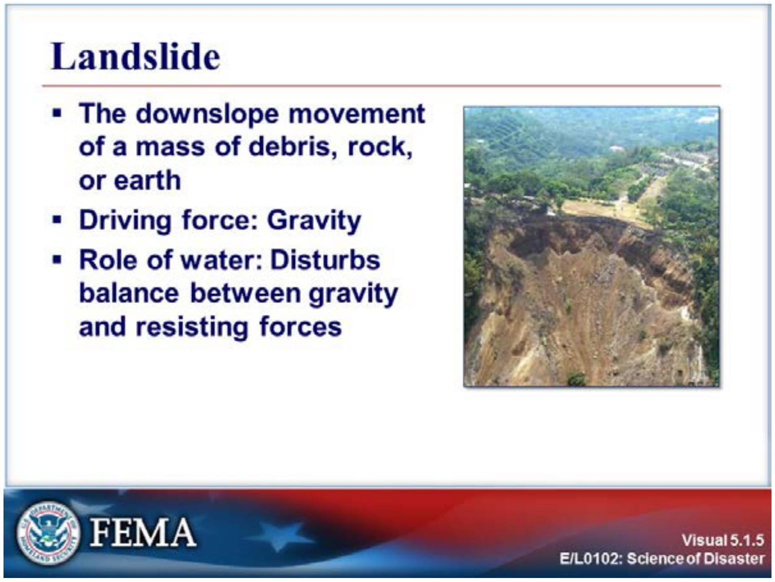
Visual 5.1.4

Key Points

This video shows a quick before and after from the Oso mud slide, using our Churchill Navigation ARS. It provides a visual to the details discussed in the previous slide about the SR530 landslide

LANDSLIDE BASICS

Visual 5.1.5



Key Points

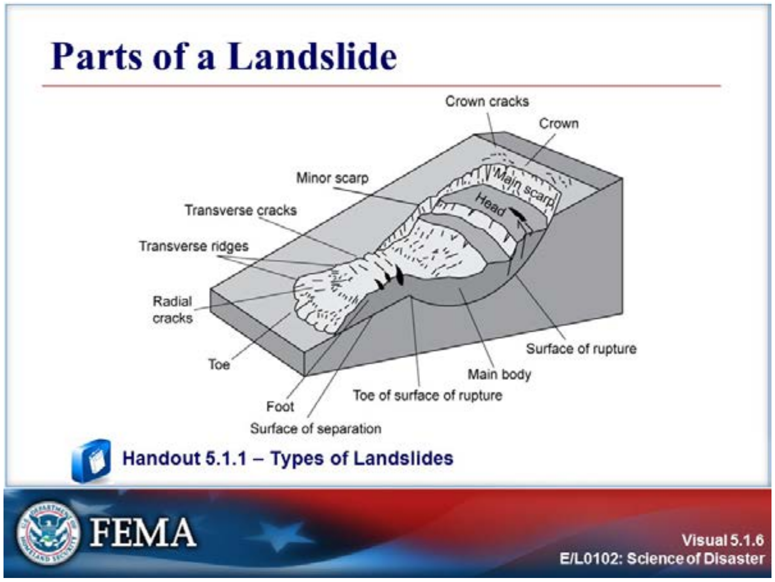
Landslides are defined as the downslope movement of a mass of debris, rock, or earth.

The driving force for all mass wasting phenomena is gravity, which pulls the material toward the center of the Earth. Typically, there is a balance of gravity with resisting forces, such as friction. This maintains the stability of the slope.

When the balance is disturbed—ground failure results. Water acts as a lubricant reducing the friction that holds material in place.

LANDSLIDE BASICS

Visual 5.1.6



Alt Text for Visual 5.1.6
Parts of a Landslide
Graphic cut of a landslide with the following labeled (top to bottom): crown cracks, crown, main scarp, head, minor scarp, transverse cracks, transverse ridges, radial cracks, toe, foot, surface of separation, toe of surface of rupture, main body, and surface of rupture.
Job Aid: Handout 5.1.1 - Types of Landslides

Key Points

This schematic illustrates the different parts of a landslide. Note that:

- The **landslide body** moves along a surface of rupture. In this illustration, the surface of rupture is curved and the motion is rotational.
- In a landslide, the main **scarp** is a vertical or subvertical face that is exposed when the slide moves downslope.
- The **toe** is the lower-most extent of the displaced material.

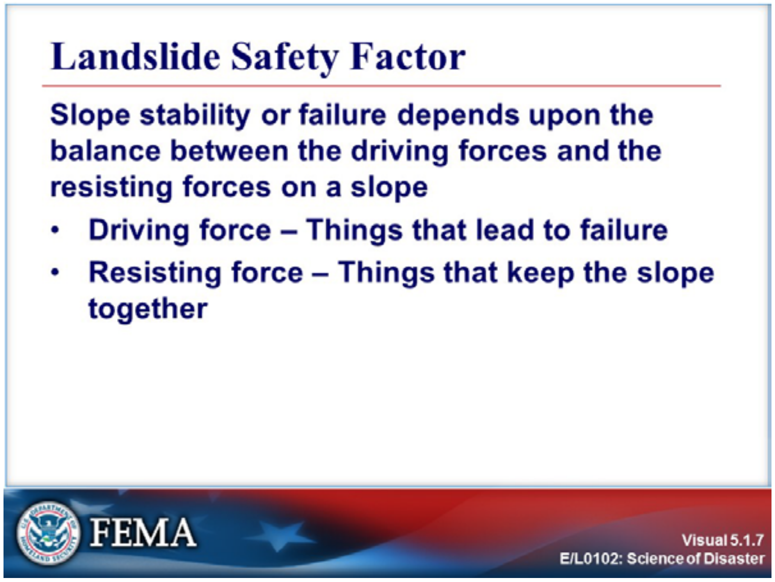
To understand landslides, scientists must understand the many variations that occur, and, thus, develop terminology to distinguish the variations.

Geologists can identify the scarps and toes of old landslides in both the rock record and in LiDAR (Light Detection and Ranging) imagery. This is remarkably useful in developing land-use restrictions.

See color handout 5.1.1: Types of Landslides

LANDSLIDE SAFETY FACTOR

Visual 5.1.7



Alt Text for Visual 5.1.7
Landslide Safety Factor
Slope stability or failure depends upon the balance between the driving forces and the resisting forces on a slope.

- Driving force – Things that lead to failure
- Resisting force – Things that keep the slope together

Key Points

Ultimately slope stability or failure depends upon the balance between the driving forces and the resisting forces on a slope.

Driving Force: Things that lead to failure

- Gravity is the dominant driving force
- Things that add weight to the slope
  - Vegetation
  - Landfill
  - Buildings

Resisting Force: Things that keep the slope together

- Shear Strength
  - Could also be vegetation

The safety factor (SF) is the ratio between the resisting and driving force.

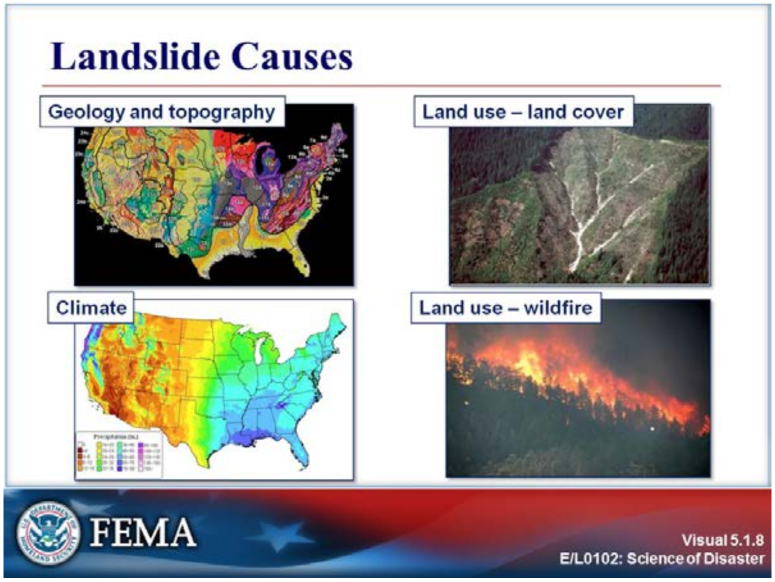
SF = Resisting Force/Driving Force

If SF > 1 the slope is stable
If SF < 1 the slope is unstable

Any prevention or mitigation will need to increase the resisting force and/or decrease the driving force.

LANDSLIDE CAUSES AND TRIGGERS

Visual 5.1.8



Alt Text for Visual 5.1.8
Landslide Causes

- Geology and topography
  Graphic of geological and topographical map of the US
- Land use - land cover
  Overhead photo of land cover on a mountain
- Climate
  Graphic of a map of the US with the climate areas highlighted in color
- Land use - Wildfire
  Photo of a wildfire

Key Points

Landslide occurrence is often described using the terms cause and trigger. First, we'll look at causes.

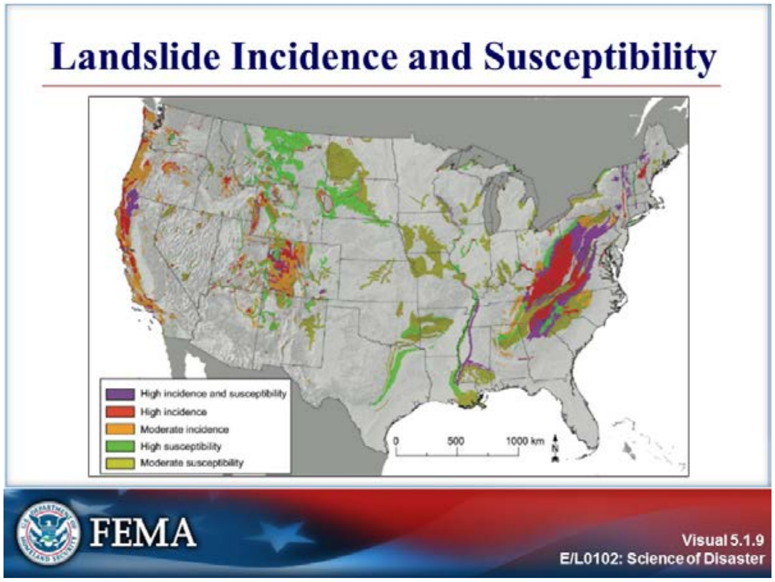
Causes are the topographic, geologic, climatic, and land use characteristics that make an area susceptible to landslides.

- A steep slope is an example of a topographic cause.
- Weak geologic materials include sedimentary rocks or heavily weathered rocks as well as natural zones of weakness, such as bedding planes and fault planes.
- Climatic conditions include heavy rainfall that can loosen material and reduce cohesion between grains.
- Land use includes human activities that directly and indirectly have an effect, such as industrial forestry, road cuts, and in some cases, wildfire.

Causes create the conditions that make a landslide possible and increase the propensity for landslides.

LANDSLIDE IMPACTS

Visual 5.1.9



Key Points

Landslide Incidence and Susceptibility Map (This link can also be accessed at the following URL: http://landslides.usgs.gov/hazards/nationalmap/)

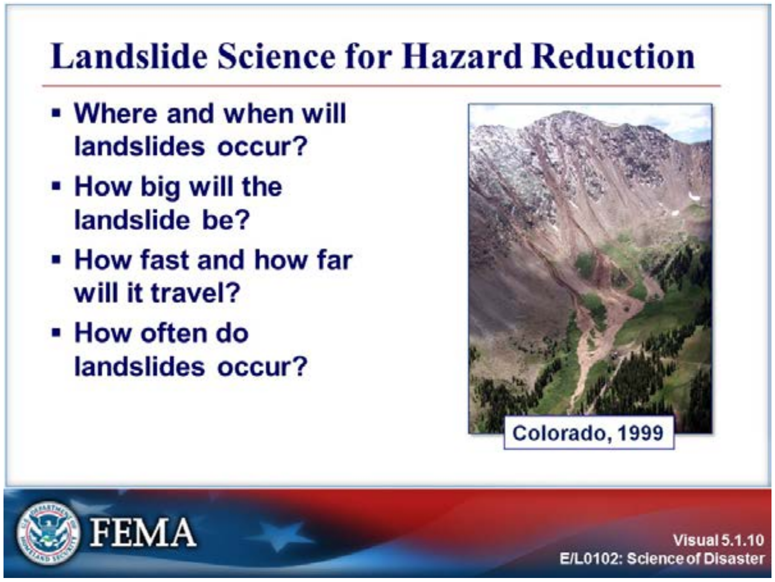
All 50 states have some areas that are at risk from landslides.

The greatest potential for losses resulting from landslides, however, exists in the:

- States along the Pacific coast
- Rocky Mountains
- Appalachian Mountains

SCIENCE FOR HAZARD REDUCTION

Visual 5.1.10



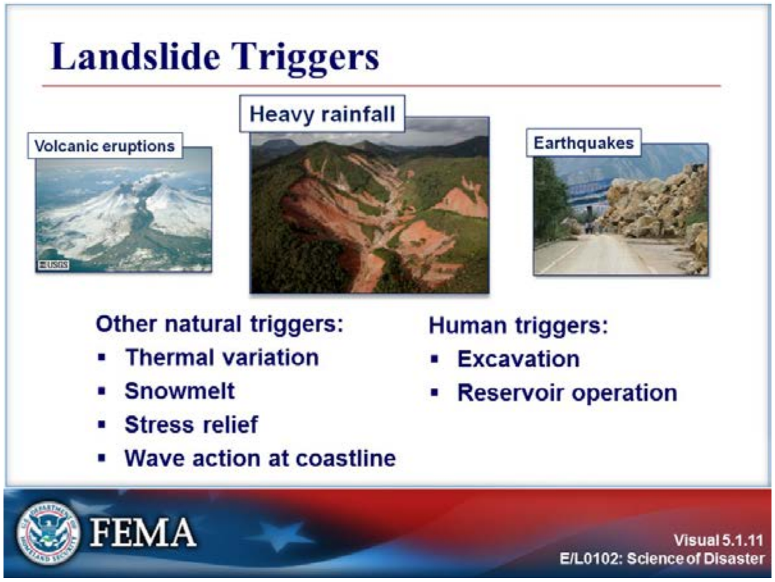
Key Points

Landslide science typically focuses on answering these four questions:

1. Where and when will landslides occur?	Answering this question involves predictions of slope instability across space and time. This requires knowledge of geologic, hydrologic, and other conditions.
2. How big will the landslide be?	These questions are intimately linked and are critical for understanding the impact of slides on people and things. To address these questions, scientists need to understand the strength of the earth materials in three dimensions, the topography of the land, the characteristics of groundwater flow, and the mixture mechanics—i.e., the interactions among earth materials, water, and channel bed.
3. How fast and how far will it travel?	
4. How often do landslides occur?	This question can be answered by using historical or geologic records and estimates of the frequency of triggering conditions, such as earthquake shaking or heavy rainfall.

LANDSLIDE CAUSES AND TRIGGERS

Visual 5.1.11



Alt Text for Visual 5.1.11
Landslide Triggers
Photo of an erupting volcano labeled Volcanic eruptions
Photo of a green and exposed, eroded area labeled Heavy rainfall
Photo of a road with landslide rocks on it labeled Earthquakes
Other natural triggers:

- Thermal variation
- Snowmelt
- Stress relief
- Wave action at coastline

Human triggers:

- Excavation
- Reservoir operation

Key Points

Many regions are susceptible to landslides because of their climate and topography. However, most landslides are triggered by a particular event or series of events. Most often the culprit is heavy rainfall or human activity. For example, 90 percent of landslides in the Pittsburgh, Pennsylvania region are a result of urban development. However, hurricanes, volcanic eruptions, and earthquakes often trigger the landslide events that take the largest toll on human life.

Landslide triggers include a variety of natural and human processes.

Natural processes may include:

- Heavy rainfall
- Volcanic eruption
- Earthquake

LANDSLIDE CAUSES AND TRIGGERS

Visual 5.1.11

- Thermal variation (extremes of hot and cold that allow moisture to enter cracks and freeze, expand, and force the crack apart)
- Snowmelt
- Stress relief (as rocks are heaved up and exposed above the ground, they may expand to release pressure that causes fractures)
- Wave action at a coastline

Although earthquake-triggered landslides often create the largest death tolls, they are typically not the cause of most landslides. Excessive rainfall triggers most landslides.

Human activities that can trigger landslides include action that changes the topography (e.g., excavations) and activities that change ground or surface water hydrology (e.g., reservoir operation).

LANDSLIDE IMPACTS

Visual 5.1.12

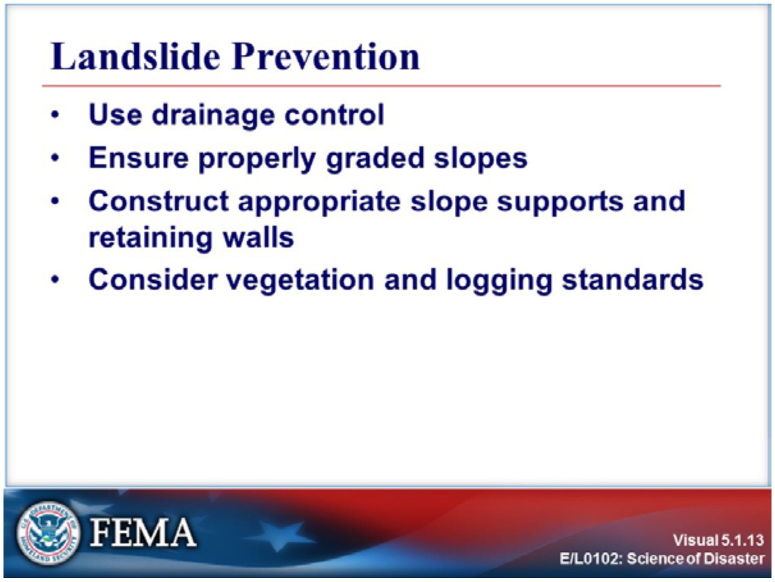
Key Points

For nonscientists, there are two key distinctions with regard to landslide impacts:

- **Slow-moving landslides** that can be quite destructive to structure and infrastructure and, thus, very expensive
- **Fast-moving landslides**, which are more likely to cause deaths and injuries

LANDSLIDE IMPACTS

Visual 5.1.13



Key Points

Any prevention measure must consider the slope stability factor that will decrease the driving force (remove weight) and increase the resisting force (add shear strength).

SF = resisting force/driving force

First and foremost, be aware of local geology. What is the history of landslides in a region? How are rivers changing course that may lead to over-steepened banks and increased landslide potential?

Reasonable and effective prevention measures include:

1) Drainage Control
   a) Keep water from infiltrating surfaces
      i) Cover the surface
      ii) Install surface drains
   b) Remove water from the subsurface by installing drains.
2) Properly grade slopes
   a) Reduce gradient to improve slope stability
   b) Install benching
   c) Install appropriate drainage in newly graded or benched slopes
3) Construct appropriate slope supports/retaining walls with
   a) Anchors
   b) Backfill
   c) Drainage

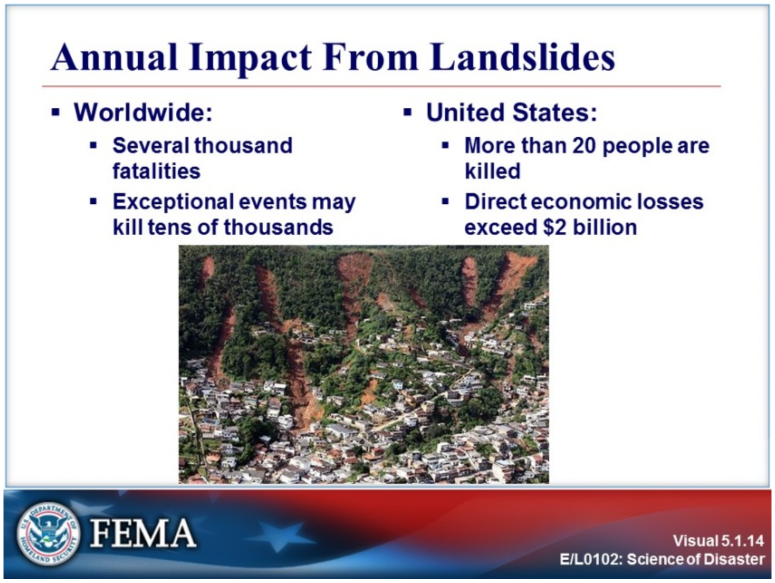
LANDSLIDE IMPACTS

Visual 5.1.13 (Continued)

4) Consider vegetation
   a) Plant vegetation that
      i) Stabilizes the slope by reducing infiltration of water
      ii) Does not add excess weight to the slope
   b) Consider logging standards
      i) Appropriate setbacks from scarps
      ii) Road construction and maintenance alters surface runoff, which affects slope stability

LANDSLIDE IMPACTS

Visual 5.1.14



Alt Text for Visual 5.1.14
Annual Impact from Landslides

- Worldwide:
  - Several thousand fatalities
  - Exceptional events may kill tens of thousands
- United States:
  - More than 20 people are killed
  - Direct economic losses exceed $2 billion

Overhead photo of a residential area with landslides flowing into them

Key Points

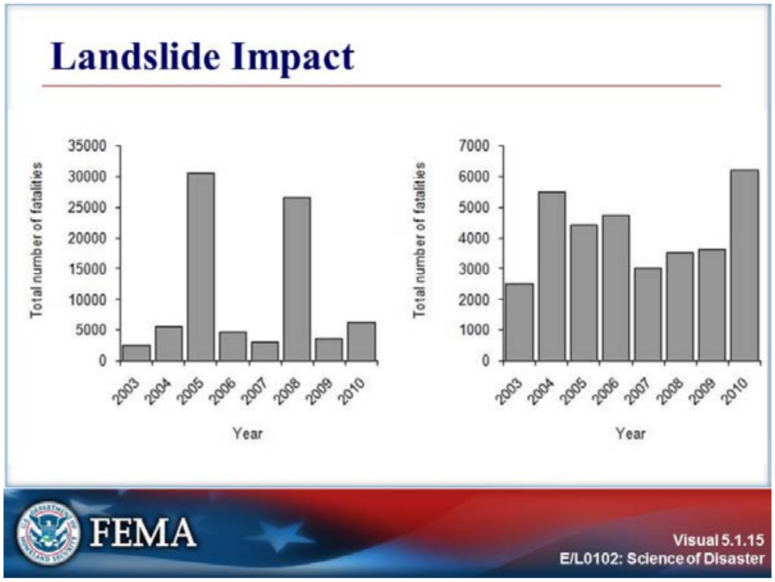
Every year there are significant losses from landslides, both in lives lost and economic losses. Because a landslide affects a relatively small area, the impacts of these disasters are often underappreciated.

Annually, worldwide, landslides result in several thousand fatalities. Exceptional events may kill tens of thousands.

Annually, in the United States, landslides result in more than 20 fatalities and direct economic losses that exceed $2 billion.

LANDSLIDE IMPACTS

Visual 5.1.15



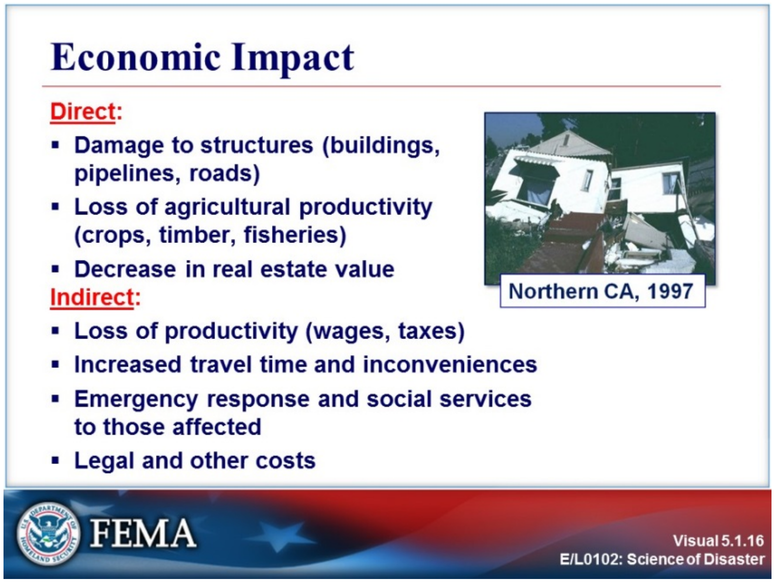
Key Points

This histogram on the left shows the worldwide fatalities as a result of landslides. The unusually high numbers of fatalities in 2005 (Kashmir earthquake) and 2008 (Wenchuan earthquake) are a result of earthquakes. The histogram on the right shows the same years with the fatalities from those earthquakes removed. This might help explain the common perception that landslides are always caused by earthquakes.

Source Global Deaths from Landslides. (This link can also be accessed at the following URL: http://blogs.agu.org/landslideblog/2011/02/05/global-deaths-from-landslides-in-2010/)

LANDSLIDE IMPACTS

Visual 5.1.16



Alt Text for Visual 5.1.16
Economic Impact
Direct:
- Damage to structures (buildings, pipelines, roads)
- Loss of agricultural productivity (crops, timber, fisheries)
- Decrease in real estate value

Indirect:
- Loss of productivity (wages, taxes)
- Increased travel time and inconveniences
- Emergency response and social services to those affected
- Legal and other costs

Photo of a demolished house labeled Northern CA, 1997

Key Points

Economics play an important role in hazard reduction. Economists look at disaster costs based on the type of cost, and whether it is direct or indirect. Examples of direct and indirect costs from landslides include:

Direct costs:

- Damage to structures (buildings, pipelines, roads)
- Loss of agricultural productivity (crops, timber, fisheries
- Decrease in real estate value

LANDSLIDE IMPACTS

Visual 5.1.16

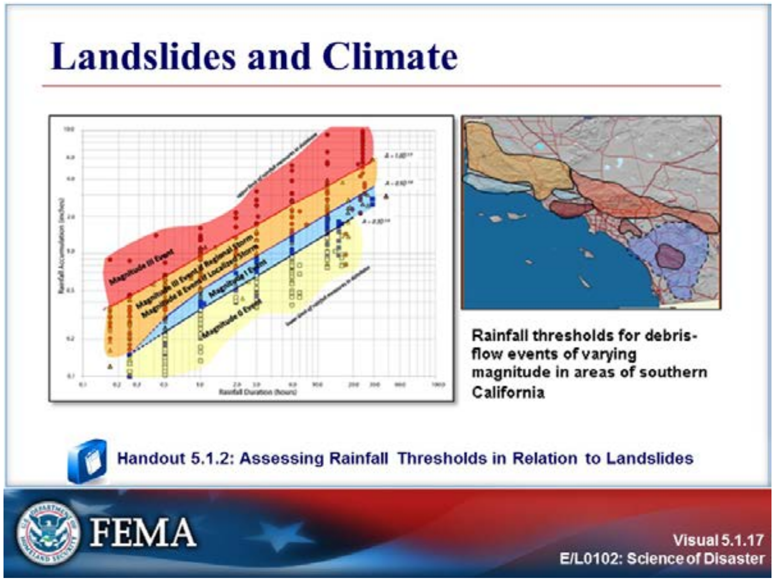
Indirect costs:

- Loss of productivity (wages, taxes)
- Increase in travel time and inconveniences
- Emergency response and social services to those affected
- Legal costs
- Any other nondirect costs

It is worthwhile to consider that litigation is still pending regarding the SR530 slide. Issues include whether authorities properly warned citizens and whether the logging companies were at fault for the landslide.

SCIENCE FOR HAZARD REDUCTION

Visual 5.1.17



Alt Text for Visual 5.1.17
Landslides and Climate
Chart showing Accumulation and Rainfall Duration in hours for magnitude 0, 1, 2, and 3 events
Overhead photo of a southern CA coastline with rainfall thresholds superimposed over it.
Rainfall thresholds for debris flow events of varying magnitude in areas of southern California
Job Aid: Handout 5.1.2: Assessing Rainfall Thresholds in Relation to Landslides

Key Points

In a few parts of the United States, landslide rainfall thresholds have been defined based on the rainfall conditions that have been associated with past landslide occurrence.

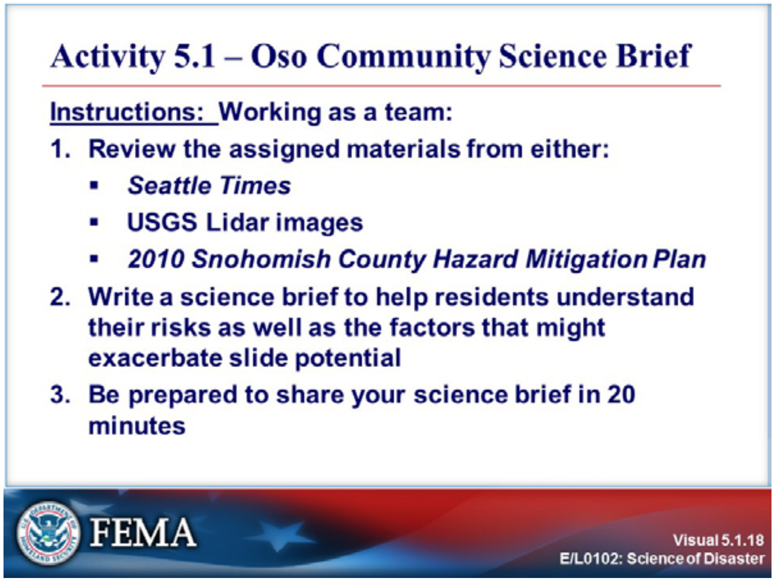
The figure on the visual shows rainfall duration versus total rainfall amount for debris flows following wildfire in southern California. If rainfall occurs above the threshold, debris flow events of differing magnitudes (colored strips on chart and map) can be expected.

The National Weather Service Forecast Offices uses rainfall threshold information to inform emergency management personnel and the public when landslides are expected.

See color handout 5.1.2: Assessing Rainfall Thresholds in Relation to Landslides, Debris Flow in Relation to Wildfire

ACTIVITY 5.1 – OSO COMMUNITY SCIENCE BRIEF

Visual 5.1.18



Key Points

Working as a team:

1. Have each table group review the assigned materials from either:
   - *The Seattle Times* that highlights red flags about the SR530 Slide Hill (See Job Aid 1 or *The Seattle Times* link (This link can also be accessed at the following URL: http://projects.seattletimes.com/2014/building-toward-disaster/)
   - The LiDAR images from the U.S. Geological Survey (USGS) (Handouts 5.1.3 – 5.1.6)
   - Chapter 14 of the *2010 Snohomish County Hazard Mitigation Plan*
2. Have the groups write a science brief to help residents understand their risks as well as the factors that might exacerbate slide potential.
3. Be prepared to share your science brief in 20 minutes.

See color handout

- 5.1.3: Oso Historical Landslide
- 5.1.4: USGS Oso Landslide LIDAR 1
- 5.1.5: USGS Oso Landslide LIDAR 2
- 5.1.6: Oso Image

ACTIVITY 5.1 – OSO COMMUNITY SCIENCE BRIEF

Visual 5.1.18 (Continued)

Job Aid 1: Red Flags Timeline

There was a history associated with landslides in the area

- **1900**: The Seattle Times reported on road construction in Snohomish County and stated, “A big landslide, some 100 yards in extent, about three miles above Oso, will have to be removed.”
- **1932**: The Stillaguamish River begins cutting a new channel undercutting the hill on which the slide occurred.
- **1937**: Aerial photos show slide activity
- **1951**: A mudflow partially dams the Stillaguamish.
- **1955**: The landslide area has expanded from 10-13 acres and a noticeable scarp has formed.
- **1965**: The landslide zone has now expanded from 13-21 acres and remains active.
- **1967**: A landslide occurs damming the river and flooding 48 lots in Steelhead Haven. A woman comments in the Seattle Times, “There have been little slides going on here for years, but nothing too serious before that I know of. They’ve always called it Slide Hill.”
- **1969**: State geologist visits the site and sees a 150-foot scarp and a mudflow hundreds of feet long. Geologist writes, “This slide has shown that major construction below any of these old scarps should be done with extreme caution.”
- **1984**: Slow moving mudflow on eastern portion of slide zone.
- **1988**: Nov. 24 a slide from within the 1967 scar pushes mud and trees into the Stillaguamish. A DNR memo states: “Continued surface and deep-seated adjustments of the material within the 1967 scar are virtual certainties.”
- **1996**: Another slide dams part of the river.
- **1999**: US Army Corp of Engineers report states, “potential for a large catastrophic failure.” The engineer recommends moving the river to the south to keep it from eroding the hill base.
- **2006**: Another slide with a 900-foot width blocks the river and creates flooding that threatens homes.
- A series of e-mails from emergency managers who acknowledge the risk but are unwilling to make predictions and presumably recommendations.
- **2009**: A hazard mitigation plan is prepared for Snohomish County to comply with federal law. It identifies the hill as a landslide hazard zone.

CHAPTER 14.
LANDSLIDES AND OTHER MASS MOVEMENTS

14.1 GENERAL BACKGROUND

A landslide is a mass of rock, earth or debris moving down a slope. Landslides may be minor or very large, and can move at slow to very high speeds. They can be initiated by storms, earthquakes, fires, volcanic eruptions, and by human modification of the land.

DEFINITIONS

Landslide—The sliding movement of masses of loosened rock and soil down a hillside or slope. Slope failures occur when the strength of the soils forming the slope is exceeded by the pressure, such as weight or saturation, acting upon them.

Mass Movement—A collective term for landslides, debris flows, falls and sinkholes.

Mudslide (or Mudflow or Debris Flow)—A river of rock, earth, organic matter and other materials saturated with water.

Sinkhole—A collapse depression in the ground with no visible outlet. Its drainage is subterranean. It is commonly vertical-sided or funnel-shaped.

Mudslides or mudflows (or debris flows) are rivers of rock, earth, organic matter and other soil materials saturated with water. They develop in the soil overlying bedrock on sloping surfaces when water rapidly accumulates in the ground, such as during heavy rainfall or rapid snowmelt. Water pressure in the pore spaces of the material increases to the point that the internal strength of the soil is drastically weakened. The soil’s reduced resistance can then easily be overcome by gravity, changing the earth into a flowing river of mud or “slurry.” A debris flow or mudflow can move rapidly down slopes or through channels, and can strike with little or no warning at avalanche speeds. The slurry can travel miles from its source, growing as it descends, picking up trees, boulders, cars and anything else in its path. Although these slides behave as fluids, they pack many times the hydraulic force of water due to the mass of material included in them. Locally, they can be some of the most destructive events in nature.

A sinkhole is a collapse depression in the ground with no visible outlet. Its drainage is subterranean, and it is commonly vertical-sided or funnel-shaped.

All these mass movements are caused by a combination of geological and climate conditions. These include steep topography, as well as the encroaching influence of urbanization. The cool, rainy Pacific Northwest climate ensures that soil moisture levels remain high throughout most of the year, and in fact are often at or near saturation during wet winter months. The geological conditions of western Washington are primarily a legacy of repeated episodes of glacial advance and retreat during the past 2 million years, and one of the most active erosive processes in the 13,000 years since the last ice disappeared has been mass wasting—the action of landslides and mudslides. These vulnerable natural conditions are being steadily affected by human residential, agricultural, commercial and industrial development and the infrastructure that supports it.

14.2 HAZARD PROFILE

Landslides are caused by one or a combination of the following factors: change in slope of the terrain, increased load on the land, shocks and vibrations, change in water content, groundwater movement, frost action, weathering of rocks, and removing or changing the type of vegetation covering slopes. In general, landslide hazard areas are where the land has characteristics that contribute to the risk of the downhill movement of material, such as the following:

- A slope greater than 33 percent
- A history of landslide activity or movement during the last 10,000 years
- Stream or wave activity, which has caused erosion, undercut a bank or cut into a bank to cause the surrounding land to be unstable
- The presence or potential for snow avalanches
- The presence of an alluvial fan, indicating vulnerability to the flow of debris or sediments
- The presence of impermeable soils, such as silt or clay, which are mixed with granular soils such as sand and gravel.

Flows and slides are commonly categorized by the form of initial ground failure, but they may travel in a variety of forms along their paths. Figures 14-1, 14-2, 14-3 and 14-4 show common types of slides in the Puget Sound region and in Snohomish County. The most common is the shallow colluvial slide, occurring particularly in response to intense, short-duration storms. The largest and most destructive are deep-seated slides, although they are less common than other types. Puget Sound's shoreline contains many large, deep-seated dormant landslides. Occasionally large catastrophic slides occur on Puget Sound.

The preponderance of landslides occurs in January after the water table has risen during the wet months of November and December. In addition to the coastal bluffs, land sliding is most prevalent around the slopes of the Puget Sound's steep, linear hills. Water is involved in nearly all cases; and human influence has been identified in more than 80 percent of reported slides.

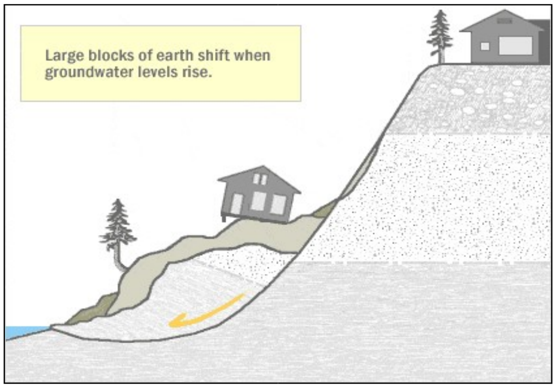


Figure 14-1. Deep Seated Slide

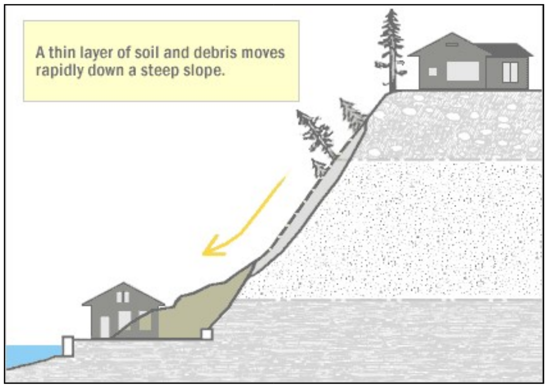


Figure 14-2. Shallow Colluvial Slide

Alt Text for Figure 14-1. Deep Seated Slide
Graphic of a house in a deep seated slide labeled--Large blocks of earth shift when groundwater levels rise.

Alt Text for Figure 14-2. Shallow Colluvial Slide
Graphic of a house in a shallow colluvial slide labeled--A thick layer of soil and debris moves rapidly down a steep slope.

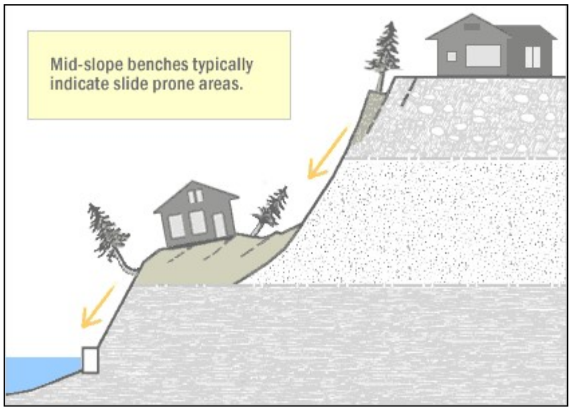


Figure 14-3. Bench Slide

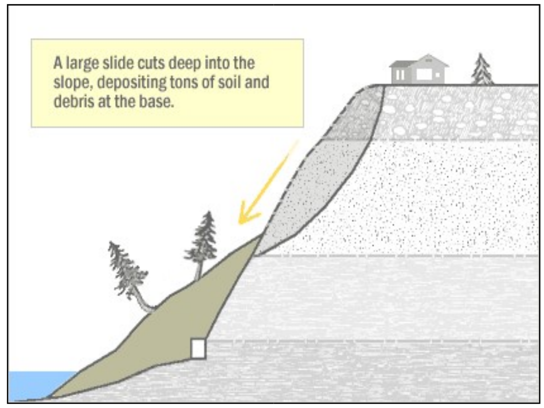


Figure 14-4. Large Slide

Alt Text for Figure 14-3. Bench Slide
Graphic of a house in a bench slide labeled--Mid-slope benches typically indicate slide prone areas.

Alt Text for Figure 14-4. Large Slide
Graphic of a house in a large slide labeled--A large slide cuts deep into the slope, depositing tons of soil and debris at the base.

14.2.1 PAST EVENTS

There is little recorded information for Snohomish County regarding landslides. During the winter storm of 1996-97, more than half of the County’s $60-70 million in reported damage occurred as a result of landslides, mudslides and debris flows. Drainage systems and catchment basins could not handle the volume of runoff, focusing the water’s energy against vulnerable slopes and man-made structures. In some cases, saturated soils simply became overloaded with the weight of snow and rainwater and collapsed. Private homeowners, particularly in areas where natural drainage has been paved, diverted or otherwise modified by man, reported significant damage. Landslide and mudslide/debris flow activity during this storm caused widespread disruption of surface transportation, closing roads and in one case derailing mail cars from a freight train. The costs of repairing road damage totaled tens of millions of dollars. Given the volume of hazardous substances shipped by road and rail through Snohomish County, it was fortunate that no serious chemical spills occurred as a result of these incidents.

A large slide occurred in Woodway, just north of the Richmond Beach neighborhood, during the early morning of January 15, 1997. It cut 50 feet into the property above, passed over the railroad tracks and knocked a freight train into Puget Sound (see Figure 14-5). Initial estimates placed the volume of the slide at 200,000 to 260,000 cubic yard, but later estimates based on additional data ranged from 100,000 to 200,000 cubic yards. The head of the slide is downslope from the Rosary Heights Convent. The bluff here is about 250 feet high, and the head scarp appears to be about 350 feet wide. The slide deposit extended from the base of the scarp across railroad tracks and into Puget Sound. Except for a large, partially intact slide block resting at the base of the scarp, the deposit consisted mostly of remolded sand and silt, containing logs and boulder-sized, joint-bounded blocks of intact Lawton clay. The remolding indicates that much of the slide broke apart and mobilized into a debris flow.

There are no records in the County of fatalities attributed to mass movement. However, across the Pacific Northwest, a number of deaths have occurred as a result of slides, slope collapses and sinkholes.

Figure 14-5. 1997 Woodway Slide

14.2.2 LOCATION

Map 14-1 shows the landslide hazard areas in Snohomish County. The basis of the mapping is as follows:

- Any area with a combination of:
  - Slopes greater than 33 percent
  - Impermeable soils (typically silt and clay) frequently interbedded with granular soils (predominantly sand and gravel)
  - Springs or groundwater seepage
- Any area that has shown movement during the Holocene epoch (from 12,000 years ago to present), or that is underlain by mass wastage debris of that epoch
- Any area potentially unstable as a result of rapid stream incision, stream bank erosion or undercutting by wave action
- Any area that shows evidence of, or is at risk from, snow avalanches
- Any area located on an alluvial fan, presently subject to or potentially subject to inundation by debris flows or deposition of stream-transported deposits.

The recognition of ancient dormant mass movement sites is important in the identification of areas susceptible to flows and slides because they can be reactivated by earthquakes or by exceptionally wet weather. Also, because they consist of broken materials and frequently involve disruption of groundwater flow, these dormant sites are vulnerable to construction-triggered sliding.

14.2.3 FREQUENCY

Landslides are often triggered by other natural hazards such as earthquakes, heavy rain, floods or wildland fires, so landslide frequency is related to the frequency of these other hazards. In Snohomish County, landslides typically occur during and after major storms.

Recent events occurred during the winter storm of 1996-97 and the October 2003 storm, which generated a few landslides, but not as many as expected, since the soil and bedrock in hilly areas were relatively dry. Recent events also occurred during the winter storms of 2006, 2007 and 2009.

14.2.4 SEVERITY

Landslides destroy property and infrastructure and can take the lives of people. Slope failures in the United States result in an average of 25 lives lost per year and an annual cost to society of about $1.5 billion. The 1996-97 storm caused about $30 million to $35 million in damage due to landslides, mudslides and debris flows. This was about half of all damage caused by the storm. The landslides caused by the storm also caused tens of millions of dollars of damage to road infrastructure.

14.2.5 WARNING TIME

Mass movements can occur suddenly or slowly. The velocity of movement may range from a slow creep of inches per year to many feet per second, depending on slope angle, material and water content. Some methods used to monitor mass movements can provide an idea of the type of movement and the amount of time prior to failure. It is also possible to determine what areas are at risk during general time periods. Assessing the geology, vegetation, and amount of predicted precipitation for an area can help in these predictions. However, there is no practical warning system for individual landslides. The current standard operating procedure is to monitor situations on a case-by-case basis, and respond after the event has occurred. Generally accepted warning signs for landslide activity include:

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavements or sidewalks
- Soil moving away from foundations
- Ancillary structures such as decks and patios tilting and/or moving relative to the main house
- Tilting or cracking of concrete floors and foundations
- Broken water lines and other underground utilities
- Leaning telephone poles, trees, retaining walls or fences
- Offset fence lines
- Sunken or down-dropped road beds
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content)
- Sudden decrease in creek water levels though rain is still falling or just recently stopped
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb
- A faint rumbling sound that increases in volume as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together.

14.3 SECONDARY HAZARDS

Landslides can cause several types of secondary effects, such as blocking access to roads, which can isolate residents and businesses and delay commercial, public and private transportation. This could result in economic losses for businesses. Other potential problems resulting from landslides are power and communication failures. Vegetation or poles on slopes can be knocked over, resulting in possible losses to power and communication lines. Landslides also have the potential of destabilizing the foundation of structures, which may result in monetary loss for residents. They also can damage rivers or streams, potentially harming water quality, fisheries and spawning habitat.

14.4 CLIMATE CHANGE IMPACTS

Climate change will impact storm patterns in Washington. This changing of the hydrograph means that the probability of more frequent, intense storms with varying duration will increase. Increase in global temperature will also affect the snowpack and its ability to hold and store water. Warming temperatures will increase the occurrence and duration of droughts, which will increase the probability of wildland fire, which impacts the vegetation that helps to support steep slopes. All of these factors working in unison would increase the probability for landslide occurrences within the planning area.

14.5 EXPOSURE

14.5.1 Population

Population could not be examined by landslide hazard area because census block group areas do not coincide with the risk areas. A population estimate was made using the structure count of buildings within the landslide hazard areas and applying the census value of 2.65 persons per household for Snohomish County. Using this approach, the estimated county population living in landslide risk areas is 13,642. This approach could understate the exposure by as much as a factor of two, so it is reasonable to assume that the exposed population may be as high as 30,000, roughly 5 percent of the total county population.

14.5.2 Property

Table 14-1 shows the number and assessed value of Snohomish County structures exposed to steep slopes. There are 4,669 structures on parcels exposed to steep slopes, worth an estimated $2.075 billion. Ninety-five percent of the exposed structures are dwellings.

Table 14-2 shows the general land use of parcels exposed to landslides. Lands used for forestry or parks are less vulnerable, while lands used for manufactured homes are highly vulnerable. The predominant land uses for parcels in cities are single-family, vacant and manufactured homes. These uses as well as timber are the predominant land uses for exposed parcels in unincorporated Snohomish County.

TABLE 14-1.
SNOHOMISH COUNTY STRUCTURES EXPOSED TO STEEP SLOPES

Jurisdiction	Buildings Exposed	Assessed Value Structure	Assessed Value Contents	Assessed Value Total	% of AV
Arlington	49	$10,347,000	$9,237,390	$19,584,390	0.9%
Bothell	175	$32,377,900	$22,670,740	$55,048,640	1.9%
Brier	45	$7,032,900	$4,953,420	$11,986,320	1.8%
Darrington	5	$980,700	$979,450	$1,960,150	1.4%
Edmonds	308	$75,028,000	$52,894,210	$127,922,210	1.9%
Everett	467	$208,200,800	$202,950,500	$411,151,300	2.6%
Gold Bar	2	$179,800	$156,130	$335,930	0.2%
Granite Falls	14	$1,570,400	$1,099,280	$2,669,680	0.7%
Index	2	$205,400	$143,780	$349,180	1.5%
Lake Stevens	51	$13,131,900	$9,443,860	$22,575,760	1.4%
Lynnwood	43	$8,192,300	$5,931,830	$14,124,130	0.3%
Marysville	86	$13,778,900	$9,670,700	$23,449,600	0.6%
Mill Creek	10	$22,048,900	$15,434,230	$37,483,130	1.2%
Monroe	37	$9,978,300	$7,053,360	$17,031,660	0.75%
Mountlake Terrace	192	$72,465,600	$50,784,000	$123,249,600	5.7%
Mukilteo	421	$107,087,800	$76,328,490	$183,416,290	4.6%
Snohomish	62	$18,614,200	$15,992,980	$34,607,180	2.8%
Stanwood	7	$667,100	$470,720	$1,137,820	0.1%
Sultan	6	$738,000	$516,600	$1,254,600	0.3%
Woodway	11	$8,004,800	$5,729,760	$13,734,560	3.8
Unincorporated	2676	$551,288,650	$410,932,140	$972,220,790	2.52%
County Total	**4669**	**$1,161,919,350**	**$903,373,570**	**$2,075,292,920**	**2.1%**

TABLE 14-2.
GENERAL LAND USE OF PARCELS EXPOSED TO LANDSLIDES

General Land Use	Cities	Unincorporated Snohomish County
Agriculture	35	418
Civic/Government	9	2
Fishery	0	5
Forest	10	238
Hotel/Motel	3	0
Industrial/Manufacturing	17	7
Manufactured/Mobile Home	505	1,162
Marine Terminals/Marinas	0	2
Medical/Health	7	0
Mining	13	185
Multi-Family	22	4
Multi-Plex Housing	44	39
Non-Residential Structure	23	161
Open Space	76	162
Other Housing/Group Quarters	1	5
Park/Playground	57	28
Parking	10	0
Recreation/Entertainment	10	33
Reference Account	0	1
Resource Production/Extraction	0	1
Religious	3	6
Retail/Service	115	17
Retirement Home/Orphanage	1	0
Roads	11	31
School/Daycare	13	1
Single Family	4,112	4,904
Timber	26	1,150
Transportation	21	61
Utility	30	48
Vacant	951	4,834
Warehouse	10	1
Water	13	20
Wood Products	1	1
Total	**6,149**	**13,527**

14.5.3 Critical Facilities and Infrastructure

Table 14-3 summarizes the critical facilities exposed to the landslide hazard. No loss estimation of these facilities was performed due to the lack of established damage functions for the landslide hazard. A significant amount of infrastructure (roads, bridges, railroads, and utilities) can be exposed to mass movements. Landslides can block egress and ingress on roads, causing isolation for neighborhoods. Roadway blockages caused by landslides can also create traffic problems, resulting in delays for both public and private transportation. This could result in economic losses for businesses. Other potential problems resulting from landslides are power and communication failures, creating problems for vulnerable populations as well as businesses.

TABLE 14-3.
CRITICAL FACILITIES EXPOSED TO LANDSLIDE HAZARDS

Critical Facilities	Hazards
Medical and Health Services	1
Government Function	0
Protective Function	0
Schools	0
Hazmat	0
Other Critical Function	0
Bridges	32
Water	1
Waste Water	2
Communications	0
Total	36

Railroads

The BNSF Railway corridor is exposed to landslides along much of its north-south and east-west routes and spurs. These areas include the tracks located along the Puget Sound bluffs from the King County line up to Everett. The Boeing Spur is located in a ravine and is extremely vulnerable. Other areas exposed to landslides include the bluffs north of Stanwood, the Bothell-Snohomish Branch and tracks located in the Cascade Mountains east of Gold Bar leading to Steven’s Pass.

Roads

Many of the major roads in Snohomish County are exposed to mass movement hazards. Access to major roads is crucial to life-safety after a disaster event and to response and recovery operations.

Bridges

Landslides can significantly impact road bridges. Mass movements can knock out bridge abutments or significantly weaken the soil supporting them, making them hazardous for use. Using Washington State bridge data, GIS analysis shows that there are 64 bridges that pass through or over landslide prone slopes.

Power Lines

Power lines are generally elevated above steep slopes; but the towers supporting them can be subject to landslides. A landslide could trigger failure of the soil underneath a tower, causing it to collapse and ripping down the lines. Puget Sound Energy lines pass through steep slope areas.

14.5.4 Environment
Environmental problems as a result of mass movements can be numerous. Landslides that fall into streams may significantly impact fish and wildlife habitat, as well as affecting water quality.

14.6 VULNERABILITY

14.6.1 Population
Due to the nature of census block group data, it is difficult to determine demographics of populations vulnerable to mass movements. In general, all of the estimated 13,642 persons that are exposed to landslides hazards (1.9 percent of total county population) are also vulnerable. Due to Snohomish County's increasing population density and the fact that many man-made structures are built on "view property" atop or below bluffs and on steep slopes subject to mass movement, more lives are now endangered by this hazard than ever before.

14.6.2 Property
A study completed for Seattle Public Utilities in 2000 showed that only about 1 percent of the land area of the region is actually vulnerable to landslides or other mass movements. This study also showed that 84 percent of the slides recorded had human related causes, indicating that people ignore signs of potential disaster in order to possess the most desirable land. Consequently, there is greater potential for damage or destruction to private and public property than if stringent landslide policies were adopted.

Although complete historical documentation of the mass movement threat in Snohomish County is lacking, the effects of slide and flow activity seen during the winter storms of 1996-97 suggest a significant vulnerability to such hazards. Countywide, the millions of dollars in damage attributable to mass movement during those storms affected private property and public infrastructure and facilities.

Loss estimations for the landslide hazard are not based on modeling utilizing damage functions, because no such damage functions have been generated. Instead, loss estimates were developed representing 10 percent, 30 percent and 50 percent of the assessed value of exposed structures. This allows emergency managers to select a range of economic impact based on an estimate of the percent of damage to the general building stock. Damage in excess of 50 percent is considered to be substantial by most building codes and typically requires total reconstruction of the structure. Table 14-4 shows the general building stock loss estimates in steep slope areas.

14.6.3 Critical Facilities and Infrastructure

Thirty-six critical facilities are exposed to the landslide hazard. A more in-depth analysis of the mitigation measures taken by these facilities to prevent damage from mass movements should be done to determine if they could withstand impacts of a mass movement.

Several types of infrastructure are exposed to mass movements, including transportation, water and sewer and power infrastructure. Highly susceptible areas of the county include the mountain and coastal roads and transportation infrastructure. At this time all infrastructure and transportation corridors identified as exposed to the landslide hazard are considered vulnerable until more information becomes available.

14.6.4 Environment

The environment vulnerable to landslide hazard is the same as the environment exposed to the hazard.

TABLE 14-4.
ESTIMATED BUILDING LOSSES DUE TO LANDSLIDE HAZARD

Jurisdiction	Building Count	Assessed Value	10% Damage	30% Damage	50% Damage
Arlington	49	$19,584,390	$1,958,439	$5,875,317	$9,792,195
Bothell	175	$55,048,640	$5,504,864	$16,514,592	$27,524,320
Brier	45	$11,986,320	$1,198,632	$3,595,896	$5,993,160
Darrington	5	$1,960,150	$196,015	$588,045	$980,075
Edmonds	308	$127,922,210	$12,792,221	$38,376,663	$63,961,105
Everett	467	$411,151,300	$41,115,130	$123,345,390	$205,575,650
Gold Bar	2	$335,930	$33,593	$100,779	$167,965
Granite Falls	14	$2,669,680	$266,968	$800,904	$1,334,840
Index	2	$349,180	$34,918	$104,754	$174,590
Lake Stevens	51	$22,575,760	$2,257,576	$6,772,728	$11,287,880
Lynnwood	43	$14,124,130	$1,412,413	$4,237,239	$7,062,065
Marysville	86	$23,449,600	$2,344,960	$7,034,880	$11,724,800
Mill Creek	10	$37,483,130	$3,748,313	$11,244,939	$18,741,565
Monroe	37	$17,031,660	$1,703,166	$5,109,498	$8,515,830
Mountlake Terrace	192	$123,249,600	$12,324,960	$36,974,880	$61,624,800
Mukilteo	421	$183,416,290	$18,341,629	$55,024,887	$91,708,145
Snohomish	62	$34,607,180	$3,460,718	$10,382,154	$17,303,590

Jurisdiction	Building Count	Assessed Value	10% Damage	30% Damage	50% Damage
Stanwood	7	$1,137,820	$113,782	$341,346	$568,910
Sultan	6	$1,254,600	$125,460	$376,380	$627,300
Woodway	11	$13,734,560	$1,373,456	$4,120,368	$6,867,280
Unincorporated	2676	$551,288,650	$55,128,865	$165,386,595	$275,644,325
County					
Total	**4669**	**$1,654,360,780**	**$165,436,078**	**$496,308,234**	**$827,180,390**

14.7 FUTURE TRENDS IN DEVELOPMENT

Landslide hazard areas are included in the “geologically hazardous areas,” one category of critical areas regulated under the state GMA for Snohomish County. They are defined as follows:

> “Landslide hazard areas” means areas potentially subject to mass earth movement based on a combination of geologic, topographic, and hydrologic factors, with a vertical height of 10 feet or more. These include the following:
>
> – Areas of historical landslides as evidenced by landslide deposits, avalanche tracks, and areas susceptible to basal undercutting by streams, rivers or waves
>
> – Areas with slopes steeper than 15 percent that intersect geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock, and which contain springs or ground water seeps
>
> – Areas located in a canyon or an active alluvial fan, susceptible to inundation by debris flows or catastrophic flooding.

Snohomish County’s 2007 buildable lands report excludes critical areas from consideration as buildable lands due to the scope of regulations affecting them. Based on the findings of this report, Snohomish County and its planning partners appear to be well equipped to deal with future growth and development within the planning area. The landslide hazard portions of the planning area are regulated by County Code (Title 30.62B) as well as by the International Building Code. Development will occur in landslide hazards within the planning area, but it will be regulated such that the degree of risk will be reduced through building standards and performance measures.

14.8 SCENARIO

Major mass movements in Snohomish County occur as a result of soil conditions that have been affected by severe storms, groundwater or human development. The worst-case scenario for mass movement hazards in Snohomish County would generally correspond with a severe storm that had heavy rain and caused flooding. Mass movement is most likely to occur during late winter when the water table is high. A short intense storm could cause saturated soil to move, resulting in landslides. After heavy rains from November to December, soils become saturated with water. As water seeps downward through upper soils that may consist of permeable sands and gravels and accumulates on impermeable silt, it will cause weakness and destabilization in the slope. As rains continue, the groundwater table rises, adding to the weakening of the slope. Gravity, poor drainage, a rising groundwater table and poor soil exacerbate hazardous conditions.

Based on historical events and steep slopes with a potential for instability, the most likely landslide areas are Everett, Mukilteo and Edmonds. However, mass movements can occur anywhere in the county that has been affected by historical landslides or that has steep slopes.

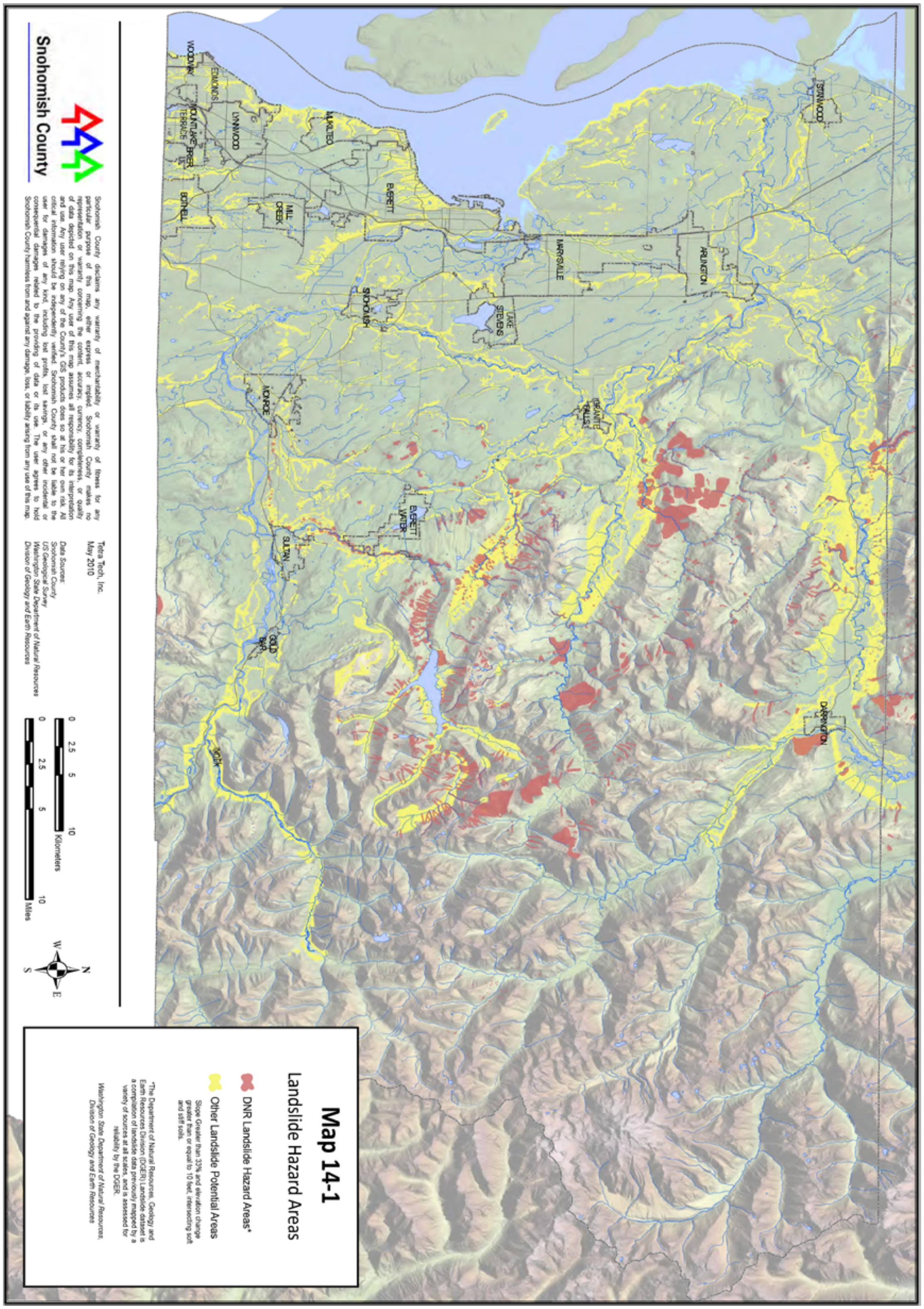
Mass movements are becoming more of a concern as development moves outside of city centers and into areas less developed in terms of infrastructure. Most mass movements would be isolated events affecting specific areas. It is probable that private and public property, including infrastructure, will be affected. Mass movements could affect bridges that pass over landslide prone ravines and knock out rail service through the county. Road obstructions caused by mass movements would create isolation problems for residents and businesses in sparsely developed areas. Property owners exposed to steep slopes may suffer damage to either property or building structures. Landslides carrying vegetation such as shrubs and trees may cause a break in utility lines, cutting off power and communication access to residents.

Continued heavy rains and flooding will complicate the problem further. As emergency response resources are applied to problems with flooding, it is possible they will be unavailable to assist with landslides occurring all over Snohomish County.

14.9 ISSUES

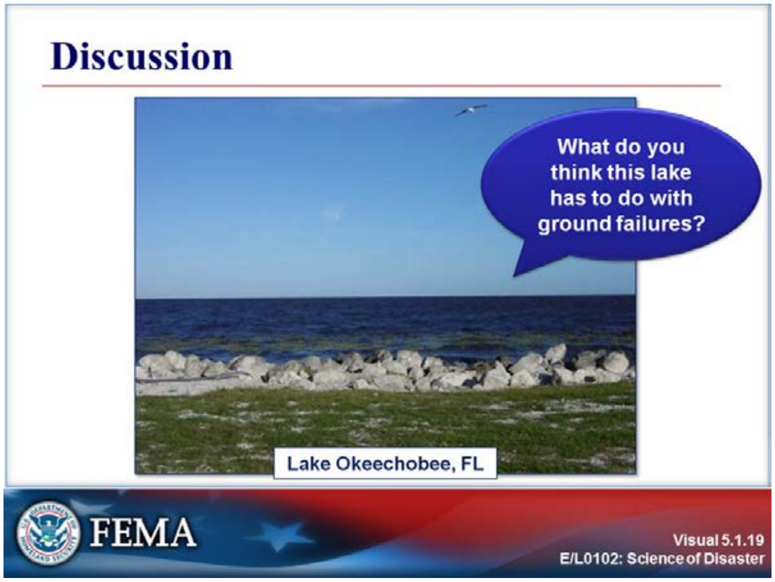
Important issues associated with landslides in Snohomish County include the following:

- There are existing homes in mass movement-prone areas, specifically on the Puget Sound shoreline, with the Cities of Everett and Mukilteo being affected significantly.
- Future development could lead to more homes in mass movement prone areas. These areas include the foothills of the Cascades, and steep slope areas above the river floodplains of the North and South Forks Stillaguamish River and the Skykomish River.
- The data and science regarding the mapping and assessment of landslide hazards is constantly evolving. As new data and science become available, assessments of landslide risk should be re-evaluated.
- The impact of climate change on landslides is uncertain. If climate change impacts atmospheric conditions, then exposure to landslide risks in Snohomish County is likely to increase.
- Landslides may cause negative environmental consequences, including water quality degradation.
- The risk associated with the landslide hazard overlaps the risk associated with other hazards such as earthquake, flood and tsunami. This provides an opportunity to seek mitigation alternatives with multiple objectives that can reduce risk for multiple hazards.


Map 14-1
Landslide Hazard Areas
DNR Landslide Hazard Areas*
Other Landslide Potential Areas
Snohomish County
Tetra Tech, Inc.
May 2010

SINKHOLE BASICS

Visual 5.1.19

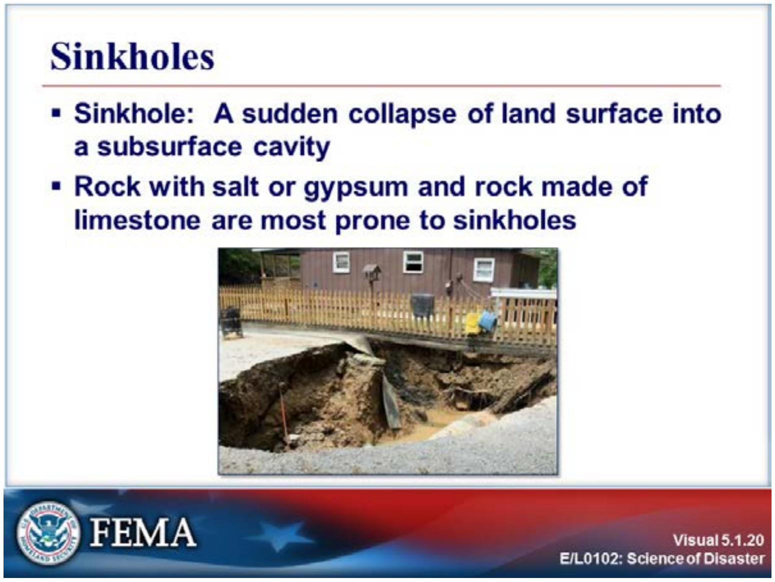


Key Points

Discussion Question: What does this lake have to do with ground failures?

SINKHOLE BASICS

Visual 5.1.20



Key Points

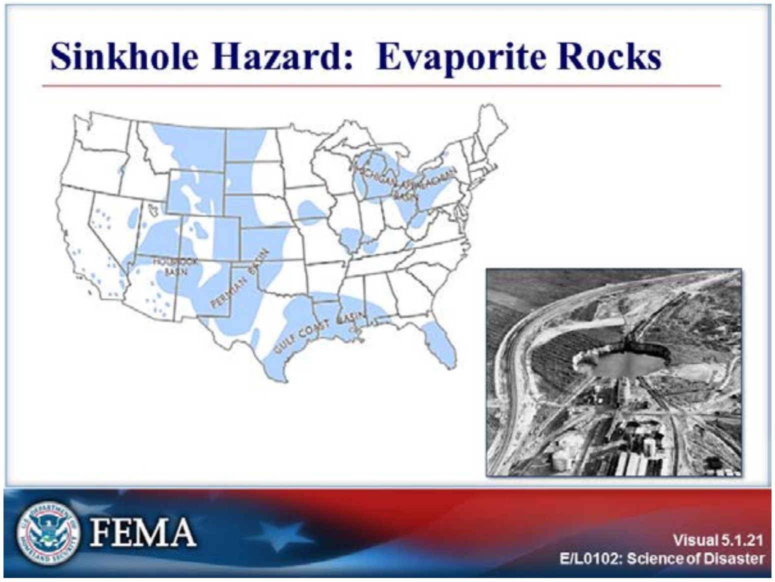
Gravity doesn't stop working when material is flat on the surface of the Earth. Sinkholes are one result of this scientific reality.

Description: A sinkhole is the sudden collapse of land surface into a subsurface cavity. Sinkholes result when the underlying bedrock dissolves away.

Susceptible rock formations: Some rocks are susceptible to dissolving in water and creating sinkholes. Rock with concentrations of salt or gypsum and rock made of limestone are most prone to sinkholes.

SINKHOLE BASICS

Visual 5.1.21



Alt Text for Visual 5.1.21
Sinkhole Hazard: Evaporite Rocks
Graphic of the US with Evaporite Rock areas highlighted
Photo of the sinkhole in Hutchinson, KS
A 300-foot diameter sinkhole with 18 feet of water in Hutchinson, Kansas. This sinkhole, attributed to operations at a salt processing company, was stabilized, and the railroad tracks through the center of the hole were relocated.

Key Points

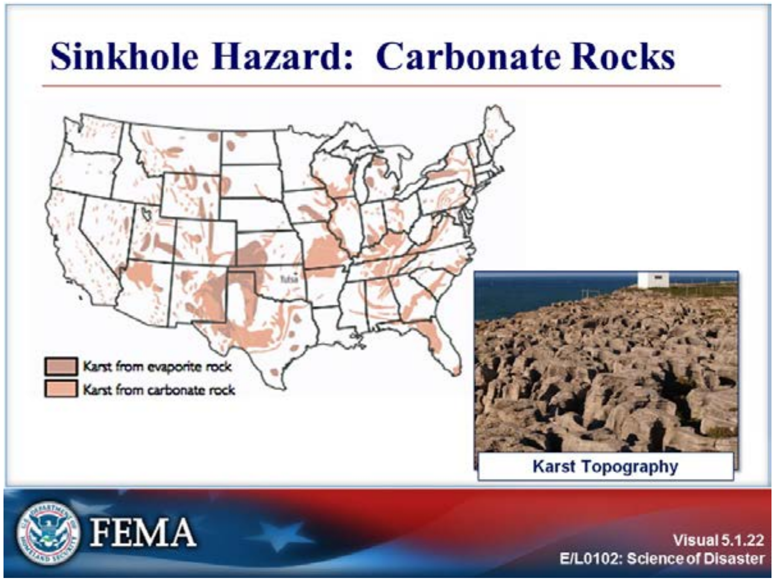
This map shows areas of the contiguous United States that are underlain by evaporite rocks, which have sufficient quantities of salt and gypsum to pose a sinkhole hazard. Hundreds of millions of years ago, these areas were inland seas. They comprise about 40 percent of the contiguous United States.

Human factors: Regardless of underlying rock type, sinkholes are increasingly common in urban areas with aging water systems. Aging and leaking water systems will also provide water that will enhance the dissolution process leading to additional sinkhole formation. When the subsurface can no longer support the surface, the surface collapses and a sinkhole is formed.

PHOTO:
A 300-foot diameter sinkhole with 18 feet of water in Hutchinson, Kansas. This sinkhole, attributed to operations at a salt processing company, was stabilized, and the railroad tracks through the center of the hole were relocated.

SINKHOLE BASICS

Visual 5.1.22



Alt Text for Visual 5.1.22
Sinkhole Hazard: Caronate Rocks
Graphic of the US with Karst from evaporite rock and Karst from carbonate rock highlighted. In the United States, under many of the pink areas shown on the map, the subsurface rocks may look very similar to what you see in this image.
Photo of Karst topography in Portugal that is above ground and clearly visible.

Key Points

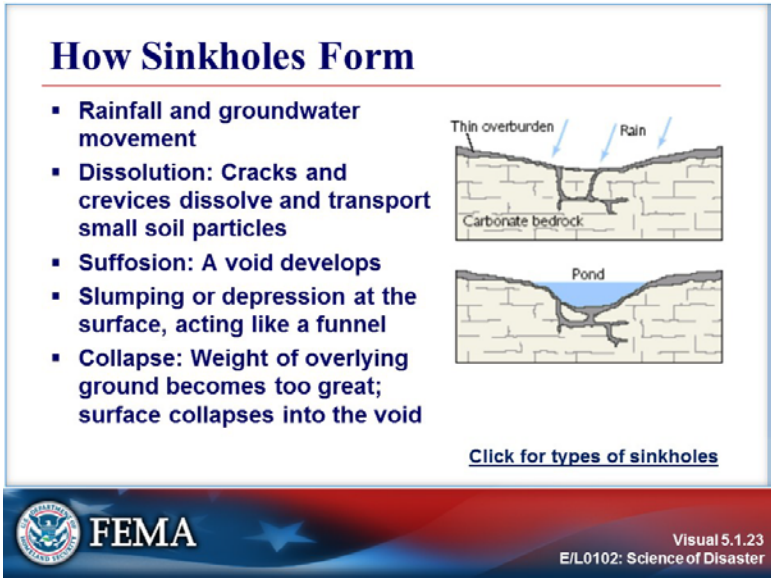
Carbonate rock (typically, limestone) dissolves readily in slightly acidic water, such as rainwater and groundwater. Carbonate bedrock in temperate and humid climates, form a distinctive terrain called Karst topography, created by the flow of water through fractures and pores in the rock. People in geographical areas with Karst topography visible on the surface should prepare for the occurrence of sinkholes.

For example, east of Tulsa, Oklahoma, about 40 percent of the United States exhibits Karst topography from carbonate rock. (These landscapes also tend to be humid, further promoting sinkhole development.)

PHOTO:
Karst topography in Portugal that is above ground and clearly visible. In the United States, under many of the pink areas shown on the map, the subsurface rocks may look very similar to what you see in this image.

SINKHOLE BASICS

Visual 5.1.23



Alt Text for Visual 5.1.23
How Sinkholes Form
- Rainfall and groundwater movement
- Dissolution: Cracks and crevices dissolve and transport small soil particles
- Suffosion: A void develops
- Slumping or depression at the surface, acting like a funnel
- Collapse: Weight of overlying ground becomes too great; surface collapses into the void

Graphic cutoff of Carbonate bedrock with thin overburden and rain falling
Graphic cutoff of Carbonate bedrock after hole has sunk and a pond has developed

Key Points

Sinkholes begin by dissolution of the bedrock, by collapse of the covering materials, and by subsidence of the cover.

The process begins with rainfall that filters through the soil and enters the underlying rock where it follows cracks and crevices in the rocks making them larger as the rock dissolves.

Soon, the cracks and crevices start transporting small soil particles, resulting in formation of a void below (suffusion) and a slumping or depression at the ground's surface.

This depression behaves like a funnel, gathering even more water and washing away more soil below.

At some point, the weight of the overlying ground becomes too great, or the dissolved area becomes too large, and the surface collapses into the void.

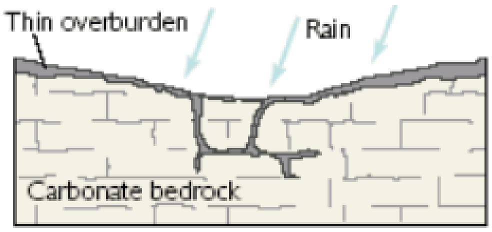
More information on the formation of three types of sinkholes is provided on the next page.

SINKHOLE BASICS

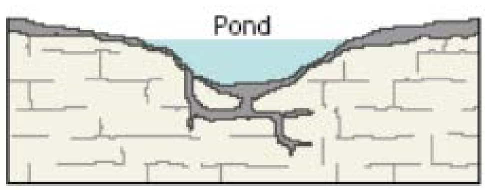
Visual 5.1.23 (Continued)

Sinkhole Formation

Dissolution Sinkholes



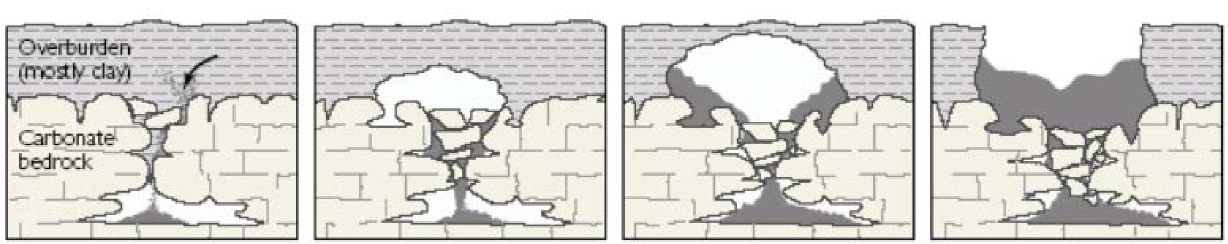
Rainfall and surface water percolate through joints in the limestone. Dissolved carbonate rock is carried away from the surface, and a small depression gradually forms.



On exposed carbonate surfaces, a depression may focus surface drainage, accelerating the dissolution process. Debris carried into the developing sinkhole may plug the outflow, ponding water and creating wetlands.

Cover-Collapse Sinkholes

Sediments spall (chip or splinter) into a cavity.	As spalling continues, the cohesive covering sediments form a structural arch.	The cavity migrates upward by progressive roof collapse.	The cavity eventually breaches the ground surface, creating sudden and dramatic sinkholes.

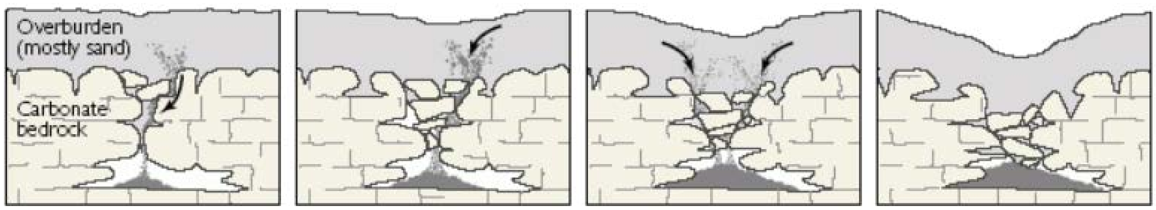


SINKHOLE BASICS

Visual 5.1.23 (Continued)

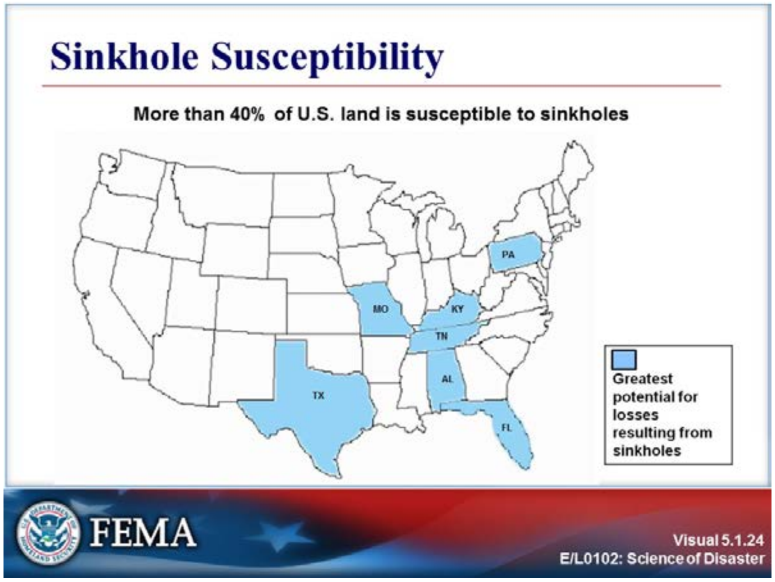
Cover-Subsidence Sinkholes

Granular sediments spall into secondary openings in the underlying carbonate rocks.	A column of overlying sediments settles into the vacated spaces ("piping").	Dissolution and infilling continue, forming a noticeable depression in the land surface.	The slow, downward erosion eventually forms small surface depressions 1 inch to several feet in depth and diameter.



SINKHOLE BASICS

Visual 5.1.24



Key Points

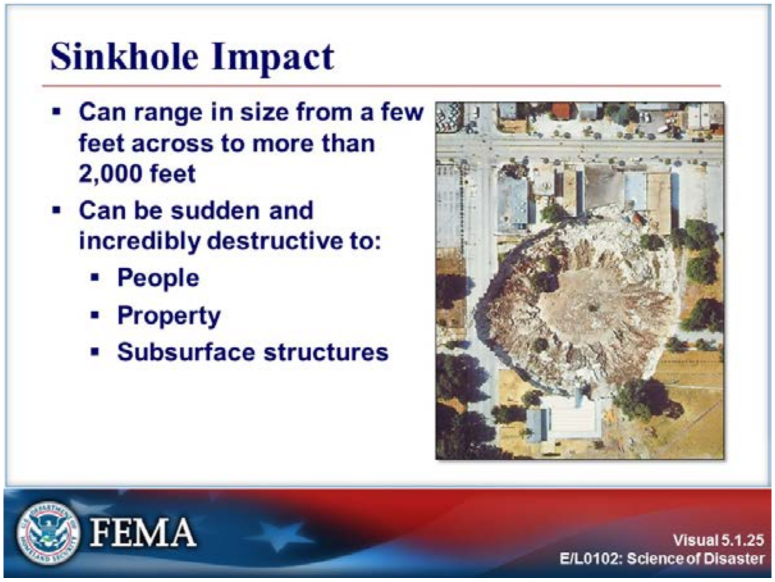
More than 40 percent of the land in the United States is susceptible to sinkholes.

As shown on the map, the greatest potential for losses resulting from sinkholes is in:

- Florida
- Texas
- Alabama
- Missouri
- Kentucky
- Tennessee
- Pennsylvania

SINKHOLE IMPACT

Visual 5.1.25



Key Points

Size and shape: Typically, sinkholes measure in feet across, or tens of feet. Sometimes (but very rarely), they can be hundreds of feet across. The largest known sinkhole is in China and is nearly 2,200 feet across.

Sinkholes also vary in shape—they can be shaped like shallow bowls, saucers, or even have vertical walls.

Impact on people and structures: Sinkholes can be catastrophically destructive to people and structures on the surface.

As an example, in March 2013, a sinkhole 30 feet wide by 30 feet deep opened up under a house near Tampa, Florida, swallowing up a bedroom and the man who was in it. Rescuers were unable to save the man.

Impact on subsurface structures: Sinkholes also pose problems for subsurface structures, such as pipelines. This hazard is important enough to the pipeline industry that it has spearheaded study to better identify specific locations at risk from sinkhole development.

PHOTO:

A sinkhole that quickly opened up in Florida, apparently eating a swimming pool, some roadway, and buildings.
(Credit: USGS)

SINKHOLE IMPACT

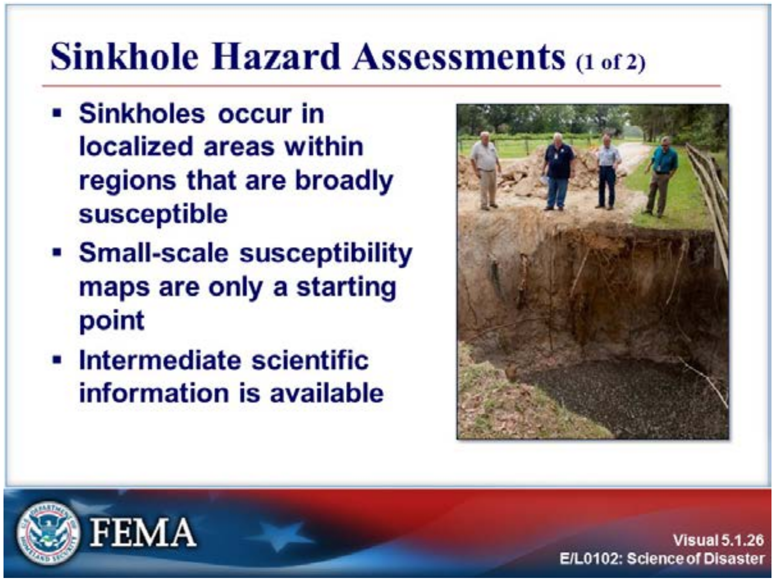
Visual 5.1.25 (Continued)

Similarly, sinkholes can cause:

- Delay of major construction projects
- Contamination of groundwater resources

SCIENCE FOR HAZARD REDUCTION

Visual 5.1.26



Alt Text for Visual 5.1.26
Sinkhole Hazard Assessments (1 of 2)

- Sinkholes occur in localized areas within regions that are broadly susceptible
- Small-scale susceptibility maps are only a starting point
- Intermediate scientific informaiton is available

Photo of workmen on the edge of a sinkhole

Key Points

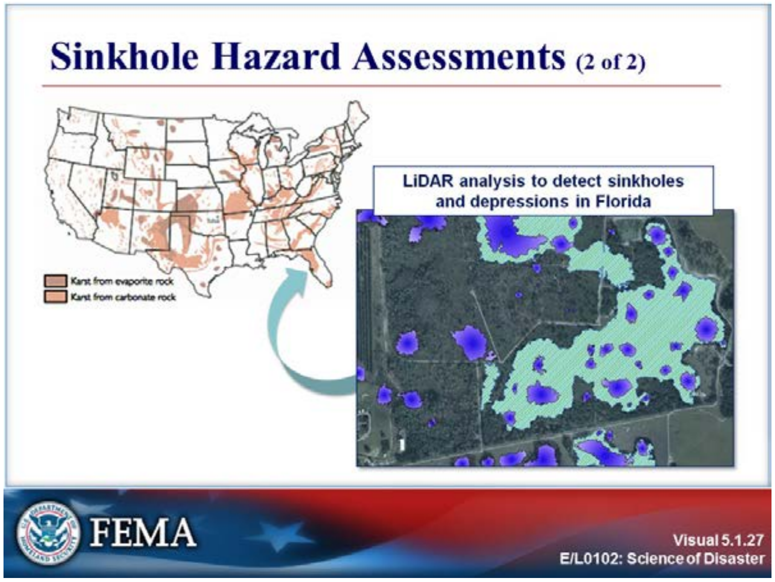
Sinkholes occur in localized areas within regions that are broadly susceptible. Small-scale maps showing the broad areas of susceptibility are only valuable as a starting point to identify areas where more detailed studies are warranted.

There are many scientific methods to get images of the subsurface, but these have not been applied to sinkhole hazard assessments. In most areas, detailed datasets about specific subsurface conditions and Karst topography evolution may never be feasible to maintain and update. (Even if that information were known, the timing of collapse could still be uncertain.)

However, there is scientific information available that is intermediate in map scale and usefulness—intermediate between information that is too broad to be useful in a particular locale and desired information that is too specific to be feasible except in very limited areas.

SCIENCE FOR HAZARD REDUCTION

Visual 5.1.27



Key Points

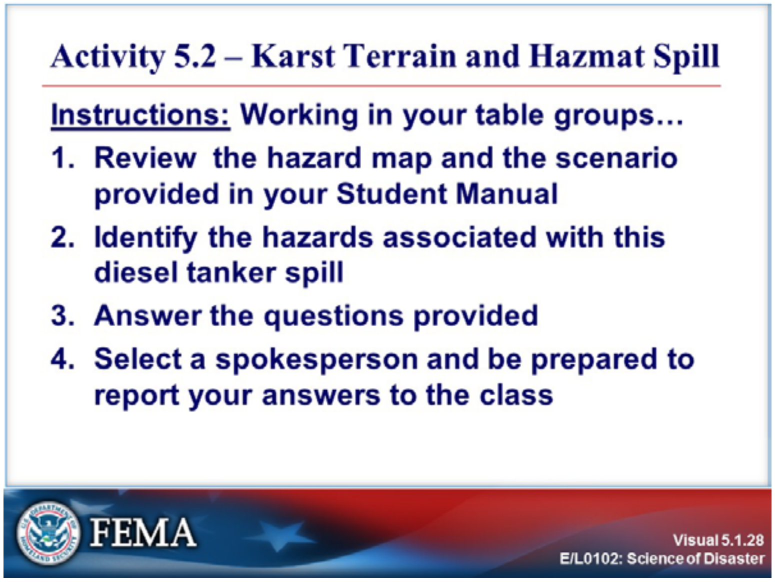
Light detection and ranging technology: Aerial photography and airborne LiDAR imaging can identify specific Karst features that may help in planning the location of critical structures. If a region is monitored over time, evolution of these Karst features may provide early warning of dangerous landscape changes.

A particularly interesting study in sinkhole hazard assessments comes from the University of South Florida. This study considers LiDAR mapping of currently visible sinkholes and depressions, as seen in the image here. It compares this with examination of aerial photos from the 1920s to identify sinkholes and depressions that have since been covered by urbanization.

Monitoring groundwater levels: In some places, it may be useful to monitor groundwater levels A 1999 study found that Florida's sinkhole development has to do with pressures at depth, where near-surface groundwater overlies a deeper groundwater reservoir.

ACTIVITY 5.2 – KARST TERRAIN AND HAZMAT SPILL

Visual 5.1.28



Key Points

Instructions: Working in your table groups…

1. Review the hazard map and the scenario provided in your Student Manual
2. Identify the hazards associated with this spill
3. Answer the questions provided
4. Select a spokesperson, and be prepared to report your answers to the class

Scenario: The map below represents a fictional neighborhood within Karst terrain. The lakes are sinkholes, and the numbers within the lakes represent the elevation above sea-level. A diesel tanker truck has overturned on the highway spilling hazardous liquid materials. The town uses groundwater for its water supply and its pumping location is labeled in the southeast corner of the map. The Pine Acres and Lake View Developments use the municipal water supply, but Fieldview Farm and Maple Dairy both use groundwater for their water needs. The average rate of groundwater movement in this region is 200 feet per hour and groundwater flows in a generally no direction.

ACTIVITY 5.2 – KARST TERRAIN AND HAZMAT SPILL

Visual 5.1.28 (Continued)

Activity 5.2 Worksheet

1) What community members would be at the greatest risk of contamination?

2) What is the risk to the municipal water supply?

3) Should the community be informed?

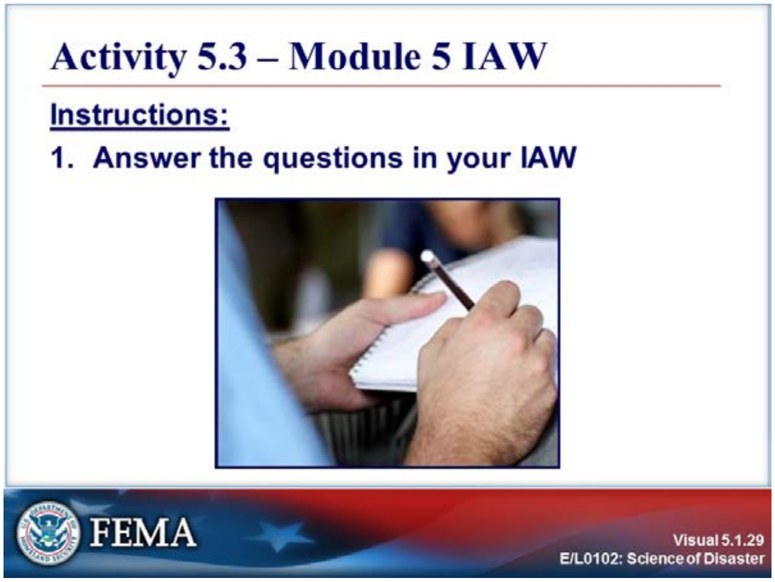
    a) If so, how?

    b) In what time frame must the community be informed?

    c) How long should warnings be maintained?

ACTIVITY 5.3 – MODULE 5 IAW

Visual 5.1.29



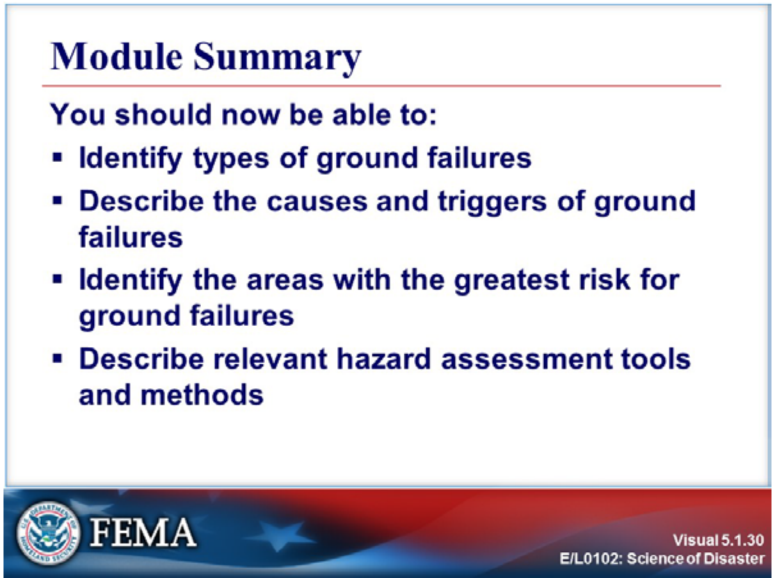
Key Points

Instructions:

1. Answer the questions in your IAW

MODULE SUMMARY

Visual 5.1.30



Key Points

Do you have any questions about the material covered in this module?

Module 6. Earthquakes and Tsunamis

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UNIT 1. EARTHQUAKES

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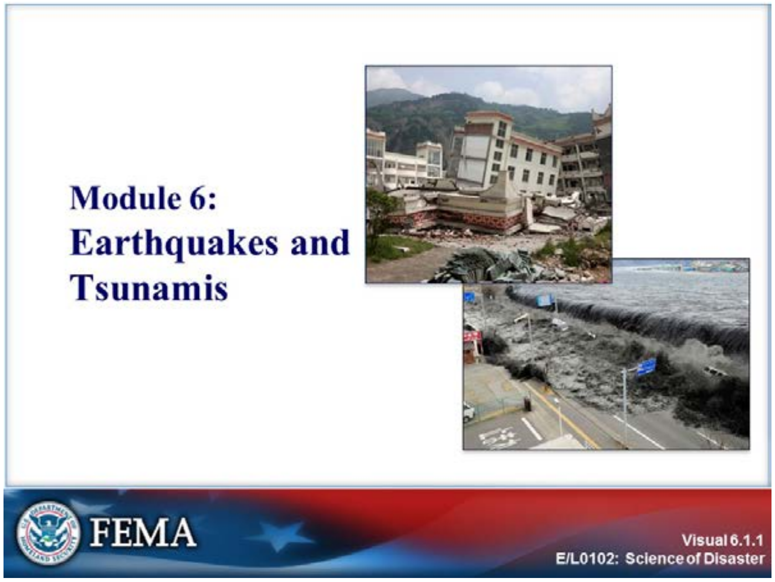
INTRODUCTION

Visual 6.1.1

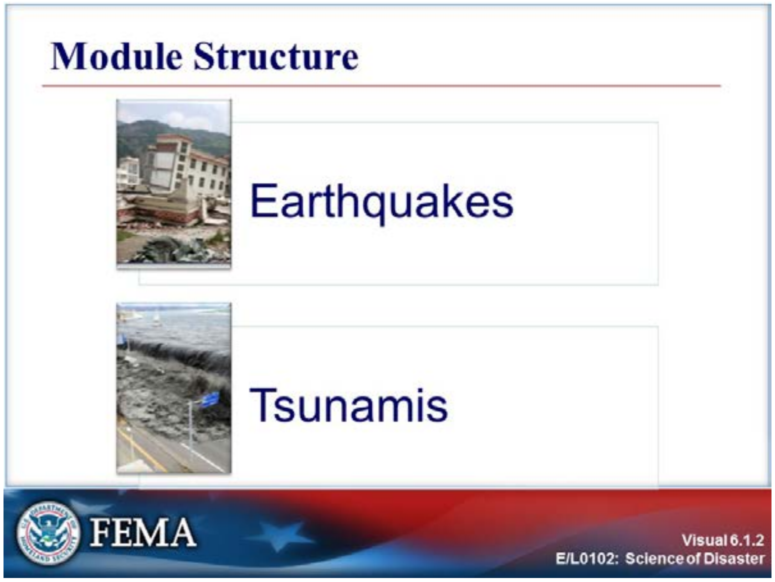


Key Points

Welcome to Module 6: Earthquakes and Tsunamis.

INTRODUCTION

Visual 6.1.2



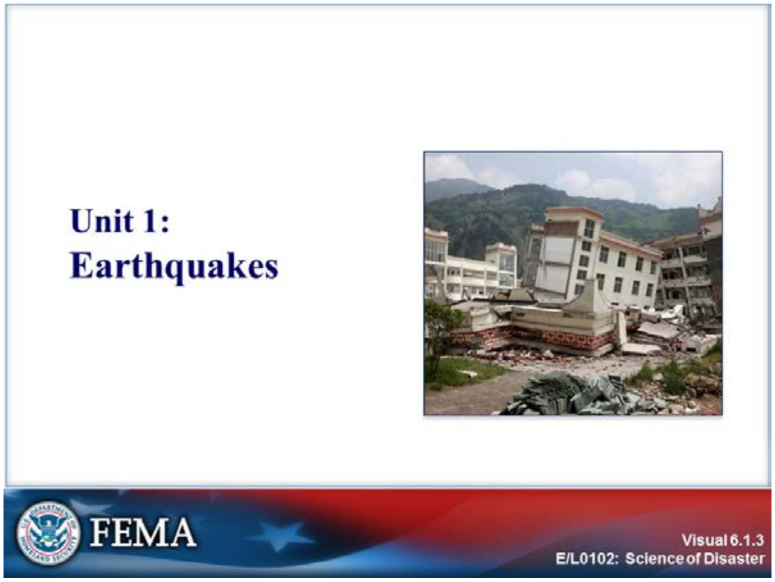
Key Points

This module consists of the following units:

Module	Time
Unit 1: Earthquakes • Activity 6.1 – Earthquake Effects (Visual 6.1.34) • Activity 6.2 – ShakeMaps (Visual 6.1.47)	2 hours 25 minutes
Unit 2: Tsunamis	30 minutes
Total Module Time:	**2 hours 55 minutes**

INTRODUCTION

Visual 6.1.3



Key Points

This unit will give you an introduction to Earthquakes.

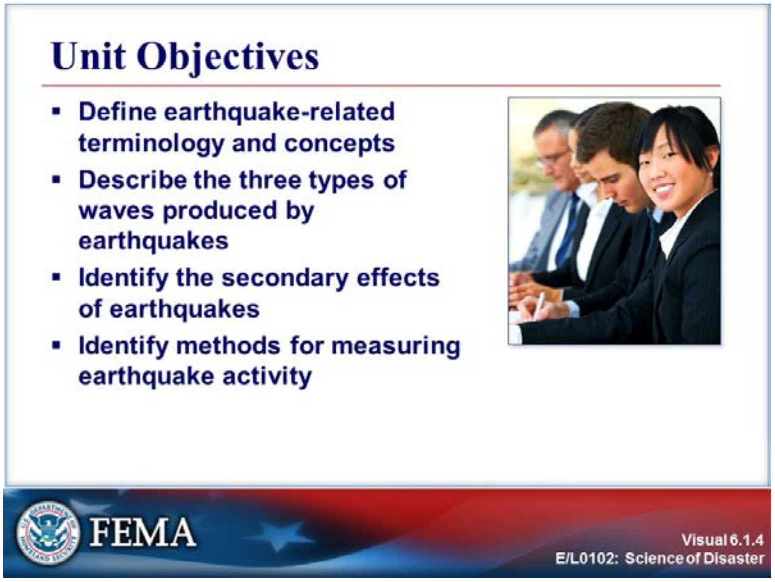
Time Plan

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Earthquake Fundamentals	40 minutes
Earthquake Occurrence and Effects Activity 6.1 – Earthquake Effects	45 minutes
Earthquake Monitoring and Forecasting Activity 6.2 – ShakeMaps	50 minutes
Unit Summary	5 minutes
Total Time	**2 hours 25 minutes**

INTRODUCTION

Visual 6.1.4

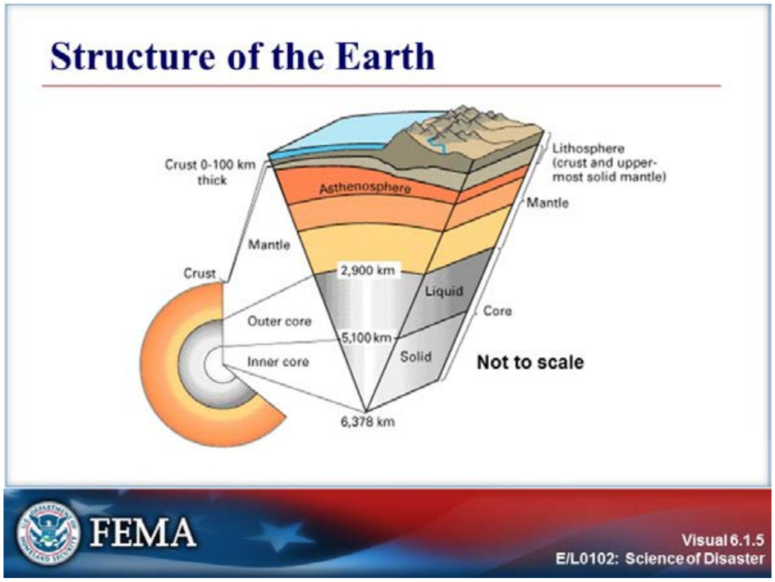


Key Points

Review the unit objectives as shown on the visual.

OVERVIEW OF THE EARTH

Visual 6.1.5



Key Points

Learning about the interior of the Earth helps us understand some of the forces that affect natural hazards.

Layers: The Earth consists of three internal layers: the core, the mantle, and the crust. This magnified cross-section of the Earth shows some of the details of those three basic layers.

Core: If you programmed your car to drive from San Diego to Nova Scotia, then drove straight down instead, you would near the center of the Earth, which is about 4,000 miles directly beneath us. The layer around the center is called the core. The inner core consists of solid iron nickel, and the outer core consists of liquid iron nickel. The flow of this extremely hot material produces the Earth's magnetic field.

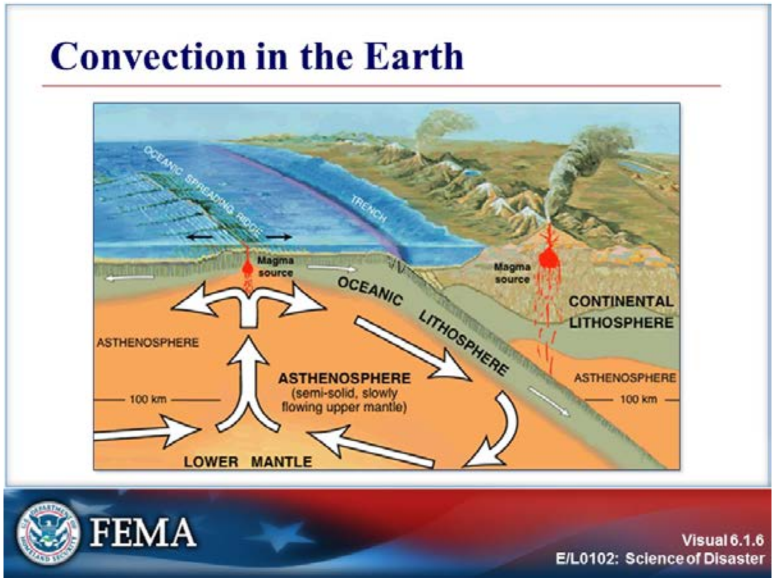
Mantle: This flow of material, called **convection,** also occurs in the next layer, the mantle (the orange section of the drawing). The mantle is the thickest of the Earth's layers. There are pockets of liquid in the mantle, but most of the mantle is solid rock.

In the mantle layer called the **asthenosphere,** this rock is under such high pressures and temperatures that it can flow even though it is a solid. Flow in the asthenosphere directly affects hazards on the surface of the Earth.

Lithosphere: The lithosphere includes the uppermost solid mantle and the crust. The crust includes oceanic crust and continental crust. All life exists on the crust of the Earth, a layer so thin that it is barely visible as a thin line when drawn to scale with the other layers of the Earth. Its height is exaggerated in this drawing in order to be visible.

OVERVIEW OF THE EARTH

Visual 6.1.6



Key Points

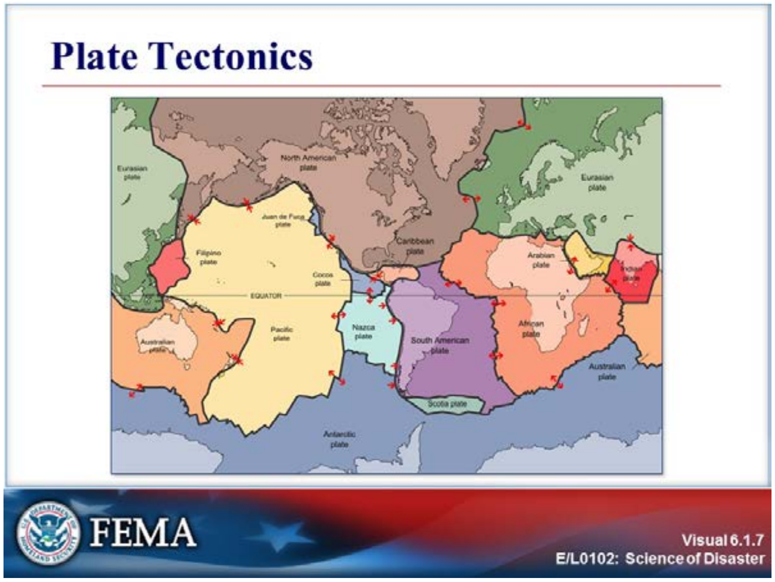
A similar process of convection within the Earth is an essential component in the creation of many of our hazards.

The heat source is a process called **radioactive decay,** in which the nucleus of an unstable atom loses energy by emitting radiation, including alpha particles, beta particles, gamma rays and conversion electrons, and release heat as they change. Thousands of miles of rock provide immense insulation, resulting in the trapping of a lot of heat inside the Earth. The hot rock deep in the mantle rises, cools, sinks—creating convection cells in the asthenosphere.

Above the asthenosphere's convection cells is a shell of cold, hard, brittle rock typically about 80 miles thick—the **lithosphere**—which includes rock of the crust and the uppermost mantle.

PLATE TECTONICS

Visual 6.1.7



The map on the visual shows the current plates and their boundaries. Most of the contiguous United States and Alaska sit on the North American Plate. Westernmost southern California is along the boundary of the Pacific plate. Hawaii lies on the Pacific Plate. The Pacific and North American Plates slide past each other at about 50 mm a year—about the rate that fingernails grow.

Key Points

Plate tectonics accounts for much of what happens at the surface of the Earth and creates natural hazards. The theory of plate tectonics states that the Earth's lithosphere is fragmented into enormous blocks of rock called **plates** that are moving relative to one another as they ride atop hotter, more mobile material.

Plate boundaries: There are three types of plate boundaries:

- Divergent boundaries—where new crust is generated as the plates pull away from each other
- Convergent boundaries—where crust is destroyed as one plate dives under another
- Transform boundaries—where crust is neither produced nor destroyed as the plates slide horizontally past each other

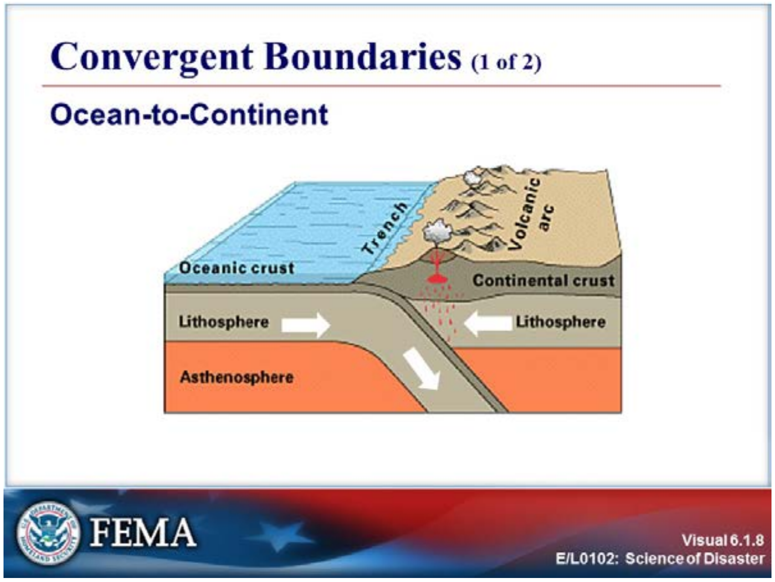
The number and sizes of plates, their directions of motion, and their styles of motion change over time, but there is no net change in size (i.e., the circumference of the Earth remains the same).

Plate locations: The map on the visual shows the current plates and their boundaries. Note:

- Most of the contiguous United States and Alaska sit on the North American Plate.
- Westernmost southern California is along the boundary of the Pacific plate. Hawaii lies on the Pacific Plate.
- The Pacific and North American Plates slide past each other at about 50 mm a year—about the rate that fingernails grow.

PLATE TECTONICS

Visual 6.1.8



Alt Text for Visual 6.1.8
Convergent Boundaries (This link can also be accessed at the following URL: https://pubs.usgs.gov/gip/dynamic/understanding.html) (1 of 2)
Ocean-to-Continent
A diagram used to show ocean-to-continent. On the left of the diagram the levels are oceanic crust, lithosphere, and asthenosphere. On the right of the diagram the levels are volcanic arc, continental crust, lithosphere and asthenosphere.

Key Points

A convergent plate boundary is a location at which two plates collide under compressional stress. This diagram shows one type of convergent plate boundary—an **ocean-to-continent** boundary. Another convergent boundary is an **ocean-to-ocean** boundary where the plates meet underneath the ocean. The kinds of rocks that underlie oceans have very different properties than the kinds of rock that make up continents, so scientists make distinctions between oceanic rock and continental rock. At a convergent boundary:

- Two plates meet and are pushed toward each other.
- As the two plates collide, if there is a big difference in density between the plates, one plate slides under the other (**subduction**), and the boundary of the two plates is marked by a trench.
- Whichever plate is denser is the one that sinks. At a continental boundary, it is always the ocean plate that subducts, because a continental plate is less dense and more buoyant. At an ocean-to-ocean boundary, the plate that is older will be denser and colder and will therefore subduct.

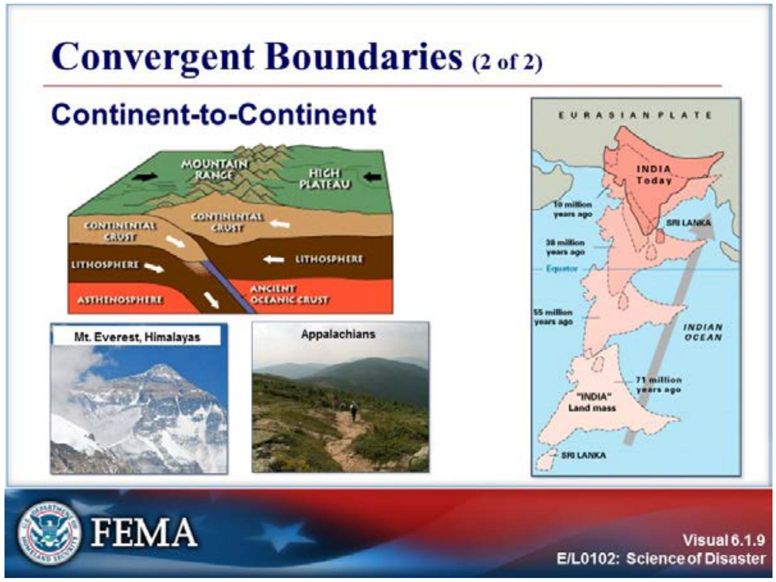
PLATE TECTONICS

Visual 6.1.8

- As the subducting plate descends into the asthenosphere, it releases water, which triggers the melting of rock, generating magma—molten rock below the Earth's surface. The magma is less dense than the surrounding rock and begins to rise toward the surface. (Recall the discussion of the convection cell.) We'll talk more about magma in a later unit.
- The rising magma creates a line of volcanic islands (if in the ocean) or a row of volcanoes embedded within a coastal mountain range (if on a continent) on the overlapping plate.
- Plate collisions produce very large earthquakes. In particular, in subduction zones, earthquakes occur in the subducting plate, the overriding plate, and in between the plates.
- Subduction zones create the largest earthquakes and the largest tsunamis on the planet.

PLATE TECTONICS

Visual 6.1.9



Alt Text for Visual 6.1.9
Convergent Boundaries (This link can also be accessed at the following URL: https://pubs.usgs.gov/gip/dynamic/understanding.html) (2 of 2) Continent-to-Continent
A diagram used to show continent-to-continent. The levels are mountain range and high plateau, continental crust, lithosphere, asthenosphere and ancient oceanic crust.
Photos of Mt. Everest, Himalayas and Appalachians
A map showing India movement from 71 million years ago until today.

Key Points

Another situation occurs when two continental plates converge. Because both plates are buoyant, neither plate subducts, and everything is pushed upward.

For example, the Himalayan Mountains are the result of India crashing into Eurasia. These mountains, along a current plate boundary, are **still growing**. Because there is no subduction, there are few (if any) volcanoes, but the region is experiencing tremendous compressional stress over a large area, leading to many earthquakes.

It can take tens of thousands of years to uplift the rock at a plate boundary, one earthquake at a time, until it is tall enough to form a mountain range. It takes even longer to wear a mountain range away.

The Appalachians, along a former plate boundary, are in the process of **weathering away**. They formed hundreds of millions of years ago, and at one time were mightier than today's Himalayas.

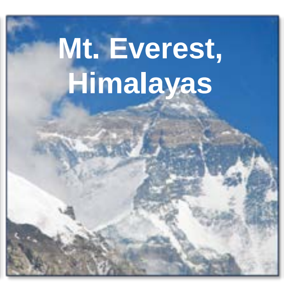
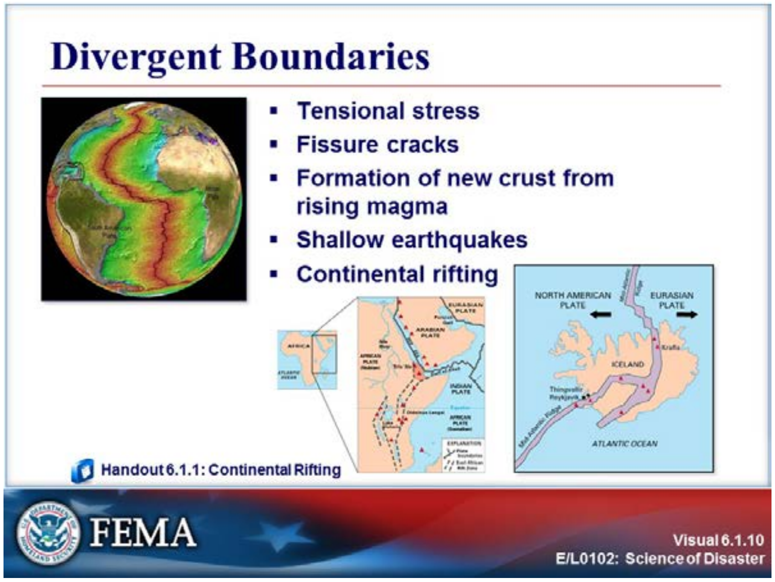


PLATE TECTONICS

Visual 6.1.10



Alt Text for Visual 6.1.10
Divergent Boundaries (This link can also be accessed at the following URL: https://pubs.usgs.gov/gip/dynamic/understanding.html)
Tensional stress
Fissure cracks
Formation of new crust from rising magma
Shallow earthquakes
Continental rifting
A globe showing a crack between the South American Plate and the African Plate. A magnified view of a map of East Africa. The map shows plate boundaries, the east African rift zone, and different plates. A map showing Iceland and the North American Plate and the Eurasian Plate.

Key Points

At a **divergent plate boundary,** two plates move away from each other under tensional stress. Shallow, low-to-medium-magnitude earthquakes occur at divergent plate boundaries.

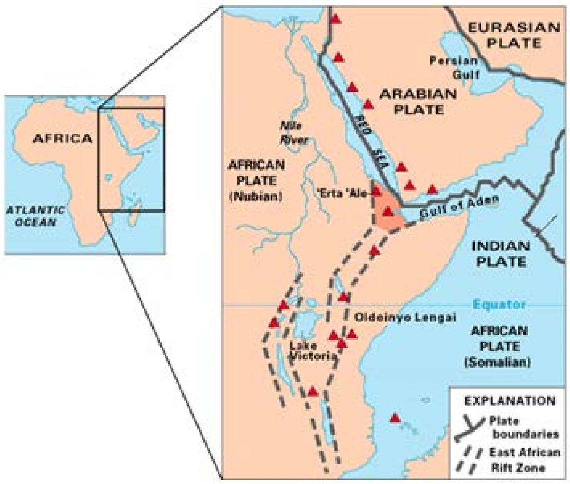
- **Under an ocean:** When a divergent plate boundary lies under an ocean, the oceanic crust becomes very thin and cracks, opening up fissures. The traditional cone-shaped volcanoes with a central vent do not form at these locations. Rather, magma moves up to the surface through the fissures and solidifies, creating new oceanic crust.

- **Under a continent:** When a divergent plate boundary lies under a continent, the process is similar, and the continent can gradually be ripped apart to form new oceans through a process called **continental rifting.**

PLATE TECTONICS

Visual 6.1.10 (Continued)

As the crust thins and fissures occur, the overall elevation of the region becomes low enough for shallow seas to form. Modern examples of a continental rifting are the Red Sea and the East African Rift valley. The Red Sea began as a continental rift and is now a mid-ocean ridge. The East African Rift (This link can also be accessed at the following URL: https://pubs.usgs.gov/gip/dynamic/East_Africa.html) valley is in the process of ripping East Africa from the main continent.

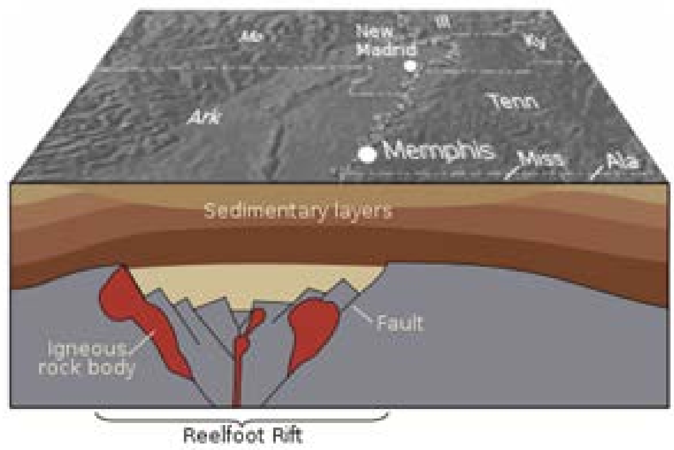


See Color Handout 6.1.1: Continental Rifting

PLATE TECTONICS

Visual 6.1.10 (Continued)

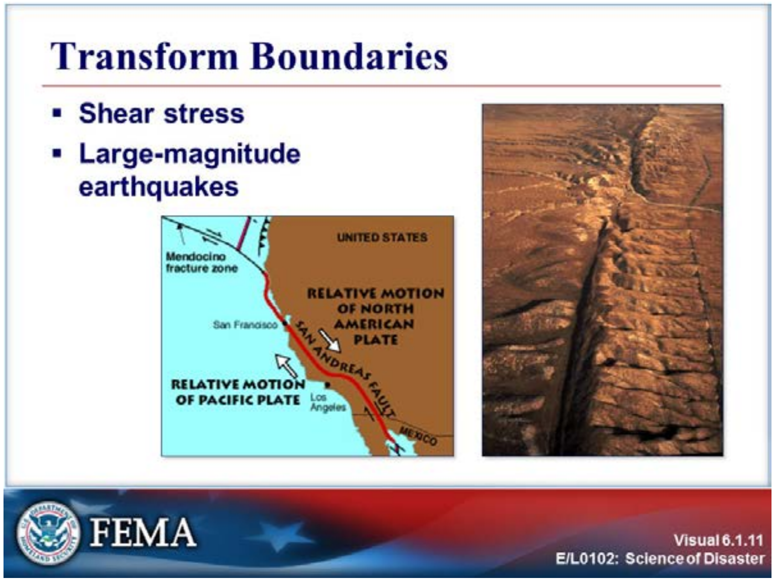
Some scientists think that earthquakes in Tennessee and Missouri result from an old, failed divergent plate boundary. They hypothesize that the New Madrid Earthquake zone (This link can also be accessed at the following URL: http://earthquake.usgs.gov/learn/topics/nmsz/1811-1812.php) is a result of an ancient (500-million-year-old) buried northeast-trending continental rift known as the Reelfoot Rift (shown in cross-section below).



This is an excellent example of how the Earth's internal forces change with time. Plate boundaries are not fixed, permanent features; they develop, change types, change locations, and even cease with time.

PLATE TECTONICS

Visual 6.1.11



Key Points

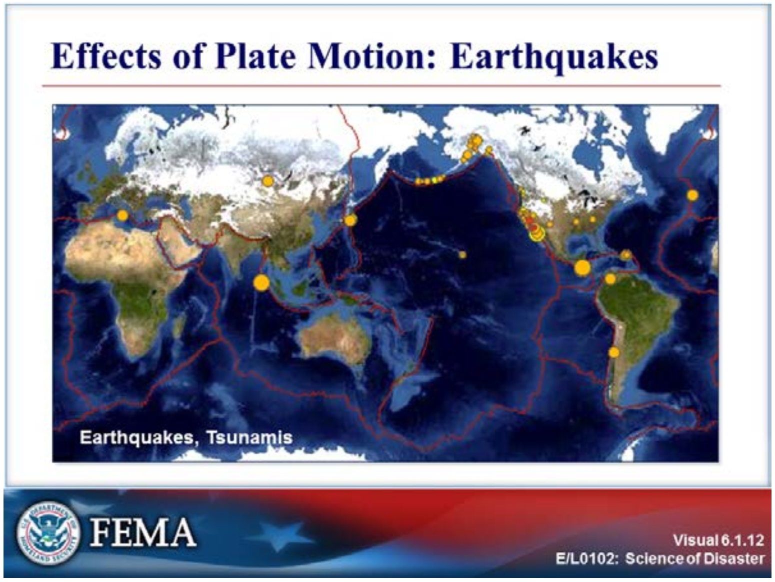
Transform plate boundaries (This link can also be accessed at the following URL: https://pubs.usgs.gov/gip/dynamic/understanding.html) occur where two plates slide past each other under shear stress.

In this situation, there is no subduction and volcanoes do not form. However, there is still tremendous frictional stress that can create large, destructive earthquakes.

The most famous example of a transform plate boundary is the San Andreas Fault running through California. This fault marks the boundary between the North American Plate and the Pacific Plate, and will be explored in greater detail in the next unit.

PLATE TECTONICS

Visual 6.1.12



Alt text for Slide 6.1.12
A global map marking earthquakes and tsunamis along plates. Earthquake points are above Africa, to the left of Indonesia, In mid-Russia and off the coast of Russia. A chain of Earthquakes occur between Russia and Alaska, with a cluster occurring between Alaska and Canada. A cluster of Earthquakes are marked along the US west coast, and across the mid-US. There is a large occurrence around Panama and out to the Leeward Islands, and an occurrence along Chile. There is also an occurrence on the plate in the Atlantic Ocean.

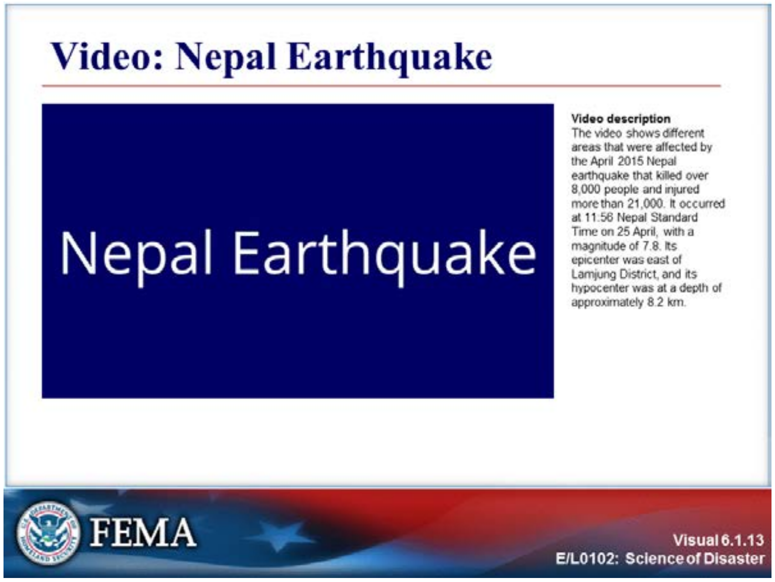
Key Points

The forces of plate tectonics create earthquakes. Most earthquakes occur near plate boundaries, represented by the lines in the map on this visual, which shows one week of earthquakes in August 2012. Earthquakes do occur away from plate boundaries, but less frequently.

Subduction-zone earthquakes can also generate **tsunamis**.

NEPAL EARTHQUAKE

Visual 6.1.13



Key Points

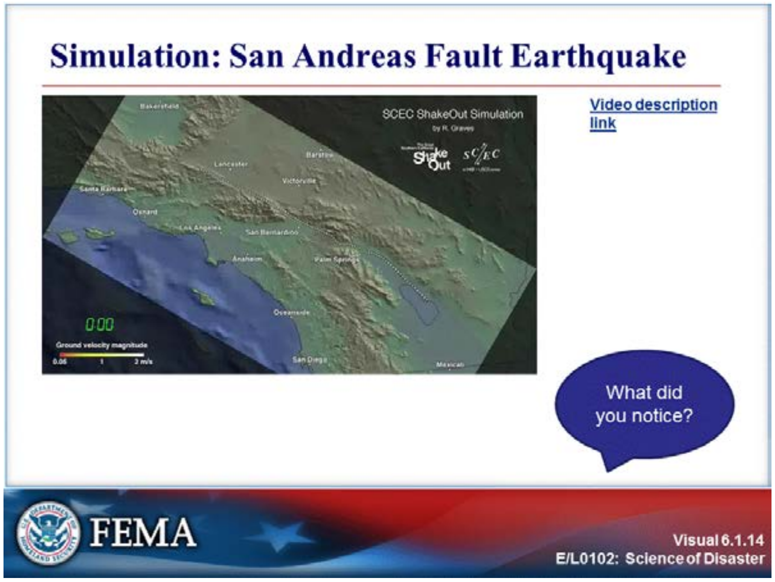
The April 2015 Nepal earthquake killed over 8,000 people and injured more than 21,000. It occurred at 11:56 Nepal Standard Time on 25 April, with a magnitude of 7.8. Its epicenter was east of Lamjung District, and its hypocenter was at a depth of approximately 8.2 km.

It was the worst natural disaster to strike Nepal since the 1934 earthquake. Hundreds of thousands of people were made homeless due to the devastating earthquake. Centuries-old buildings were destroyed at UNESCO World Heritage sites in the Kathmandu Valley, including some at the Kathmandu Durbar Square, the Patan Durbar Square, the Bhaktapur Durbar Square, and the Changu Narayan. Geophysicists and other experts had warned for decades that Nepal was vulnerable to a deadly earthquake, particularly because of its geology, urbanization, and architecture.

Outside the Valley, the Manakamana Temple in Gorkha, the Gorkha Durbar, the Rani Mahal in Palpa District, the Dolakha Bhimsensthan in Dolakha District, and the Nuwakot Durbar were partially damaged.

FAULTS

Visual 6.1.14



Key Points

This animation illustrates many important aspects of the earthquake process, which we will discuss in this unit. This computer simulation, created through the collaboration of Earth scientists and computer scientists, shows the travel of earthquake waves generated by a rupture on the San Andreas Fault in southern California. This is a hypothetical magnitude-7.8 earthquake called the Shakeout scenario earthquake.

The San Andreas Fault extends for hundreds of miles along the plate boundary in California. The simulation focuses on the southern terminus of the Fault, which begins at the Salton Sea and extends to the northwest. The San Andreas Fault ruptures all the way to the surface of the Earth, and to a depth that varies from about 6 to 10 miles.

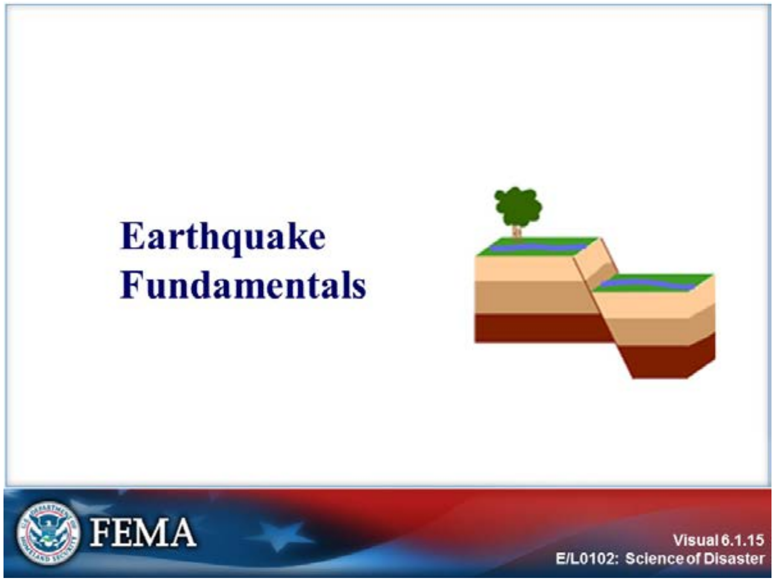
The dashed line indicates the 200 miles of Fault that will rupture in this single earthquake. If a shorter section of the Fault ruptured, the earthquake would be smaller. If a longer section of the Fault ruptured, the earthquake would be bigger.

In the lower left of the screen is a green counter that ticks off seconds after the Fault rupture begins. The white, yellow, and red colors indicate the velocity of the waves that carry the energy away.

Discussion Question: What did you notice?

EARTHQUAKE FUNDAMENTALS

Visual 6.1.15



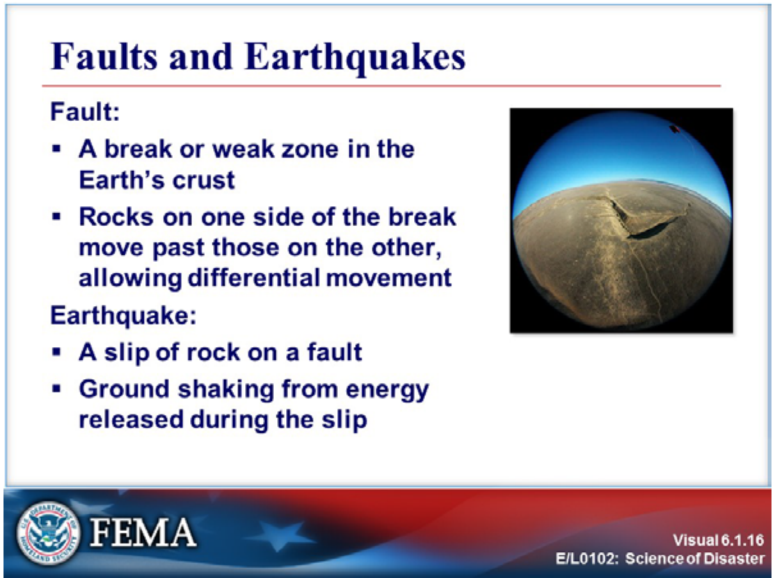
Key Points

This unit will focus on the following main topics:

- Earthquake fundamentals
- Earthquake occurrence and effects
- Earthquake monitoring and forecasting

DEFINITIONS

Visual 6.1.16



Alt Text for Visual 6.1.16
Faults and Earthquakes
Fault:

- A break or weak zone in the Earth's crust
- Rocks on one side of the break move past those on the other, allowing differential movement

Earthquake:
A slip of rock on a fault

- Ground shaking from energy released during the slip
- Photo of a crack in the Earth created from an earthquake.

Key Points

Faults: A fault:

- Is a break or weak zone between two blocks of rock
- Allows **differential movement** between two blocks of rock

Differential movement means that the two blocks move in different directions. Scientists can measure the relative changes in the positions of the two blocks but, because of the lack of an outside frame of reference, cannot detect how each block moved alone.

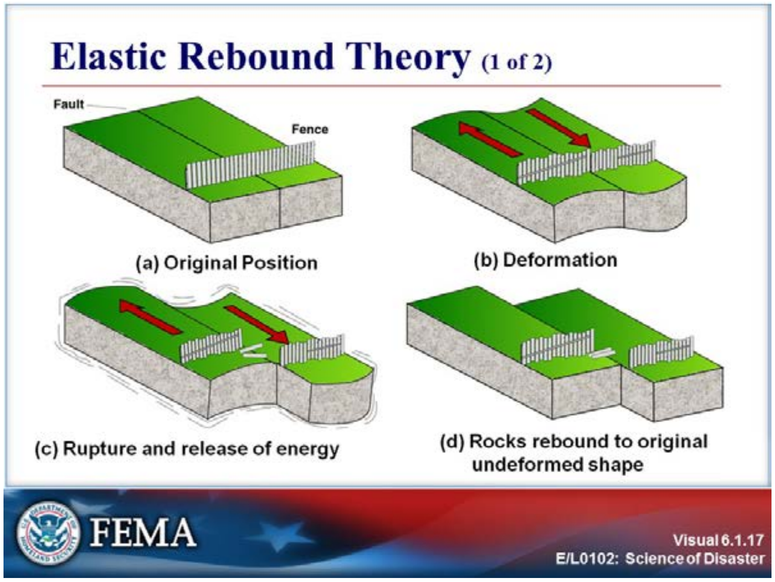
Earthquakes: The term *earthquake* is used to describe:

- The slip of rock on a fault, and
- The resulting ground shaking from energy that gets released during the slip, and *sometimes*
- Energy released from volcanic or other processes

(This very basic definition will be elaborated on throughout this unit.)

ELASTIC REBOUND THEORY

Visual 6.1.17



Alt Text for Visual 6.1.17
Elastic Rebound Theory (1 of 2)
Four steps of the elastic process

1. Original position
2. Deformation
3. Rupture and release of energy
4. Rocks rebound to original undeformed shape

Key Points

To understand the science of earthquakes, it is helpful to know about the Elastic Rebound Theory, which forms the basis of scientific investigation into earthquakes.

Following a 1906 earthquake in California, a flurry of scientific investigations studied the root causes of earthquakes. Henry Fielding Reid, a Professor of Geology at Johns Hopkins University, proposed the Elastic Rebound Theory to explain the phenomenon of earthquakes, a theory that survives to this day.

The theory states that, like a stretched rubber band, the Earth's lithosphere stores elastic energy that is released suddenly in an earthquake—the equivalent of breaking or cutting a rubber band.

There are four steps in this elastic process:

a) Original position (strain in the rocks builds)
b) Deformation (rocks bend under elastic strain)
c) Rupture and release of energy (strain is released and rocks snap—i.e., an earthquake)
d) Rocks rebound to original, undeformed shape (i.e., become stable)

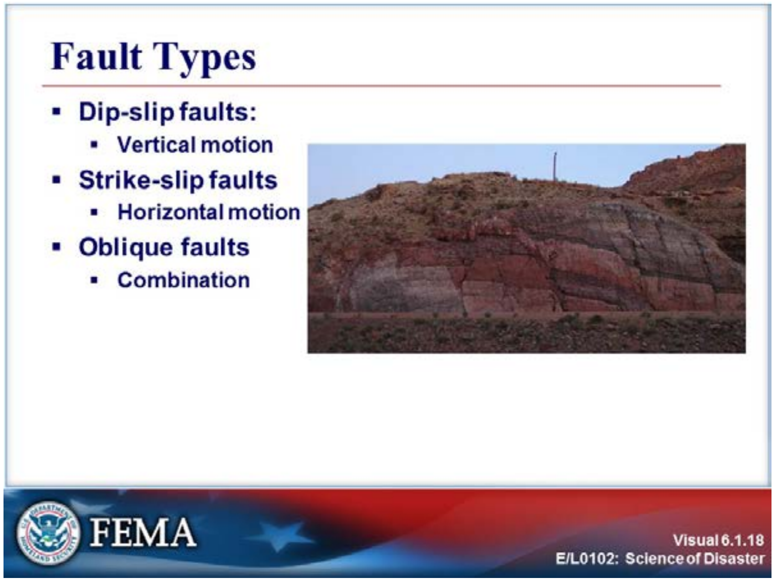
ELASTIC REBOUND THEORY

Visual 6.1.17 (Continued)

Regardless of the style of motion, enormous blocks of rock do not move easily. In fact, the edges of the plates are locked by frictional forces most of the time, while the body of the plate continues to move slowly.

FAULTS

Visual 6.1.18



Key Points

Fault types: There are different classifications of faults based on the movement of the rock, which we will look at in subsequent visuals:

- Dip-slip faults, including normal and reverse, which involve vertical movement
- Strike-slip faults, which involve lateral movement
- Oblique faults, which involve both vertical and lateral movement

Fault planes and fault zones: Faults are typically modeled as planes between rocks. (The reality is more complicated; it is often more appropriate to think of a fault as a zone of deformation rather than as a sharp planar feature.)

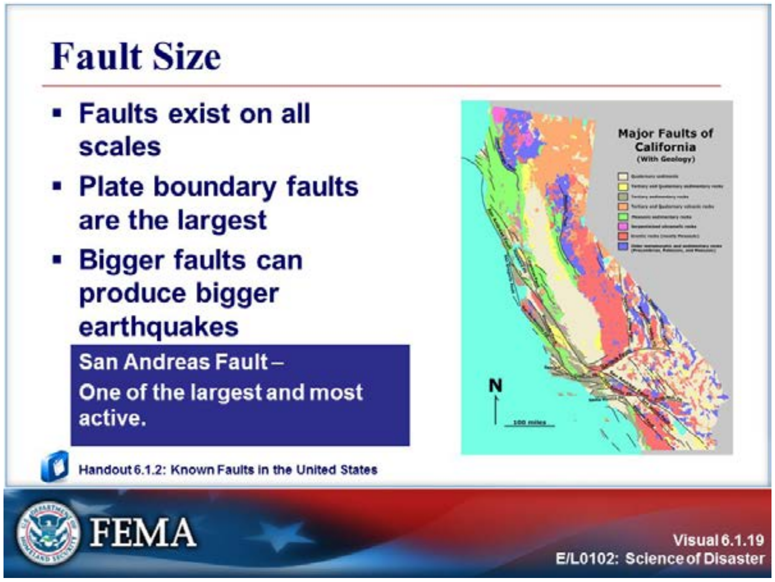
A **fault plane** extends laterally and vertically. A typical fault that is large enough to produce a damaging earthquake will extend at least 6 miles deep into the Earth and might be hundreds of miles long.

Typically only part of a fault will allow movement in a single earthquake. Thus, scientists distinguish between the fault plane, which is the full extent of the fault, and the **rupture plane,** which is the part of the fault that allows movement in a single earthquake.

Scientists talk interchangeably about “fault rupture,” “fault movement,” “fault slip,” “earthquake rupture,” and “earthquake slip.” All of these are ways to talk about the process in which a weak zone, the fault, allows movement of blocks of rock that meet at the fault.

FAULTS

Visual 6.1.19



Alt Text for Visual 6.1.19
Fault Size
Faults exist on all scales
Plate boundary faults are the largest
Bigger faults can produce bigger earthquakes
San Andreas Fault –
One of the largest and most active.
Handout 6.1.2: Known Faults in the United States
Map of the major fault lines in California

Key Points

Faults exist on all scales. Some faults are so small that the movement of the rocks can only be detected with a high-power microscope.

Plate boundary faults, which allow movement between two plates, are the largest faults on the planet. For example, the San Andreas Fault (shown in the photo) is easily visible from space.

In general, the bigger the fault, the bigger the earthquakes it can produce.

U.S. Faults: The map on the next page shows areas in the contiguous United States where faults have been identified that have the potential to create damaging earthquakes.

In some places, a broad area is identified as having known faults, but the exact location of each fault is not known. Some faults obviously deform the surface of the Earth and can readily be mapped. Other faults are buried under sediments or otherwise hidden, and can only be found when an earthquake is detected, or when there is examination of subsurface features, such as during oil company exploration. Faults often create barriers that block the movement of oil, gas, and water.

FAULTS

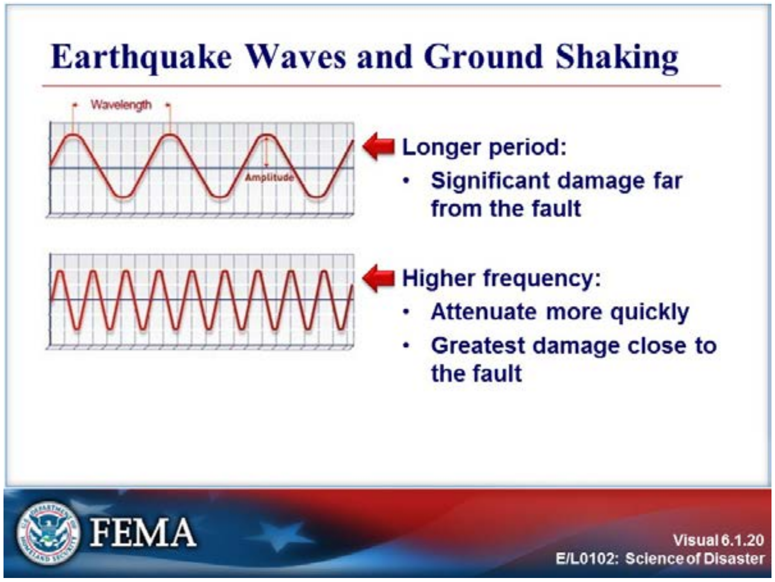
Visual 6.1.19 (Continued)

There are many more faults than are shown on this map. Some that are capable of causing earthquakes have not been identified. Some are older faults that are not aligned so that they will produce earthquakes with the current tectonic forces; however, they might become active again should the forces change sufficiently.

See Color Handout 6.1.2: Known Faults in the United States

EARTHQUAKE WAVES

Visual 6.1.20



Key Points

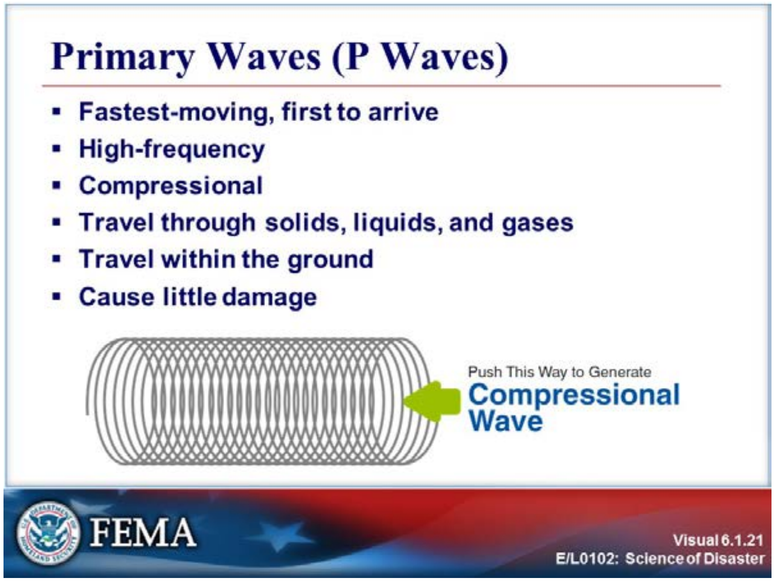
In an earthquake, the ground shaking is caused by energy waves propagating through the ground.

Effect of wave properties:

- The highest-frequency waves will attenuate (decrease) the most quickly. Therefore, they will cause the greatest damage close to the fault.
- The longest-period waves, created by the largest earthquakes, can cause significant damage hundreds of miles from the fault.

EARTHQUAKE WAVES

Visual 6.1.21



Alt Text for Visual 6.1.21
Primary Waves (P Waves)

- Fastest-moving, first to arrive
- High-frequency
- Compressional
- Travel through solids, liquids, and gases
- Travel within the ground
- Cause little damage

A diagram to show movement of primary waves. An arrow pointing through the waves that says "push this way to generate compressional wave"

Key Points

Scientists also distinguish between body waves and surface waves. Body waves move through the Earth, and surface waves stay on the surface.

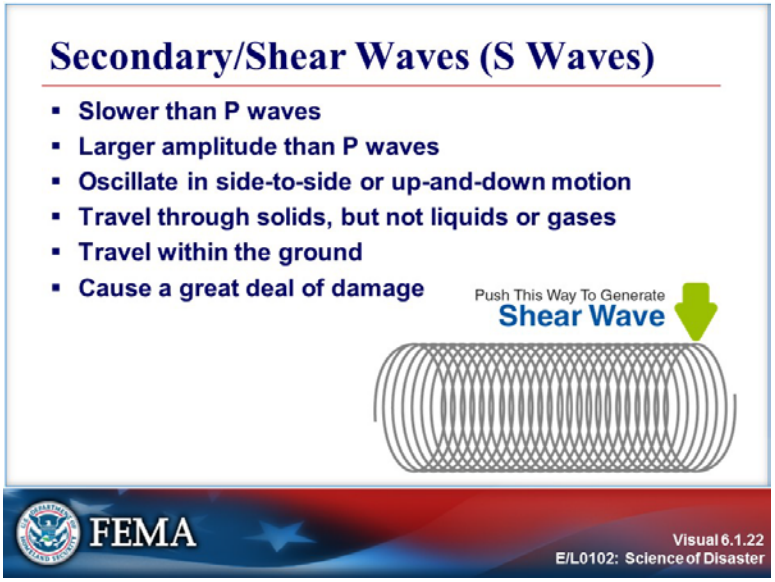
Body waves include primary waves (P waves) and secondary/shear waves (S waves), and they travel through the Earth with different types of motion.

Characteristics of P waves:

- Are the fastest moving, and the first to arrive. They move at about 6 miles per second, about twice as fast as secondary waves:
  - ~ 1.71 times the speed of secondary waves
  - ~ 2 to 3 times the speed of surface waves
  - Typically 1 second separation between P and S waves for nearly every 5 miles traveled
- Have a high frequency
- Are compressional
- Travel through solids, liquids, and gases
- Travel within the ground
- Cause little damage

EARTHQUAKE WAVES

Visual 6.1.22



AI Text for Visual 6.1.22
Secondary/Shear Waves (S Waves)

- Slower than P waves
- Larger amplitude than P waves
- Oscillate in side-to-side or up-and-down motion
- Travel through solids, but not liquids or gases
- Travel within the ground
- Cause a great deal of damage

A diagram to show movement of secondary/shear waves. An arrow pointing down to the waves that says "push this way to generate shear wave".

Key Points

Characteristics of S waves:

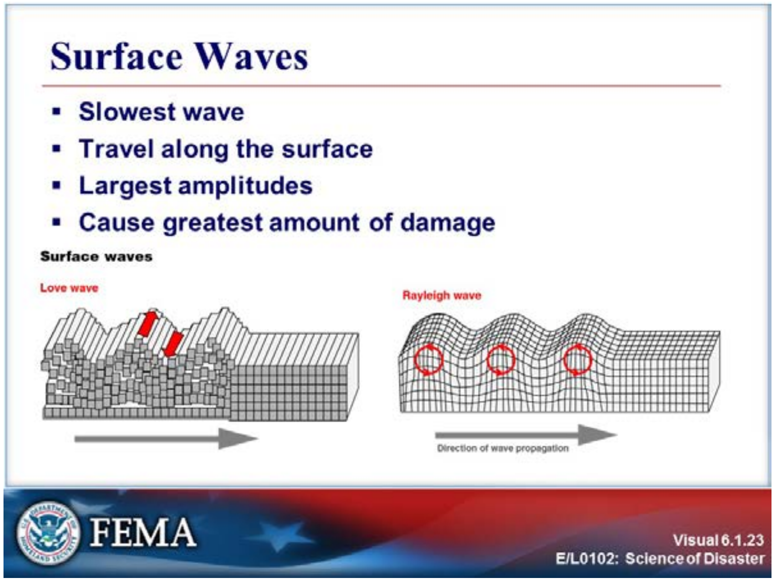
Secondary/shear waves (S waves) shake the ground more severely and cause more damage.

S waves:

- Are slower than P waves
- Have a larger amplitude than P waves
- Oscillate in a side-to-side or up-and-down motion
- Travel through solids, but not liquids or gases
- Travel within the ground
- Cause a great deal of damage

EARTHQUAKE WAVES

Visual 6.1.23



Key Points

Characteristics of surface waves: Surface waves are the slowest-moving and the most damaging of the waves. They also have the largest amplitudes.

Types of surface waves: Surface waves may either be Love waves or Rayleigh waves (R waves).

- **Love waves:**
  - Are the fastest surface wave
  - Move side to side

- **Rayleigh waves (R waves):**
  - Move like ocean waves, rolling up and down and side to side
  - Are the most damaging wave

EARTHQUAKE WAVES

Visual 6.1.24

Key Points

This animation models the movement of different waves during the ShakeOut scenario earthquake we saw at the beginning of this unit.

- **Two views:** On the left is an overhead view, showing the earthquake starting at the Salton Sea and rupturing the fault to the northwest. On the right is a perspective view from the air above downtown Los Angeles.

- **Colors:** The colors represent the highest intensity of ground shaking at that site since the earthquake began. The highest intensities are closest to the fault and in the sedimentary basins.

- **Sequence:**
    - Lower-intensity waves are the first waves. These are the **P waves.** They begin to reach downtown Los Angeles about 45 seconds after the earthquake begins.
    - Then the slower **S waves** arrive, greatly increasing the intensity of shaking. These waves are lower -frequency and bring a rolling motion.
    - The **surface waves** are the last to arrive and cause the most severe shaking. From this perspective, you can also see the reverberation as the waves resonate in the sedimentary basin underlying downtown Los Angeles.

EARTHQUAKE WAVES

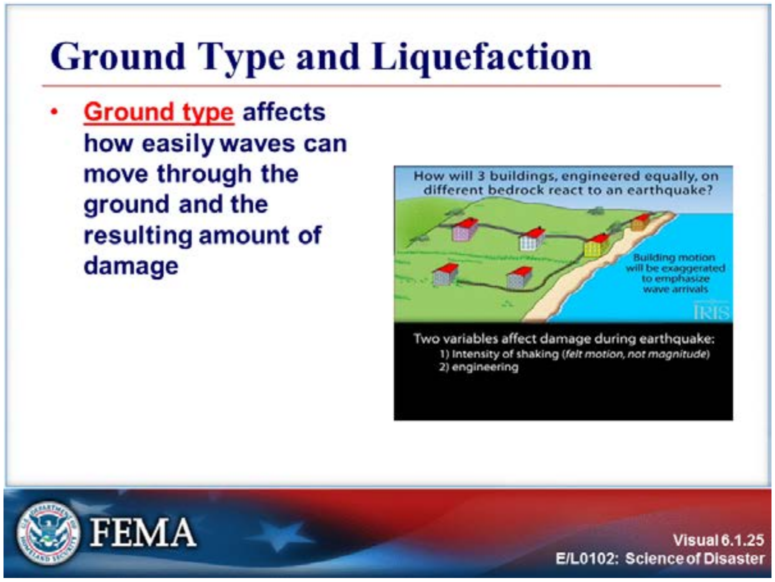
Visual 6.1.24 (Continued)

- **Exaggeration:** Although the shaking will be severe in any magnitude-7.8 earthquake, it would not be this relentless. In this animation, the amplitude of the waves (their height) is vertically exaggerated 1,000 times so that it can be seen at this scale.

- **Elapsed time:** Because the earthquake begins some distance away, the really strong shaking from this earthquake takes more than a minute to arrive in downtown Los Angeles (earthquake waves travel more slowly than radio waves). That fact, plus basic understanding of earthquake wave properties, forms the basis for Earthquake Early Warning systems.

EARTHQUAKE EFFECTS

Visual 6.1.25



Key Points

Liquefaction is common in earthquakes. Many soils and sediments have pores that can fill with groundwater. When these sediments undergo strong shaking, the pore pressure increases and in certain soils, the groundwater shoots upward, which injects groundwater into overlying soil.

The drawings on the visual show a schematic depiction of soil grains and groundwater, before and during liquefaction.

The injected water causes the soil to behave temporarily like a liquid rather than a solid. Most buildings and infrastructure are not constructed to sit on liquid, and although the liquefaction may last less than a second, tremendous damage can result.

It takes strong shaking, liquefiable soils, and groundwater near the surface to produce liquefaction, however. The 1994 Northridge California earthquake caused less liquefaction than it might have, because drought had lowered groundwater levels in many areas.

EARTHQUAKE EFFECTS

Visual 6.1.25 (Continued)

Transcript:

Narrator: The motion of similar buildings on different bedrock will be exaggerated to show the arrivals of compressive P, shearing S, and rolling surface waves from a regional earthquake. Three consecutive seismograms will show the changing frequency and amplitude resulting from changing rock type.

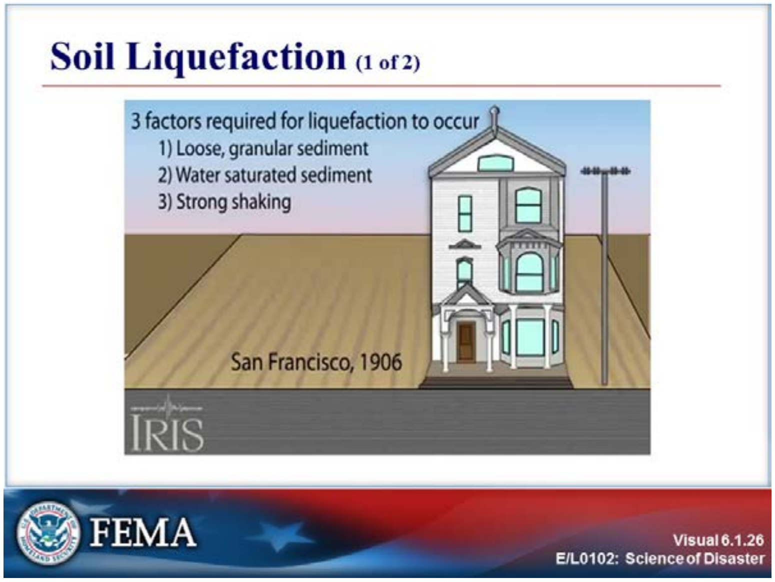
The initial P wave arrives with a compressive bump and rarely causes much damage. The slower shearing S wave introduces a side-to-side motion that can throw loose objects to the floor and may crack walls.

The rolling surface waves are the most damaging in unconsolidated sediment. As surface waves enter the sedimentary layer they slow down and increase in size, causing buildings to roll. If not engineered for the motion, they can crack and tumble. But even a well-engineered building can sink during the shaking and liquefaction of underlying wet sediment.

The first seismogram from the pink building on solid ground shows low-amplitude high-frequency waves. When the waves hit softer ground they slow down and increase in amplitude. It’s this higher, slowing roll that is so destructive during an earthquake.

EARTHQUAKE EFFECTS

Visual 6.1.26



Key Points

Video description:

Still picture with a house "Three factors required for liquefaction to occur: Loose, granular sediment, Water saturated sediment, Strong shaking. San Francisco, 1906

Look below surface: shows layer of loose, granular sediment and then saturated by ground water. Earthquake happens. Liquefaction of ground under house. House shaking

Question "Why did this happen?"

Answer Earthquake waves cause water pressures to increase in the sediment. Sand grains lose contact with each other leading to loss of sediment strength & liquid-like behavior.

www.iris.edu/educate

Photo of a house damaged during earthquake with caption: Photo from earthquake, San Francisco 1906. Area is underlain by marsh deposits that were covered by artificial fill in the 1800s. (photo & text from U.S. Geological Survey)

EARTHQUAKE EFFECTS

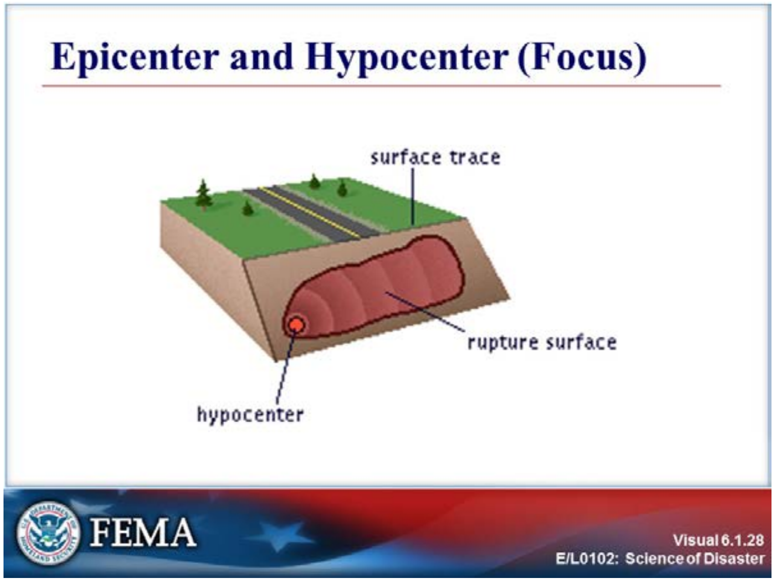
Visual 6.1.27

Key Points

Video description:
The image shows a real-life example of soil liquefaction taken from the 9.0-magnitude earthquake that took place in Japan in 2011.

THE EPICENTER

Visual 6.1.28



Key Points

Epicenter: An epicenter is the point on the Earth's surface that is directly above the point where the fault first starts to rupture, which is called the hypocenter or focus.

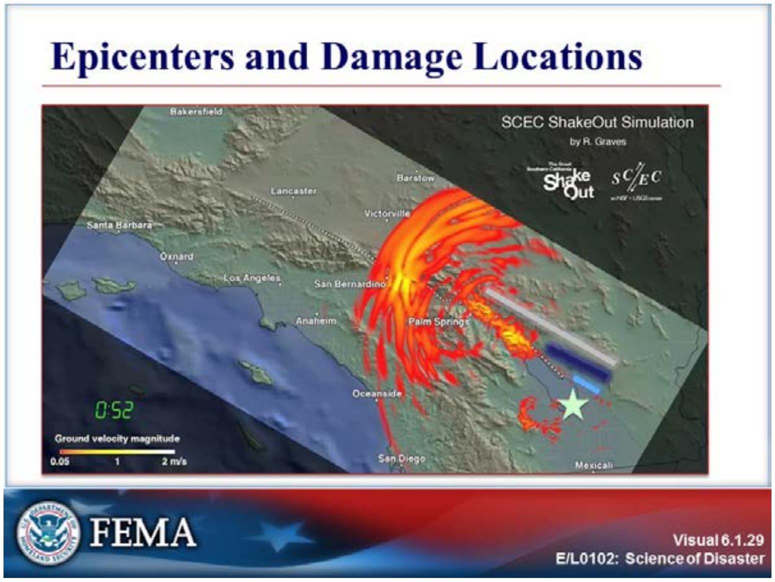
This image helps to illustrate the relative locations of the epicenter and hypocenter, as well as other key elements of earthquakes.

Here we see a fault plane that dips into the Earth. This fault happens to reach all the way to the surface of the Earth, and the intersection of the fault plane with the surface is called the surface trace. An earthquake has just occurred.

Hypocenter: Directly below the epicenter, on the fault plane, is the hypocenter, where the earthquake begins. The entire fault plane did not rupture in this earthquake. The part of the fault that does allow movement during this earthquake is the rupture surface.

THE EPICENTER

Visual 6.1.29



Key Points

Strongest shaking: During any earthquake, shaking is usually strongest closest to the fault. Because the epicenter is directly above the fault, it will experience some of the strongest shaking. As the energy waves move away from the fault, they lose energy.

Small vs. large earthquakes: When an earthquake is small, the fault rupture surface will be small, and the location of the epicenter gives a good indication of where to look for damage from the earthquake. In larger earthquakes, the epicenter only indicates one of many places where strong shaking could cause damage.

Extent of damage: In the image on the visual (from the ShakeOut simulation we watched):

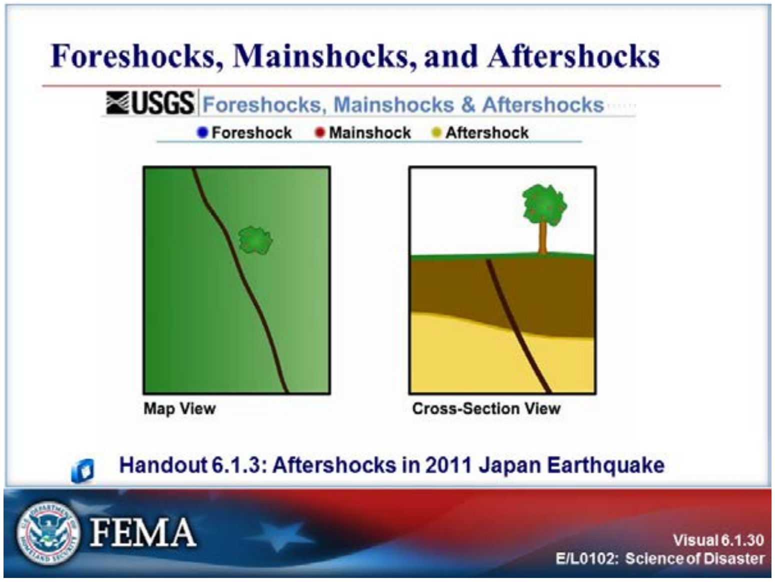
- The green star represents the epicenter—but the dashed line represents the 200 miles of fault that ruptures
- **Every community along those 200 miles will experience shaking as strong as at the starting point.** (In addition, there are locations away from the fault, such as in sedimentary basins that undergo resonance, where shaking will be strong even though the waves have lost some energy as they travelled away from the fault)

Comparison with other earthquakes: Notice the three lines on the right:

- Light blue—shows the length of fault that would rupture in an earthquake about the size of the 2011 magnitude-5.8 Virginia earthquake
- Dark blue—shows the comparable length of fault that would rupture in an earthquake about the size of the 1994 magnitude-6.7 Northridge earthquake
- Gray—shows a rupture for an earthquake comparable to the 2010 Haiti earthquake

EARTHQUAKE SEQUENCE

Visual 6.1.30



Key Points

When an earthquake occurs, the movement of rock along the fault and the traveling energy waves cause stress changes in the Earth. The stress changes result in additional earthquakes that are called **triggered** events.

When any earthquake occurs, additional earthquakes must be expected. In fact, after any earthquake, there is an increased likelihood of additional bigger earthquakes for about three (3) days.

An earthquake sequence, with foreshocks, a mainshock, and aftershocks.

- A **foreshock** is a relatively smaller earthquake that precedes the largest earthquake in a series.
- A mainshock is the largest earthquake in a sequence, sometimes preceded by one or more foreshocks (not all mainshocks have foreshocks), and almost always followed by many aftershocks.

See Color Handout 6.1.3: Aftershocks in 2011 Japan Earthquake

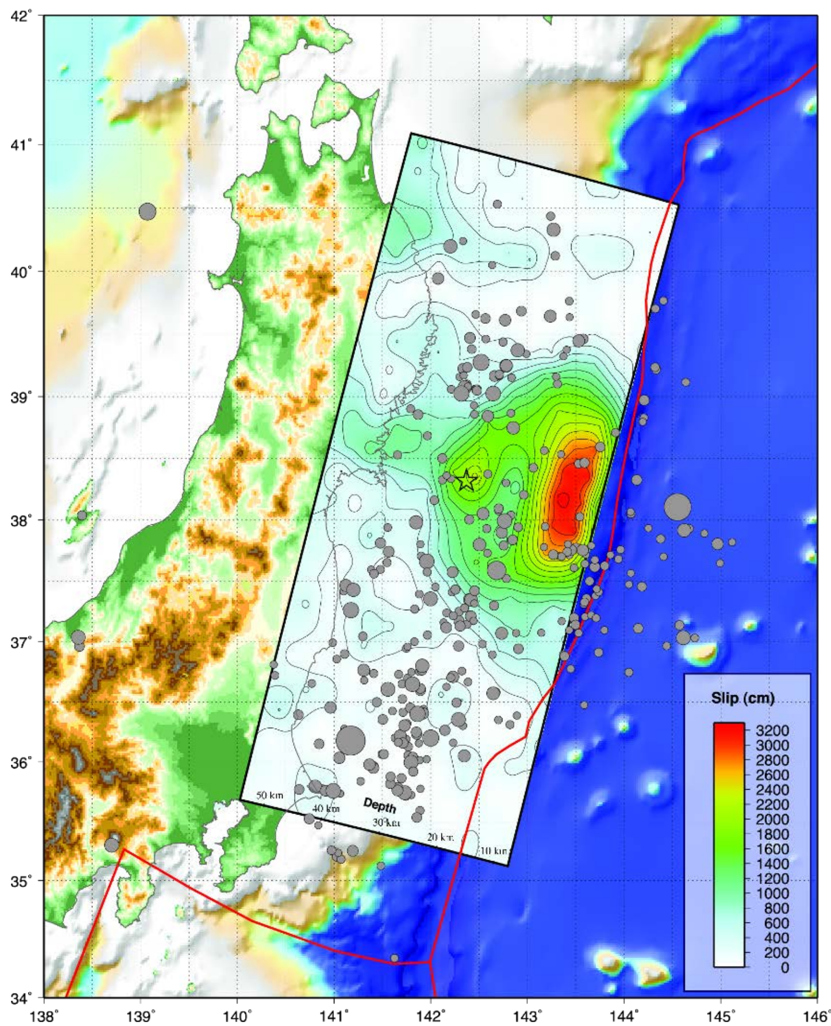
EARTHQUAKE SEQUENCE

Visual 6.1.30 (Continued)

- An **aftershock** is an earthquake that follows the largest shock of an earthquake sequence. It is smaller than the mainshock and within 1 to 2 rupture lengths distance from the mainshock.
    - Aftershocks can continue over a period of weeks, months, or years.
    - In general, larger mainshocks are followed by more numerous aftershocks, which continue longer.
    - About 6 percent of the time, the aftershock is bigger than the mainshock. When this occurs, scientists rename the events. The earlier earthquake becomes a *foreshock* and the new, larger earthquake becomes the mainshock.

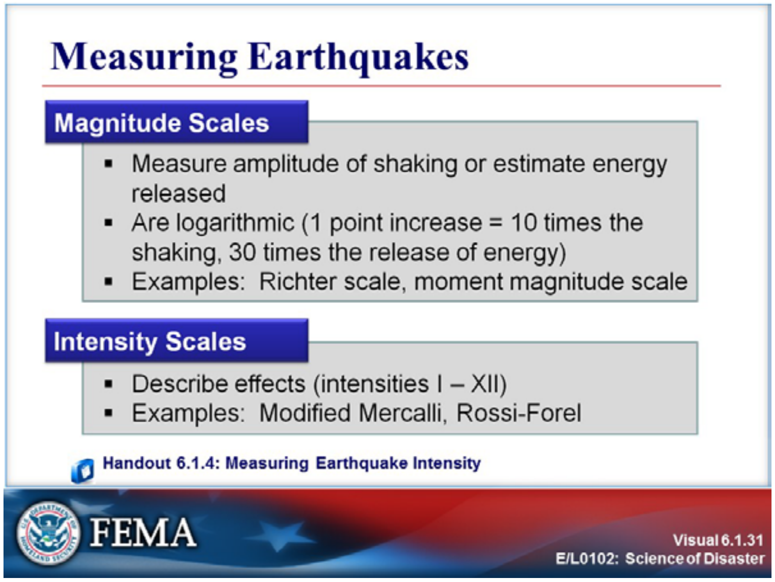
Below is a surface projection of the slip distribution from the 2011 Japan earthquake superimposed on General Bathymetric Chart of the Oceans (GEBCO) bathymetry. Red lines indicate major plate boundaries. Gray circles are aftershock locations, sized by magnitude.

Aftershocks in 2011 Japan Earthquake



MEASURING EARTHQUAKES

Visual 6.1.31



Alt Text for Visual 6.1.31
Measuring Earthquakes
Magnitude Scales

- Measure amplitude of shaking or estimate energy released
- Are logarithmic (1 point increase = 10 times the shaking , 30 times the release of energy
- Examples: Richter scale, moment magnitude scale

Intensity Scales

- Describe effects (intensities I–XII)
- Examples: Modified Mercalli, Rossi-Forel

Handout 6.1.4: Measuring Earthquake Intensity

Key Points

The sense of motion along a fault provides information about the forces acting on the rock and the fault, which affect estimates of how frequent and how large earthquakes can be, and also helps scientists to identify which fault is responsible for a particular earthquake.

Magnitude scales: Earthquake magnitude is a measure of the amount of energy released in an earthquake. When the media reports on an earthquake they talk about magnitude “on the Richter scale.” However, the Richter scale was an early method to calculate earthquake size based on the amplitude of shaking measured by a particular kind of seismometer, which is an instrument that records ground shaking. The Richter scale has since been supplanted by methods such as moment magnitude that do a better job of estimating the amount of energy released in an earthquake.

Magnitude scales are base 10 logarithmic scales, so when a magnitude goes up one point, the amplitude of shaking goes up by 10 times and the released energy goes up by 30 times.

MEASURING EARTHQUAKES

Visual 6.1.31 (Continued)

An earthquake will be assigned only one magnitude, although that measure will probably fluctuate as new data come in that help to refine the number. The bigger the magnitude, the bigger the earthquake—that is, the longer the shaking lasts, the stronger the shaking can be, and the greater the likelihood of damage.

Intensity scales: An intensity scale describes the severity of an earthquake in terms of its effects on the Earth's surface and on humans and their structures. There are many intensities for an earthquake, depending on location, unlike the magnitude, which is one number for each earthquake. This is a subjective assessment of what the earthquake was like for a particular person at a particular location.

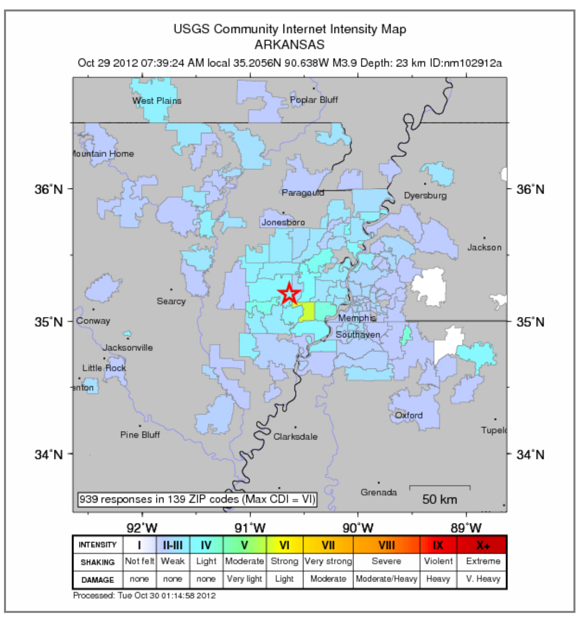
See Color Handout 6.1.4: Measuring Earthquake Intensity

The map below shows reports of intensity from nearly 1,000 people who felt a small earthquake in Arkansas in 2012. For this single earthquake of magnitude 3.9, intensities ranged from barely perceptible to strong shaking that could cause some damage.

The intensity scale, which is indicated with Roman numerals, ranges from I to XII. Intensities of VI and higher can cause significant damage.

Several scales exist, but the ones most commonly used in the United States are the Modified Mercalli scale and the Rossi-Forel scale.

The table on the next page relates the Modified Mercalli scale to earthquake size.



Alt text for graphic

USGS Community Internet Intensity Map of Arkansas on October 29, 2012 at 7:39 AM local 5.2056N 90.638W M3.9 Depth 23 km ID: nm102912a. Image shows that light shaking and no damage is around a star area, with strong shaking and light damage below and weak to no shaking and damage as the map moves away from the star in the middle.

MEASURING EARTHQUAKES

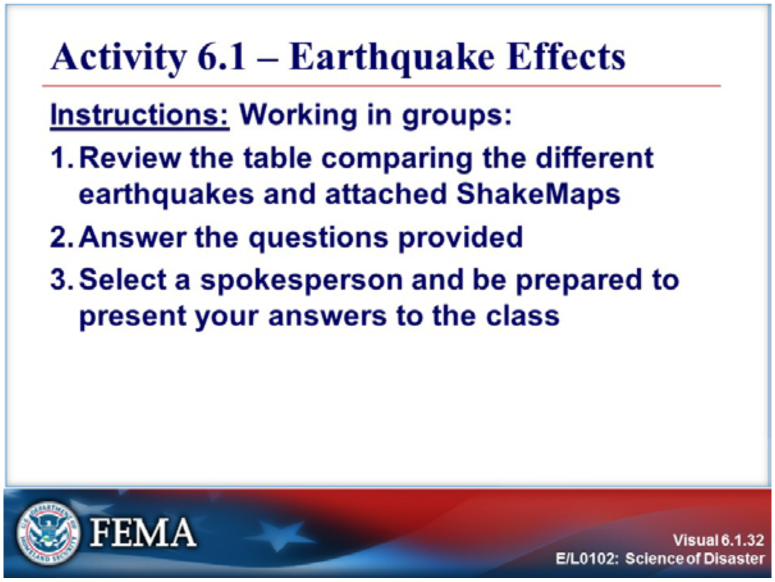
Visual 6.1.31 (Continued)

Modified Mercalli vs. Earthquake Size

Modified Mercalli Scale			Richter Scale
I. II.	Felt by almost no one. Felt by very few people.	2.5	Generally not felt, but recorded on seismometers.
III. IV. V.	Tremor noticed by many, but they often do not realize it is an earthquake. Felt indoors by many. Feels like a truck has struck the building. Felt by nearly everyone; many people awakened. Swaying trees and poles may be observed.	3.5	Felt by many people.
VI. VII.	Felt by all; many people run outdoors. Furniture moved, slight damage occurs. Everyone runs outdoors. Poorly built structures considerably damaged; slight damage elsewhere.	4.5	Some local damage may occur.
VIII. IX.	Specially designed structures damaged slightly, others collapse. All buildings considerably damaged, many shift off foundations. Noticeable cracks in ground.	6.0	A destructive earthquake.
X.	Many structures destroyed. Ground is badly cracked.	7.0	A major earthquake.
XI. XII.	Almost all structures fall. Very wide cracks in ground. Total destruction. Waves seen on ground surfaces; objects are tumbled and tossed.	8.0 and up	Great earthquakes.

ACTIVITY 6.1 – EARTHQUAKE EFFECTS

Visual 6.1.32



Alt Text for Visual 6.1.32
Activity 6.1 – Earthquake Effects
Instructions: Working in groups:
1. Review the table comparing the different earthquakes and attached ShakeMaps
2. Answer the questions provided
3. Select a spokesperson and be prepared to present your answers to the class

Key Points

Instructions: Working in groups:

1. Review the table (Activity 6.1 –Job Aid 1) comparing the different earthquakes and attached ShakeMaps. (Handouts 6.1.5 – 6.1.7)
2. Answer the questions provided.
3. Select a spokesperson and be prepared to present your answers to the class.

See Color

- Handout 6.1.5: Haiti Shakemap
- Handout 6.1.6: Chile Shakemap
- Handout 6.1.7: Honshu Shakemap

ACTIVITY 6.1 – EARTHQUAKE EFFECTS

Visual 6.1.32 (Continued)

Activity 6.1 – Job Aid 1

	Haiti	Chile	Honshu
Date	1/12/2010	2/27/2010	3/11/2011
Time	21:53:10 UTC	06:34:14 UTC	05:46:24 UTC
Magnitude	7.0	8.8	9.0
Highest Instrumental Intensity	X+	VII	X
Depth	13 km	23 km	29 km
Tectonic Location	Left-lateral strike-slip motion at the boundary between the Caribbean plate and the North American plate. No vertical displacement observed at the surface.	Thrust fault at the boundary between the Nazca Plate and the South American Plate. Rupture exceeded 100 km in width and extended 500 km parallel to the coast. 2 meters of vertical uplift observed	Thrust fault at the boundary between the Pacific and North American plate. Fault moved upward 30-40m and slipped over an area 300 km long by 150 km wide.
Distance from Population	25 km from Port-au-Prince	105 km from Concepcion	129 km East of Sendai, Honshu, Japan. 177 km ENE of Fukushima, Honshu, Japan.
Foreshocks	No significant increase in activity prior to the main shock.	No significant increase in activity prior to the main shock.	Large foreshocks over the previous two days. M7.2 followed by three M6 earthquakes.
Aftershocks	In the six weeks following, 59 aftershocks of a magnitude 4.5 or greater occurred.	In the six weeks following, more than 800 earthquakes of a magnitude 4.5 or greater occurred in the region.	In the six weeks following, more than 2000 earthquakes of a magnitude 4.5 or greater occurred in the region.

ACTIVITY 6.1 – EARTHQUAKE EFFECTS

Visual 6.1.32 (Continued)

Activity 6.1 – Job Aid 1 (Continued)

	Haiti	Chile	Honshu
Deaths	>200,000 deaths 300,000 injured	523 deaths 12,000 injured	15,891 deaths 5,314 injured.
Dollars in Damages	7.8 billion	30 billion	309 billion
Secondary Effects	Tsunamis were reported locally with wave heights of less than 15 cm. Cholera outbreak. More than 470,000 cases with 6,631 deaths.	Tsunamis were reported across the Pacific. Maximum wave heights were recorded in Valparaiso at 261 cm.	Tsunami affected the entire island of Honshu with maximum runup height of 37.88 meters. Tsunami reported throughout the Pacific Rim with heights up to 2 meters. Fires, Dam failure, Landslides, Liquefaction
Economic Status	2015 GDP $19 billion Ranked 148th in world Poorest country in the western hemisphere. 80% of country lives below the poverty line. 54% live in abject poverty.	2015 GDP $422 billion Ranked 44th in world 15% of country lives below the poverty line.	2015 GDP $4.8 trillion Ranked 5th in world 16% of country lives below the poverty line. Poverty has been steadily increasing at a rate of 1.3% since the 1980s.

ACTIVITY 6.1 – EARTHQUAKE EFFECTS

Visual 6.1.32 (Continued)

Activity 6.1 Worksheet

1. Consider how the following geological factors lead to greater number of casualties. What factors do you think are most important and why?
   - Magnitude
   - Depth
   - Fault/Tectonic Motion
   - Epicenter Location

2. What additional factors may affect the number of casualties and the amount of damage?

Factors:	Relevance to Casualties and Damages
Magnitude	
Depth	
Fault/Tectonic Motion	
Epicenter Location	
Other Factors	

3. For personal reflection – How would different parts of your community be affected by a natural disaster such as an earthquake? Are there particular regions that would be at greater risk?

EARTHQUAKE OCCURRENCE

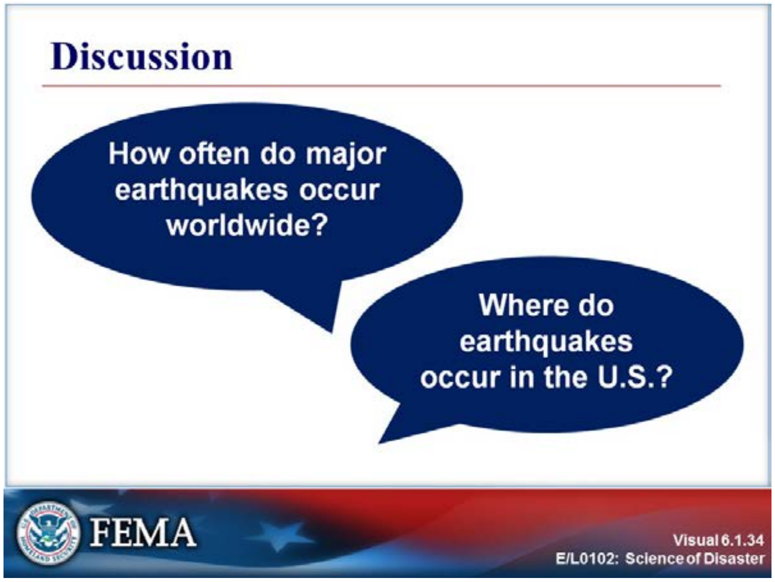
Visual 6.1.33

Key Points

The next part of this unit discusses how frequently earthquakes occur and provides an overview of their effects.

EARTHQUAKE OCCURRENCE

Visual 6.1.34



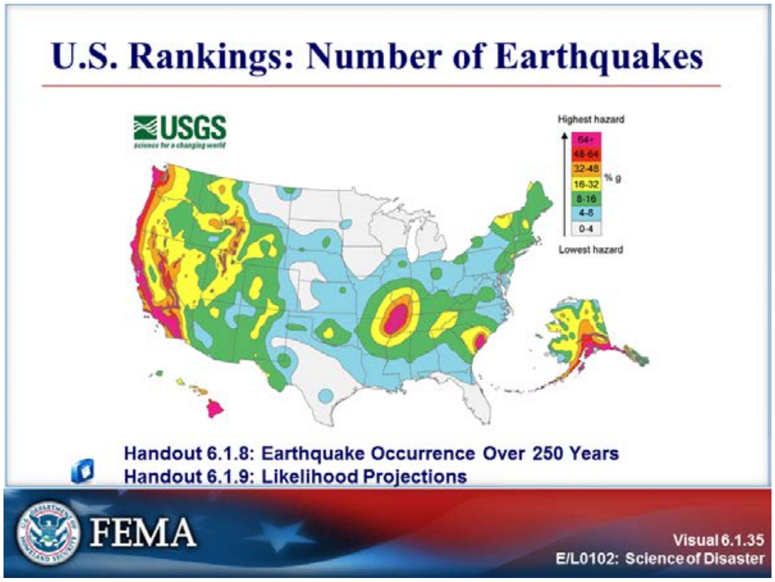
Key Points

<u>Discussion Question</u>: How often do you think major earthquakes (7 and above) occur worldwide?

<u>Discussion Question</u>: Where do earthquakes occur in the United States?

EARTHQUAKE OCCURRENCE

Visual 6.1.35



To view map Earthquake occurrence over 250 years (This link can also be accessed at the following URL: http://earthquake.usgs.gov/monitoring/anss/)

Key Points

State rankings over 29 years: This map ranks the States by the greatest number of earthquakes of magnitude 3.5 or above, based on instrumental records from 1974 to 2003. A magnitude 3.5 earthquake is large enough to feel but unlikely to cause damage.

The top 10 States are colored bright yellow (Alaska was the top producer); the next 10 are colored orange; remaining States with at least one event in 30 years are light yellow, and States that had none are colored gray.

Even in this short timeframe, two patterns emerge:

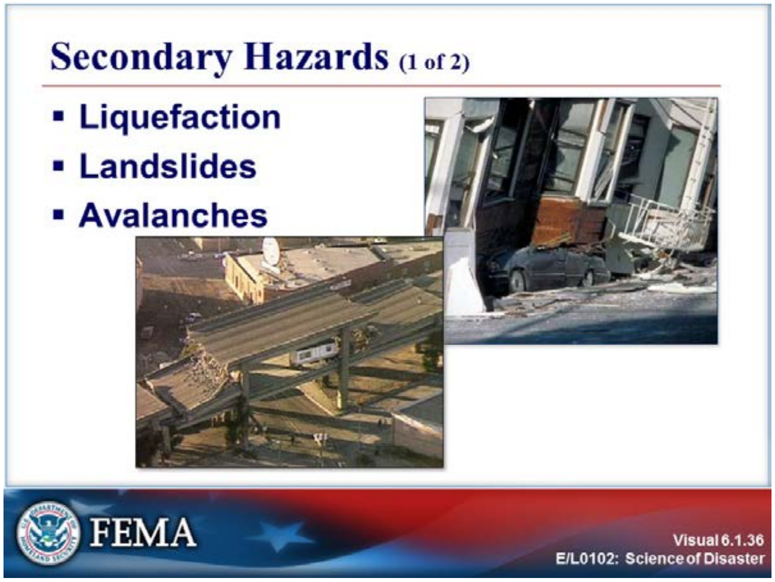
- The western States and the area around the southern Mississippi River have earthquakes more often than other places in the United States.
- It is important to remember that earthquakes can occur anywhere. It is reasonable to expect a "feelable" earthquake anywhere in the country, and the rankings of most States will shift over time.

Earthquake occurrence over 250 years: The map on the next page shows earthquakes detected during about 250 years in the United States—a much larger scale than on the visual. Looking at this longer-term data set, the previous trends are still apparent, with more earthquakes in the western U.S. and along the Mississippi River. With the longer time span, important additional information emerges, including the large and very damaging earthquake that occurred in Charleston, South Carolina, in 1886. During that earthquake, few buildings escaped damage and many were completely destroyed.

See Color Handout 6.1.8: Earthquake Occurrence Over 250 Years and
Handout 6.1.9: Likelihood Projections

EARTHQUAKE EFFECTS

Visual 6.1.36



Key Points

Hazards that result because of another hazard are called secondary hazards.

Many of the hazards related to earthquakes are secondary hazards caused by ground shaking or surface fault rupture. Examples include:

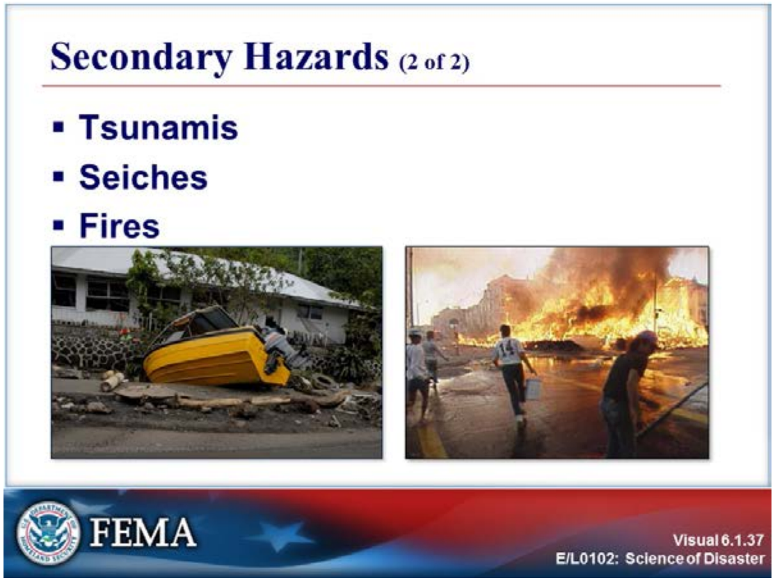
- Liquefaction
- Landslides and avalanches
- Tsunamis and seiches
- Fires

PHOTOS:

The photos show infrastructure and building collapse damage in San Francisco due to liquefaction caused by the 1989 magnitude 7.2 Loma Prieta (World Series) earthquake.

EARTHQUAKE EFFECTS

Visual 6.1.37



Key Points

Tsunamis: Underwater earthquakes in the ocean floor can trigger tsunamis—a series of water waves caused by the displacement of a large volume of a body of water. Tsunamis will be covered in the next unit.

Fires: Sometimes an earthquake's secondary hazard can cause more destruction than the primary hazards of ground shaking or fault rupture. Fires are an example.

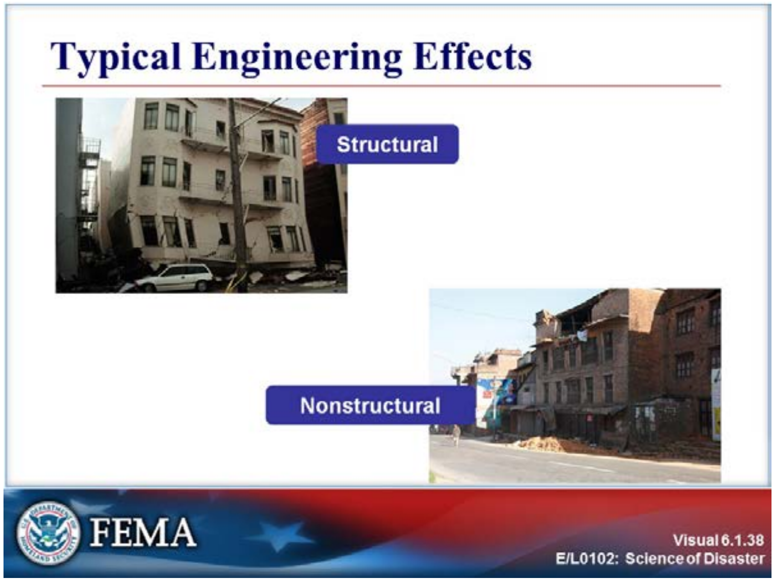
Fires occur following all earthquakes that strongly shake human settlements. In large metropolitan areas comprised of densely spaced wooden buildings, the fires have grown into catastrophic conflagrations. The two largest peacetime urban conflagrations in history (in San Francisco in 1906 and in Tokyo in 1923) were caused by earthquakes.

Earthquakes can start a fire very easily, as well as impeding firefighting by damage to buildings, water systems, communications, and transportation systems. For example, earthquakes can contribute to fires through:

- Numerous and simultaneous ignitions
- Damage that degrades fire-resistive features of buildings
- Decreased pressure in water supply mains
- Damage to water conveyance systems
- Damaged or saturated communications systems
- Disruption of transportation

EARTHQUAKE EFFECTS

Visual 6.1.38



Key Points

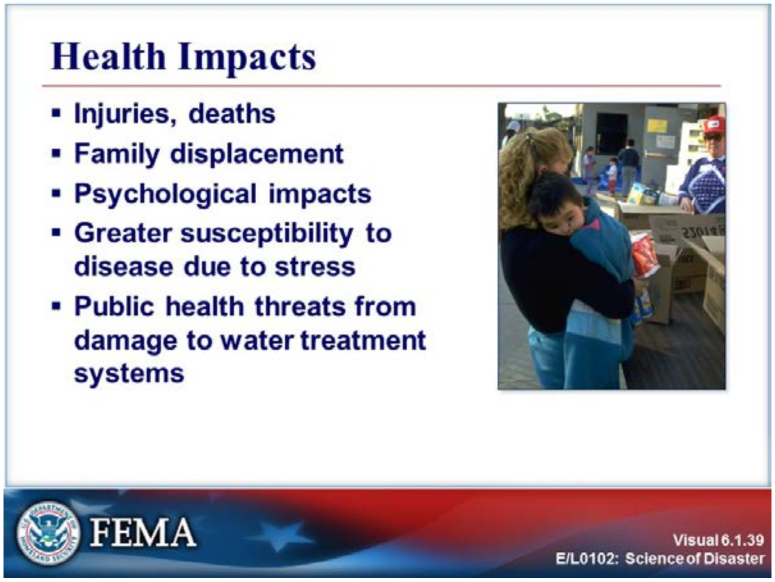
There is a saying in the earthquake engineering world: “Earthquakes don’t kill people, buildings kill people.”

Building damage can be structural or nonstructural. Unreinforced masonry construction is especially vulnerable to structural damage.

Nonstructural damage is often the major source of injury and damage in buildings that do not collapse.

EARTHQUAKE EFFECTS

Visual 6.1.39



Key Points

Direct impacts on health and safety from earthquakes include:

- Injuries and deaths caused by falling debris, building collapse, landslides, and secondary fires
- Family displacement, leading to stress, unsanitary living conditions, and public health issues
- Psychological impacts. Regarding the Japan earthquake and Fukushima accident, the psychological trauma of perceived risk and the evacuation have been determined to be far more detrimental than the radiation health risk of the nuclear accident
- Greater susceptibility to disease and exacerbation of chronic health issues due to stress
- Public health threats associated with compromised water treatment and wastewater treatment facilities, refugees living in cramped conditions without adequate sanitation, and damage to public health infrastructure. The cholera epidemic in Haiti after the 2010 earthquake resulted in more than 6,000 deaths and more than 350,000 hospitalizations

EARTHQUAKE EFFECTS

Visual 6.1.40

Key Points

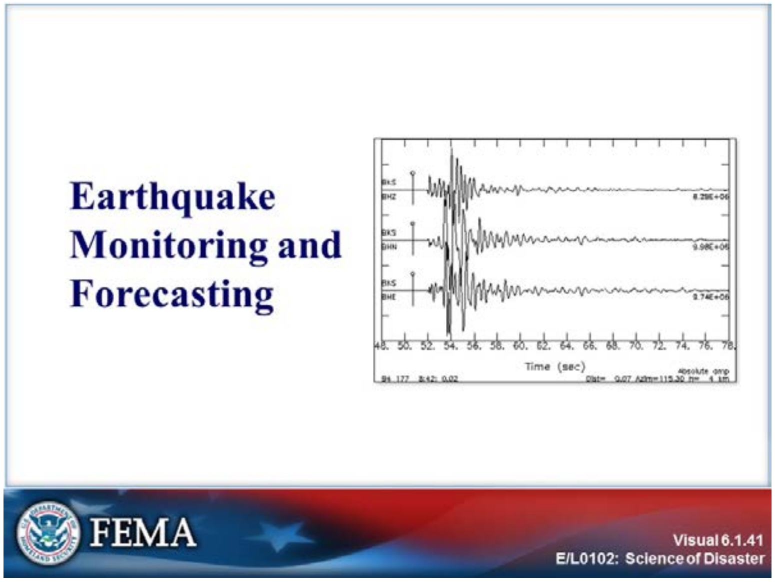
Although the acute direct health impacts of earthquakes are clearly extensive and most visible, environmental geochemists have identified numerous longer-term, sometimes less obvious health impacts resulting from environmental contaminants produced by the disaster.

Some of the many possible contaminants that can be produced by earthquakes include:

- Hazardous chemicals released from damaged or burning industrial facilities in the form of toxic gases, liquid chemicals, or smoke
- Smoke or other combustion products from earthquake-generated urban firestorms
- Toxicants in dusts from building collapse, including:
  - Caustic alkalis
  - Lead
  - Antimony
  - Mercury
  - Asbestos

EARTHQUAKE MONITORING AND FORECASTING

Visual 6.1.41

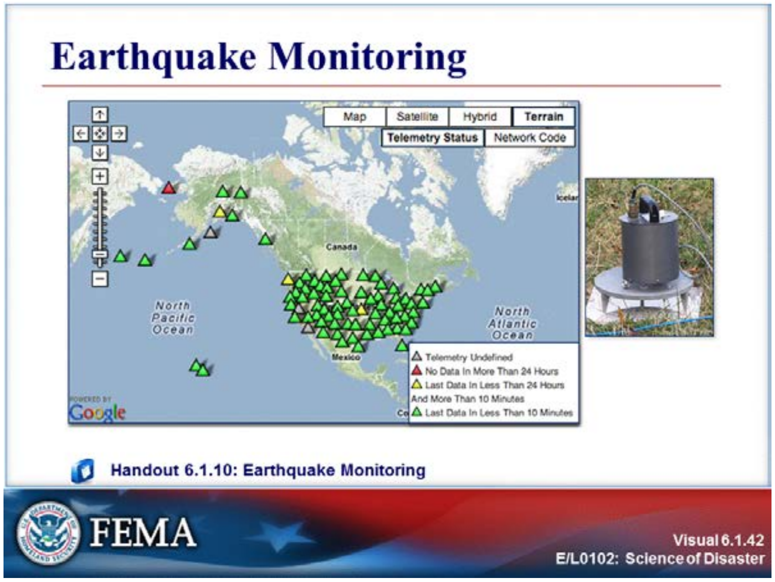


Key Points

This final section of the unit will discuss earthquake monitoring and forecasting.

EARTHQUAKE MONITORING AND FORECASTING

Visual 6.1.42



Alt Text for Visual 6.1.42
Earthquake Monitoring (This link can also be accessed at the following URL: http://earthquake.usgs.gov/monitoring/operations/network.php?virtual_network=ANSS)
A map showing earthquake monitoring:

- Telemetry Undefined
- No Data In More Than 24 Hours
- Last Data in Less Than 24 Hours And More Than 10 Minutes
- Last Data in Less than 10 minutes

Handout 6.1.10: Earthquake Monitoring

Key Points

Throughout the United States, earthquakes are monitored by networks of scientific instruments. This involves two key areas of study:

- **Seismicity:** The geographic and historical distribution (the “where?” and “how often?”) of earthquakes
- **Seismology:** The study of earthquakes and the structure of the Earth by both naturally and artificially generated seismic waves

Seismometer system: The map on the visual shows locations of seismometers that continuously record ground motion for the Advanced National Seismic System. Additional stations are operated by regional networks in areas of higher seismicity. Other instruments are deployed temporarily to capture data during aftershock sequences or for other scientific studies.

Seismometers can measure ground motion in three orientations (typically north/south, east/west, and up/down), capturing a complete representation of ground motion at a site.

EARTHQUAKE MONITORING AND FORECASTING

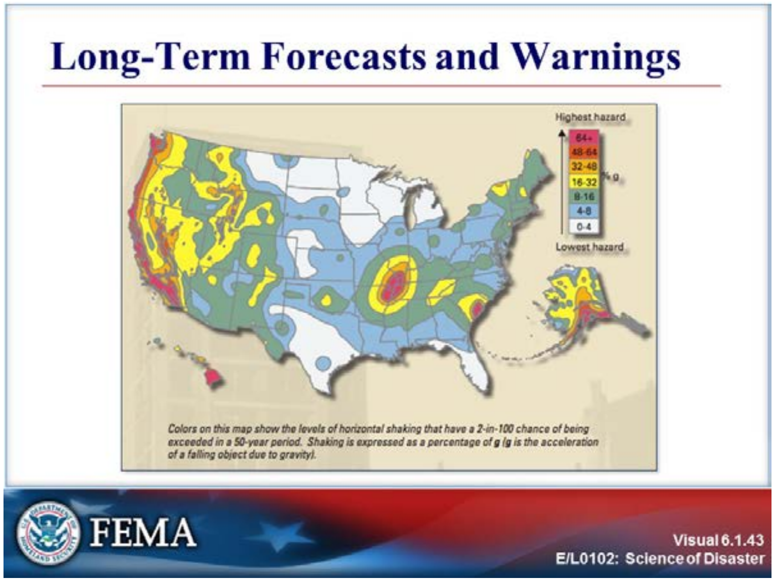
Visual 6.1.42 (Continued)

GPS networks: The map on the visual shows locations of global positioning system (GPS) networks, which monitor deformation as earthquake faults accumulate strain, or rupture. Some GPS stations operate continuously, while others are deployed temporarily.

See Color Handout 6.1.10: Earthquake Monitoring

EARTHQUAKE MONITORING AND FORECASTING

Visual 6.1.43



Alt text for image 6.1.43
Map showing the levels of horizontal shaking that have a 2-in-100 chance of being exceeded in a 50-year period. Shaking is expressed as a percentage of g (g is the acceleration of the falling object due to gravity). There is the highest hazard along the west coast (with 64+% g) to 16-31%g towards central US. Towards the mid-west the highest hazard moves to 8-16%g. Central US has 4-8 highest hazard, with an increase to 64+%g around the borders where Arkansas, Missouri, Kentucky, Tennessee and Mississippi meet. There is an increase of Earthquakes along South Carolina along the Atlantic Ocean at the highest hazard of 64+%g. The Northeast is from 8-16%g highest hazard. Alaska has an earthquake hazard of 64+ along the south coast, decreasing northwards up to 0-4%g. Hawaii has the highest hazard on the Island of Hawaii at 64+, Kihei is 32-48, Honolulu us 16-32, and Koloa is 8-16%g. The mid-north states have a low hazard from 0-4. South Florida and South Texas also have a low of 0-4%g.

Key Points

Prediction: To put it simply, scientists cannot predict earthquakes. An earthquake prediction requires three components: statements of when, where, and what size the earthquake will be.

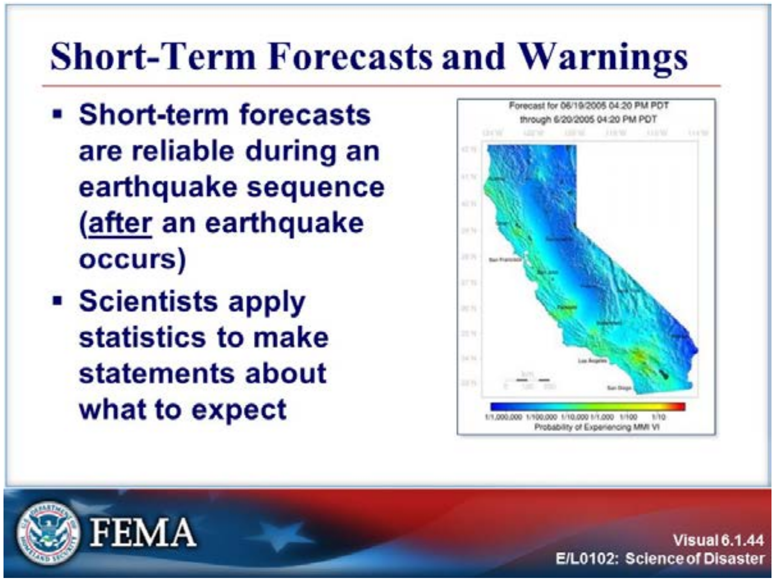
Within the scientific community there is debate about whether it will ever be possible to predict earthquakes, even with unlimited data and additional understanding. Earthquakes involve chaotic processes and may be inherently unpredictable.

Forecasts: What scientists can do instead is to develop earthquake forecasts. These are statements that involve probabilities and uncertainties and discuss the likelihood of an earthquake happening over a particular timeframe.

This National Seismic Hazard Map is an example of a long-term forecast—in this case, the chance of exceeding a certain level of shaking in 50 years.

EARTHQUAKE MONITORING AND FORECASTING

Visual 6.1.44



Key Points

Forecast reliability: Long-term earthquake forecasts are more accurate than short-term earthquake forecasts. This is the opposite of weather forecasting, where short-term weather forecasts for the next day are substantially more accurate than the long-term climate forecasts that cover decades.

Short-term earthquake forecasts are most reliable during an earthquake sequence—that is, **after** an earthquake has occurred. At that point, scientists can apply the statistics regarding occurrence of foreshocks and aftershocks to make statements about what to expect next.

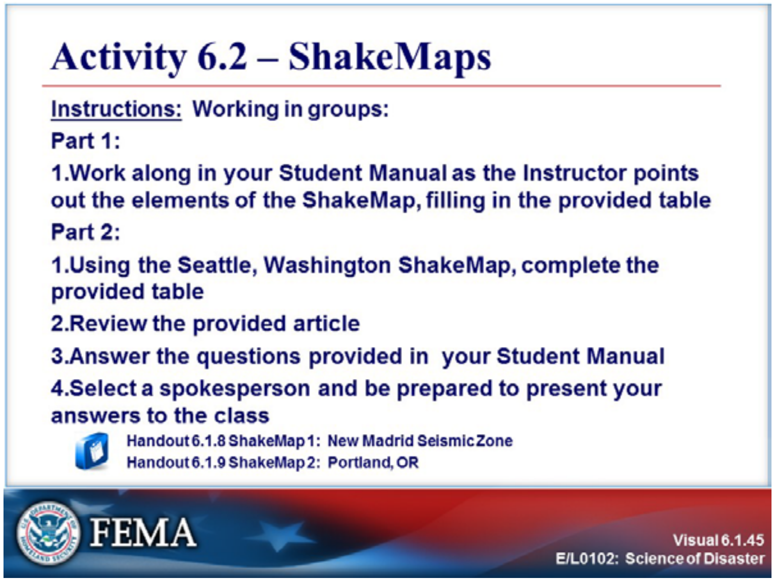
Earthquake Early Warning is operational in several countries, including Japan and Mexico, and is being prototyped in California. An Earthquake Early Warning system uses computers that detect that a large earthquake has begun, then calculate how long until strong shaking will arrive at a given location, and then send an alert that can prepare communities in many ways.

The map shows an early, discontinued prototype of an “operational earthquake forecasting” system that used earthquake occurrence and statistics to forecast likelihood of damaging ground shaking in the next 24 hours. A new version of this product is currently in development in a collaboration among scientists and emergency managers.

Earthquake Early Warning successfully protected Japan from most damage during the magnitude-9 Tohoku earthquake in 2011. It was the accompanying tsunami that caused widespread devastation.

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.45



Key Points

<u>Instructions</u>: Working in groups:

Part 1:

1. As the Instructor points out the elements of the Portland ShakeMap (Handout 6.1.11), fill in the provided table in your Student Manual.

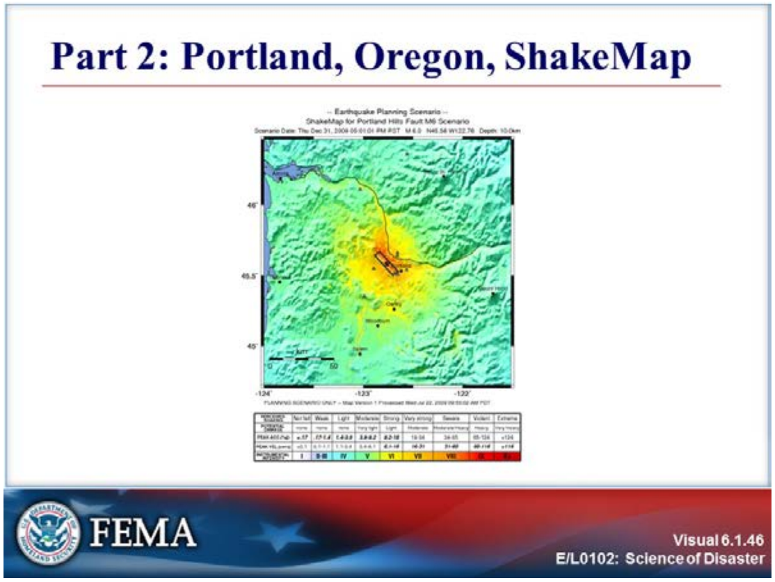
Part 2:

1. Review the provided article (Activity 6.2 Job Aid).
2. Answer the questions provided in your Student Manual (Activity 6.2 Worksheet).
3. Select a spokesperson and be prepared to present your answers to the class.

See Color Handout 6.1.11 ShakeMap 2: Portland, OR

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46



Key Points

Activity 6.2 Worksheet

<u>Scenario</u>: You are the Emergency Management Director for Multnomah County (Portland), Oregon. The County's Zoning Administrator has drafted for the County Board's consideration for adoption new ordinances that meet current recommendations for your risk profile. There has not been a damaging earthquake in many years, and there is some concern among community leaders that the additional costs of compliance may be an undue burden on the homeowners and businesses in your County. Your supervisor, the County Executive, has asked you to work with the Zoning Administrator to create a tabletop exercise to show community leaders (elected officials, business leaders, leading citizens, media) about the risk of the area.

The USGS has provided the Administrator with a "likely but not the most catastrophic" scenario for your area in the form of the following ShakeMap.

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

Event Name	
Magnitude	
Fault Rupture Length (km)	
Highest Intensity	
Area w/ Potential Damage (km*2)	
Area w/ Heavy or Very Heavy Damage (km*2)	
Cities in Heavy Damage Zone	

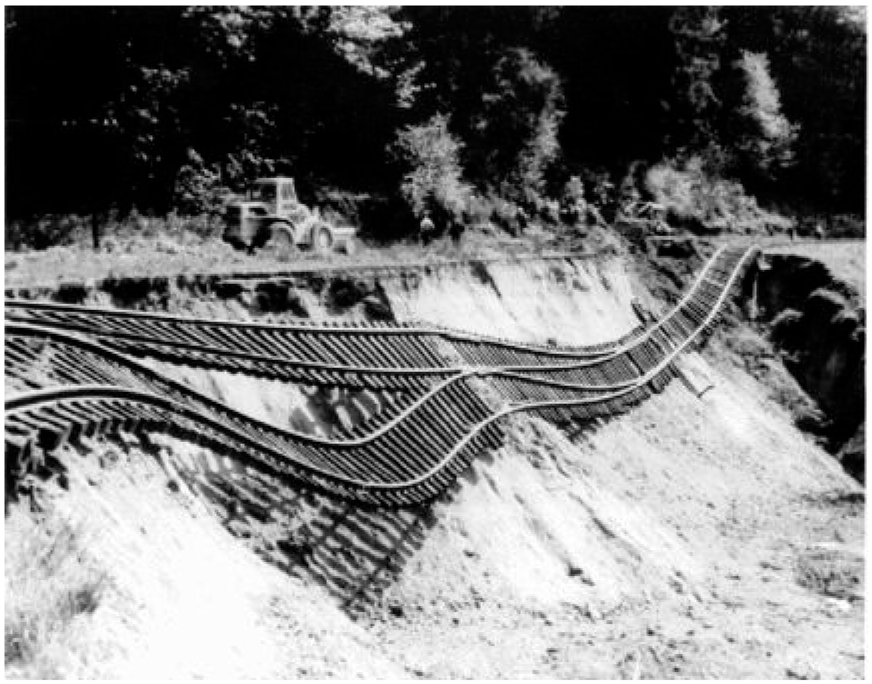
ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

Activity 6.2 Job Aid

Cascadia Subduction Zone: Are Portland and Seattle prepared for an earthquake and tsunami?
By on July 22, 2010 at 8:18 AM, updated July 15, 2015 at 5:10 PM

Top of Form



www.pnsn.org

A landslide near Olympia, Washington after a 1965 earthquake.

Bottom of Form

A string of recent earthquakes along Western coastlines, from Mt. Redoubt in Alaska to Chile in South America, has led many to wonder if the Pacific Northwest is next. In fact, on July 19 a 5.1 magnitude earthquake hit off the coast of Vancouver, British Columbia.

ACTIVITY 6.2 – SHAKEMAPS

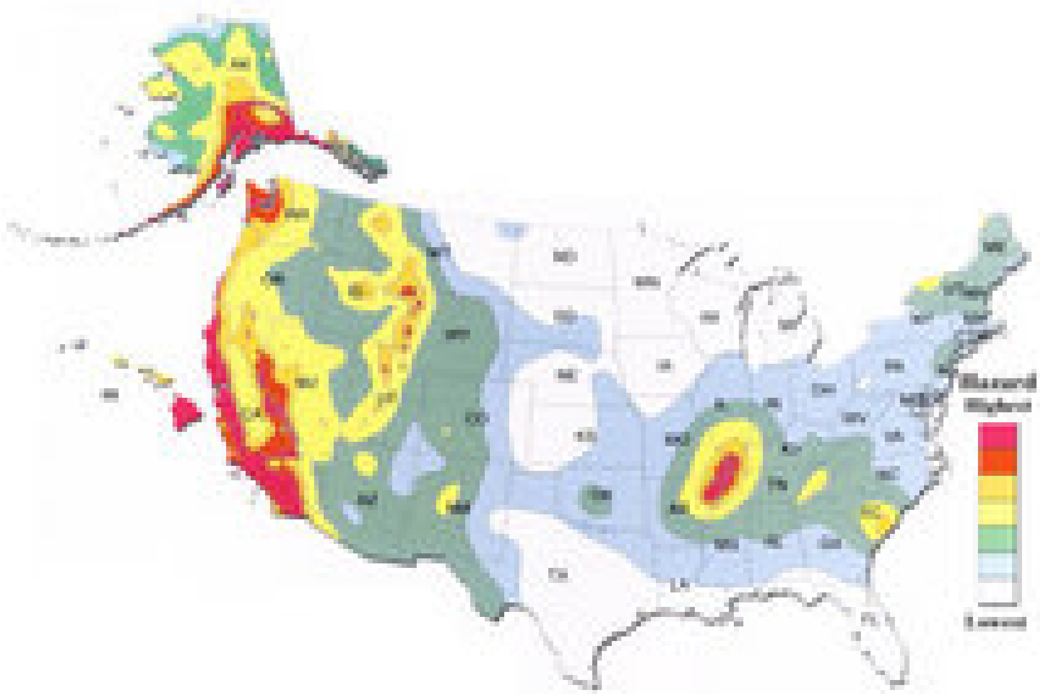
Visual 6.1.46 (Continued)

Will Oregon buildings and roads crumble? Are Local and State governments prepared? Do citizens have proper supplies in their homes, should a massive quake bring local and regional commerce to a halt?

For West Coast inhabitants, quakes in California are expected. The San Andreas Fault, the world's longest fault line, runs more than 800 miles through the State. But what about Washington and Oregon?

Oregon State Senate President Peter Courtney has earthquake preparedness high on his list of priorities. He spoke about Portland earthquake building codes at a town hall in April 2010.

Portland building codes: Can they handle the 'mother of all quakes'? Experts talk about Portland earthquake building codes at a town hall in April 2010.



USGS Earthquake hazard map (This link can also be accessed at the following URL: http://earthquake.usgs.gov/monitoring/anss/) of the highest danger zones in the U.S.

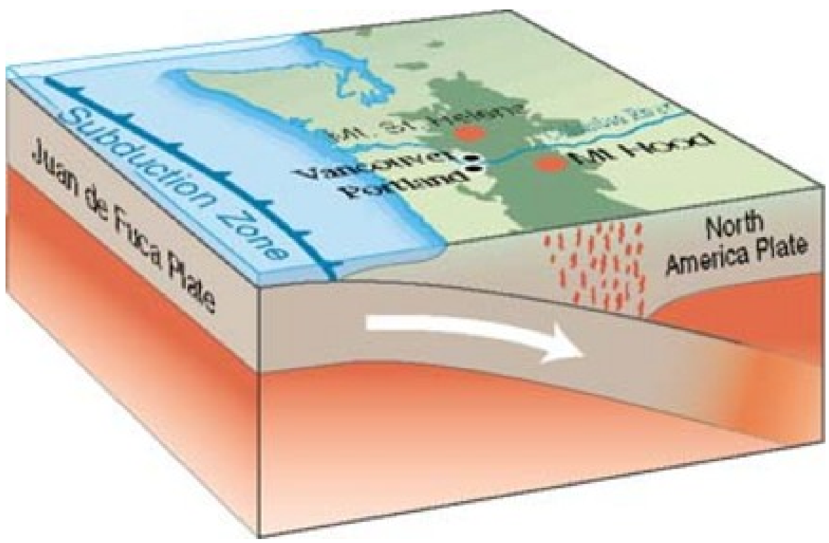
ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.48 (Continued)

Earthquake hot spots

Washington and Oregon are in one of the most dangerous U.S. earthquake zones. In a list of states ranked by number of earthquakes with a magnitude 3.5 or higher in the past 30 years, Alaska holds the number one spot and, not surprisingly, California is second.

Washington is ranked fifth with 424 quakes, and Oregon is not far behind in the 10th spot with 73 quakes. Why are Washington and Oregon ranked so high?



The Cascadia Subduction Zone lies around 50 miles off the coast of Oregon, Washington, British Columbia, and Northern California.

Cascadia Subduction Zone

About 50 miles offshore under the Pacific Ocean runs the Cascadia Subduction Zone, reaching from Northern California to British Columbia—more than 600 miles long. Unlike the San Andreas Fault, where two tectonic plates butt up against each other, in a subduction zone one plate is pushed under the other.

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

In Cascadia, the *Juan de Fuca Plate* is being shoved under the *North American Plate*.

According to the Pacific Northwest Seismic Network, subduction zones produce the largest earthquakes, which can exceed magnitude 9.0. Cascadia has a history of significant quakes every 400 years and experts predict that after years of storing up energy, another Cascadia quake is due.

In subduction zone earthquakes, not only are there strong, long ground-shaking events, but multiple aftershocks and tsunamis.

Scientists agree it's not a matter of if, but when….

On May 12, a magnitude 5.1 quake centered about 300 miles southwest of Portland struck off the Oregon Coast. May 14 brought a swarm of earthquakes near Mt. Hood ranging from magnitude 2.4 to 3.0. On May 25, an earthquake hit near Seattle. On July 19, a 5.1 magnitude earthquake hit off the coast of Vancouver, British Columbia. Should you consider these wake-up calls or are you tempted to push the snooze button again?

Earthquake damage outside Seattle's Union Station, 1965.

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

Is the Pacific Northwest ready for the next big one?

The 7.2 Easter earthquake on the California/Mexico border and the 8.8 Chile earthquake in February have given experts cause for alarm. If a country with stricter earthquake building codes than Japan and California loses as many buildings and people as Chile did, how will cities like Portland and Seattle fare?

Peter Yanev, an engineer who advises companies how to build to withstand earthquakes, says not well:

Many seismologists believe the Pacific Northwest is overdue for another mega-quake. Yet in cities like Seattle, Vancouver, and Portland, Ore., hardly any building is designed to withstand such a huge jolt.

...Pacific Northwest cities are full of buildings with slender structural frames and fewer and smaller shear walls. In a mega-quake, many of the region's iconic tall buildings would probably collapse. The loss of life and property from such a disaster would be far worse than the damage and death suffered in Chile.

Yanev calls the Chile quake the most important in 100 years, primarily because it is the largest quake to hit a developed nation with strict earthquake building codes. After the last major quake in 1960, Chile strengthened its earthquake building standards to give the country some of the strictest.

Building to withstand earthquakes

Earthquake building codes are based on a city's likelihood of being hit by a major quake and according to Yanev, this means Seattle's and Portland's buildings are only half the strength of California's, much less Chile's.

Do strict building codes necessarily mean stronger buildings? No. Though the codes are in place, not all are enforced.

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

"I've never made walls this thin for this kind of building," said civil engineer Carolina Astorga, showing the AP the damaged foundations of her 19-story apartment building in Santiago.

She moved in a month before the quake. Now the building is sunken, leaning, and uninhabitable.

It's not enough to have a good law, you have to follow it, says Rodolfo Saragoni, the University of Chile's top seismic engineer.

-- The Associated Press

Buildings and bridges: How does Portland measure up?

How will structures in the Northwest fare in a major quake and what kind of codes are in place that ensure the public's safety?

Buildings

Oregon's building codes are called the Oregon Structural Specialty Codes, previously the Uniform Building Codes, and have been around since 1973. Scientists' understanding of the Cascadia Subduction Zone is relatively new—around 20 years.

Because of this, Ivan Wong of the URS Corporation said around 99 percent of Oregon's buildings are not designed to withstand the amount of gravitational acceleration or "ground G" found in a subduction zone earthquake.

"Prior to 1988 ... our building code maps did not consider the Cascadia Subduction Zone."

Wong described what to expect from a subduction zone earthquake at a town hall meeting during the Seismological Society of America's annual meeting. Although the building codes have been reworked since 1973, they are not foolproof.

With 30 years of engineering experience, Jed Sampson of the Portland Bureau of Development Services said,

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

"The problem with our state code is the majority of the things we designed for after 1993, I believe, are going to perform pretty well ... but our old buildings are really going to have problems. Those buildings are not designed for earthquakes. The problem is ... the seismic load was very low until 1988. In 1993 we actually started designing for the seismic forces."

Commercial structures designed before 1993 were not built to withstand earthquakes and according to the codes, it's not until an existing building changes use that it is required to retrofit. A grandfather clause says if an office building in the '20s is still an office building today, then the owners aren't required to retrofit, which means that a substantial number of existing structures have not been upgraded.

Craig Weaver of the U.S. Geological Survey agrees, *"...the building codes currently don't do a very good job of handling the long-period motions we expect from a subduction zone earthquake."*

Besides commercial structures, a report from 2007 by the Oregon Department of Geology and Minerals Industry (DOGAMI) shows that more than 1,000 schools, hospitals and other emergency facilities are at "high" or "very high" risk to collapse during a major earthquake. Portland Public Schools, with 89 campuses and a population of 46,000 students, not including teachers and staff, could be destroyed. Seventy-five percent of these school facilities were built before 1930 and only two were built in the last 30 years, according to Sampson.

Yumei Wang of DOGAMI called some of the schools "death traps" because during a major quake they will most likely end up in rubble piles.

In February, 13 public education buildings and 11 emergency service facilities in Oregon were chosen to receive grants worth $15 million from the Seismic Rehabilitation Grant Program (SRGP). The program seeks to physically strengthen schools and emergency service buildings.

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

Top of Form

ODOT
Seismic retrofit of Marquam Bridge using restrain cables

Bottom of Form

Bridges and roads

If Oregon's buildings are at risk to tumble during an earthquake, how do its bridges and roads measure up?

According to a study done by ODOT in 2009, 64 percent of Oregon bridges were built before the '70s when earthquakes weren't a major consideration in the construction process. Of approximately 2,550 State-owned bridges studied in 1993 for seismic deficiencies, more than 1,600 were found to have "insufficient capacity to resist earthquake loading."

At the time of the 1993 CH2M Hill Seismic Prioritization Report, a lack of funding limited the retrofitting process. In 2009, only 178 bridges had received a seismic retrofit and not necessarily the State's most vulnerable, according to the report.

Liquefaction

Besides the "G" forces in a subduction earthquake, another cause of structural failure is liquefaction—the process of soil transforming suddenly from a solid to a liquefied state. Many of our roads and bridges sit on soil prone to liquefaction. Wang said,

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

"The Fremont Bridge was designed in 1960 to very inadequate, if any, seismic standards. Not only the bridge itself, but the approaches and the abutments are subject to problems with poor soils."

Oregon's bridges and roads are definitely on shaky ground, but according to Wang, so are most of Oregon's liquid fuel supplies and some very important high-voltage electric transmission lines. Should a major quake hit, this reality poses a serious threat to Oregon and Washington's infrastructures.

What needs to be done?

There is much to be done to make the Pacific Northwest more earthquake-resilient.

"Earthquake science alone does not make Oregon or the nation a safer place. The science needs to be bridged into action." — Yumei Wang, DOGAMI

Wang gave three critical recommendations:

- Improve the safety in coastal communities that are at risk for tsunamis.
- Prioritize and mitigate critical infrastructures on poor soils such as ODOT bridges.
- Fix weak structures—highlighting schools and emergency facilities.

How is the local government handling the idea of a mega-earthquake?

The longest-tenured member serving Oregon's legislature in the past 10 years, Oregon State Senate President Peter Courtney has backed 10 successful seismic safety bills. He is personally invested in preparing Oregonians for a disaster of this magnitude.

"If the mother-of-all-quakes is coming to Oregon, my Oregon, in the next 50 years, it's coming at any time. That's the first thing I tell the public."

In November 2002, more than 50 percent of voters approved legislation to spend $1 billion to retrofit schools, police, hospitals, and fire stations.

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

Since then, according to Courtney, Governors, the National Guard, State agencies and emergency services have fought the decision. A few months ago, nine years after the bond measures passed, grants have finally been awarded.

Why the delay? Courtney says it's because the priorities weren't there, attitudes weren't right, or people assume we have another 50 years before a major quake hits this area. He said people need to personalize it in order to make anything happen. It won't become a State issue until it becomes a Local issue.

"If the individual is not prepared to deal with this and want it in the family, no state legislature, no government, no state agency, will make it happen. It is as simple as that." -- Peter Courtney

ACTIVITY 6.2 – SHAKEMAPS

Visual 6.1.46 (Continued)

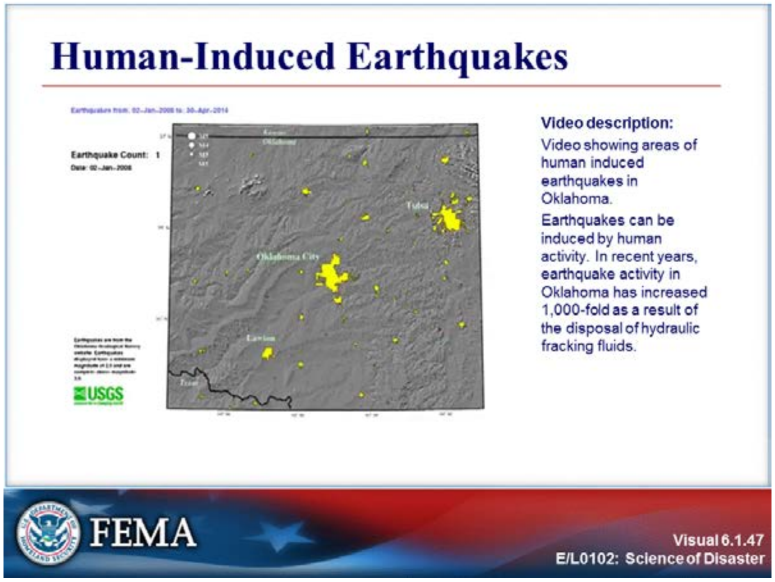
Activity 6.2 Part 2 Worksheet

1. **You are brainstorming what points you want to highlight to the exercise participants. Use the ShakeMap and information from the news article to create bullet points of learning lessons that can be incorporated into the scenario (i.e., use science to highlight the risks and bring people to the idea of mitigating the risk to citizens with stronger building codes).**

2. **Whom might you invite as technical expertise to answer questions in your exercise?**

HUMAN-INDUCED EARTHQUAKES

Visual 6.1.47



Key Points

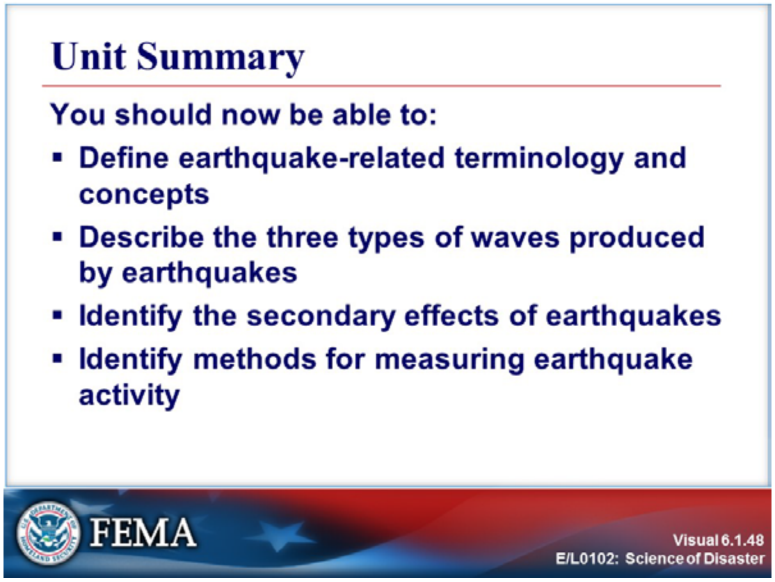
Earthquakes can be induced by human activity. In recent years, earthquake activity in Oklahoma has increased 1,000-fold as a result of the disposal of hydraulic fracking fluids.

Year	# of Earthquakes > 2.5 Magnitude In the first 6 months of each year
2000	0
2005	3
2010	70
2013	113
2014	817
2015	1,526
2016	1,074

Hydraulic fracturing is a technique used to recover oil and natural gas from rock units that have low permeability. Water and various chemicals are injected at high pressure into rock units that have oil and natural gas. The injected water creates pathways (i.e., fractures) for the hydrocarbons to move through the rock and rise to the surface to be recovered. The fracking process does not generate earthquakes, but the disposal of the fluids does. The most common method of disposing the fluids is injecting them into highly porous and permeable rock units at great depth. In Oklahoma City, four wastewater injection wells inject 4 million barrels of fluids into the ground every month. The effect of water injection is to lubricate any old fault zones and increase the fluid pressure, which reduces the frictional forces holding the fault together. As a result, earthquakes occur. Forty-five percent of earthquakes in Oklahoma have been attributed to four injection wells. And earthquakes as far as 20 miles away from injection wells have been linked to the injection process.

UNIT SUMMARY

Visual 6.1.48



Key Points

Do you have any questions about the material covered in this unit?

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UNIT 2. TSUNAMIS

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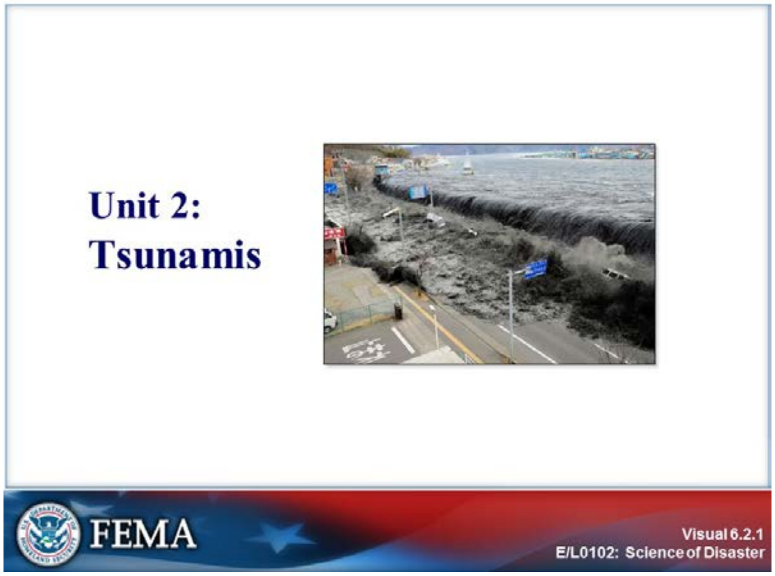
INTRODUCTION

Visual 6.2.1



Key Points

Welcome to Unit 2: Tsunamis.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Characteristics of Tsunamis	10 minutes
Tsunami Effects	5 minutes
Tsunami Distribution and Warnings	5 minutes
Unit Summary	5 minutes
Total Time	**30 minutes**

INTRODUCTION

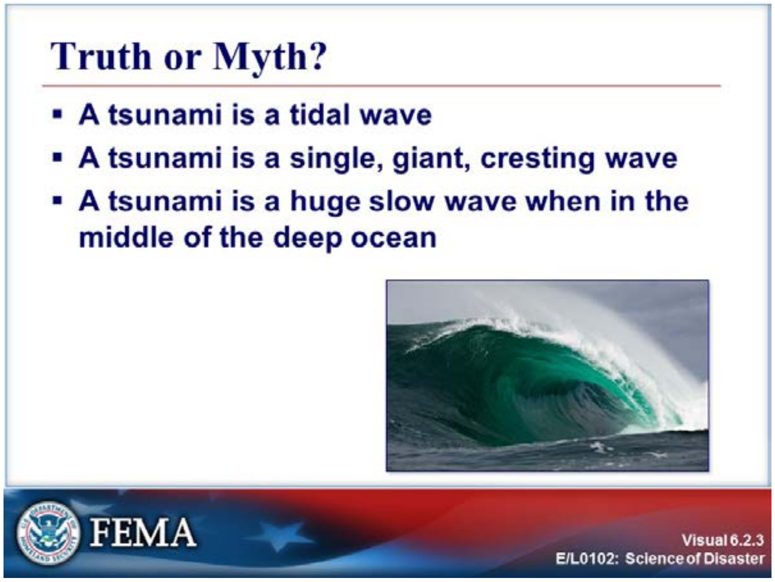
Visual 6.2.2

Key Points

Review the unit objectives as shown on the visual.

INTRODUCTION

Visual 6.2.3



Key Points

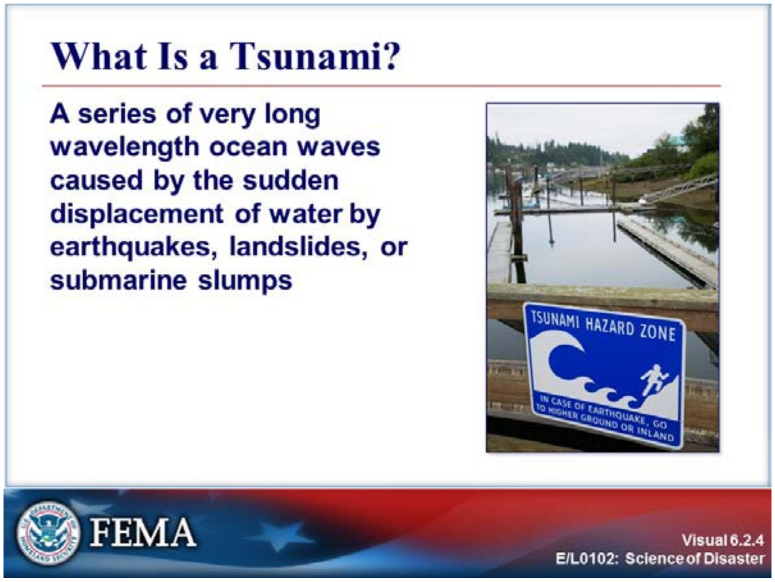
Truth or myth? A tsunami is a tidal wave.

Truth or myth? A tsunami is a single giant cresting wave.

Truth or myth? A tsunami is a huge slow wave when in the middle of the deep ocean.

INTRODUCTION

Visual 6.2.4



Key Points

A tsunami is a series of very-long-wavelength ocean waves caused by the sudden displacement of water by earthquakes, landslides, or submarine slumps. The word tsunami comes from a Japanese word meaning “harbor wave.” This is pertinent because tsunamis cause destruction particularly in harbors and marinas. Tsunamis are among the most devastating of geologic disasters. Like other hazards, tsunamis come in many sizes, and the most common are small tsunamis that cause little or no harm.

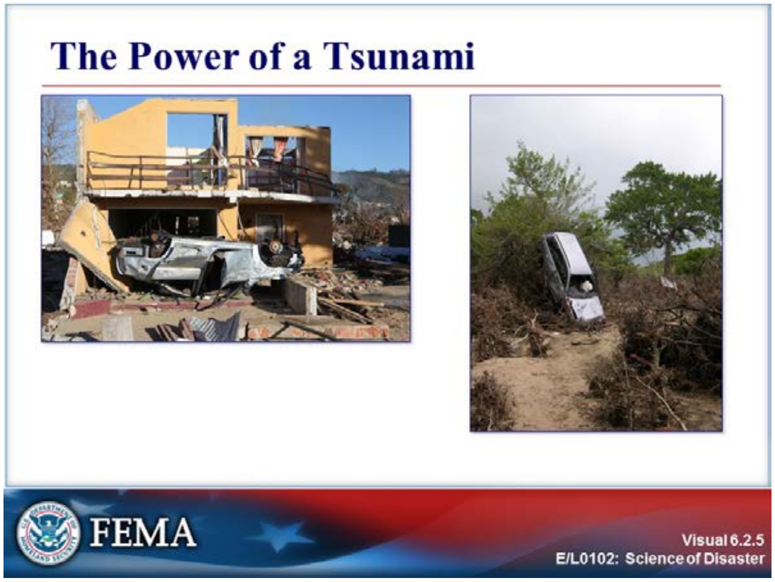
Tsunamis are **secondary hazards,** which means that they are created as a consequence of another hazard that rapidly displaces a large volume of water.

Undersea earthquakes are the most common cause of tsunamis, and the biggest undersea earthquakes (magnitude 8.8 or larger) create tsunamis with enough energy to cause damage thousands of miles away. Earthquakes large enough to generate extremely large tsunamis occur at a frequency of decades rather than millennia. Other events that cause tsunamis include:

- Underwater landslides
- Volcanic eruptions
- Calving icebergs
- Meteorite impacts (very rarely)

INTRODUCTION

Visual 6.2.5



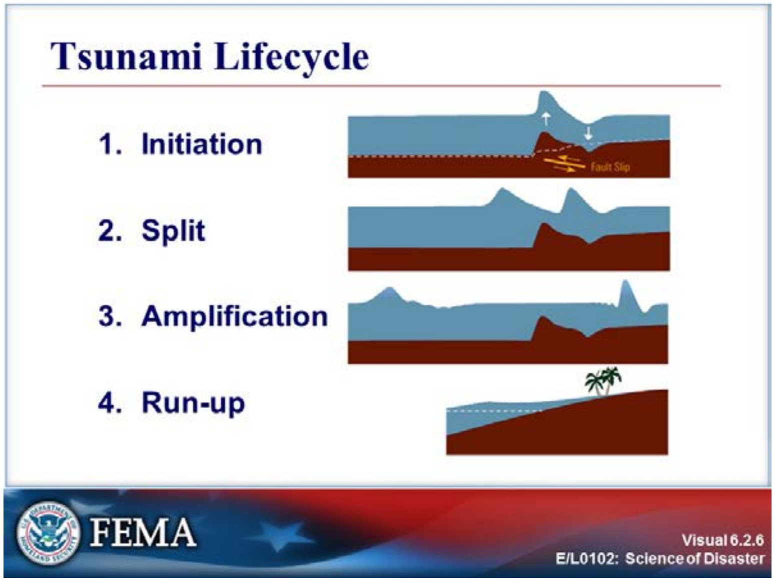
Key Points

Tsunamis are among the most devastating of geologic disasters. For example, these photos show:

1. A house and a car destroyed by a tsunami in the coastal city of Dichato, Chile. The tsunami height was about 32 feet following a magnitude-8.8 earthquake on February 27, 2010. Several hundred homes were destroyed (Credit: U.S. Geological Survey, photo by Walter D. Mooney).
2. A car transported by the 2004 tsunami in Sri Lanka (Credit: U.S. Geological Survey, photo by Dr. Robert Morton).

CHARACTERISTICS OF TSUNAMIS

Visual 6.2.6



Key Points

Tsunami lifecycle: There are four phases of a tsunami lifecycle:

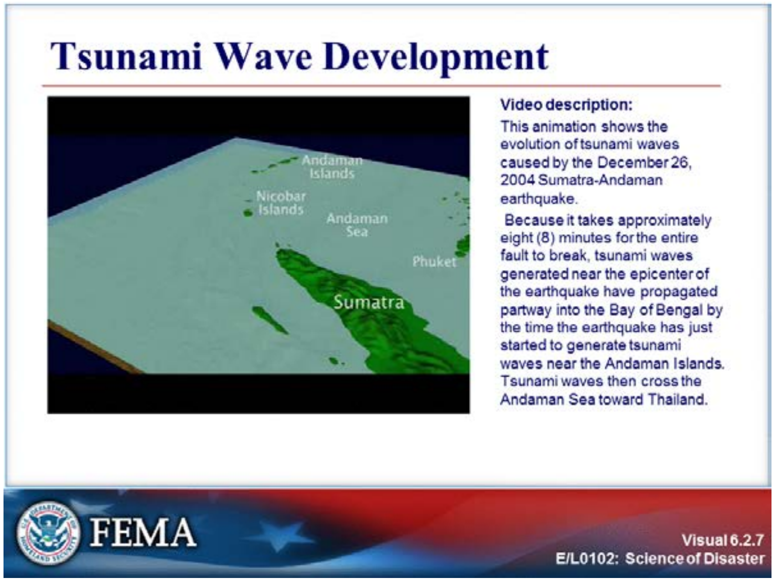
1. **Initiation:** A geological event causes the tsunami. Water displaced during an earthquake uplifts some seafloor (up arrow) and down-drops other seafloor (down arrow).
2. **Split:** The entire column of water gets displaced and splits into a distant tsunami (moving toward the deep ocean) and local tsunami (moving toward the nearby coast).
3. **Amplification:** The local tsunami's amplitude increases. When a tsunami reaches shallower water near shore, it slows down, and the energy that previously went into speed now goes into amplitude.
4. **Run-up:** The tsunami's peak travels on shore.

Height: The wave heights are greatly exaggerated in these images. In the open ocean, the waves may be only inches higher than the ocean surface—even in the largest tsunamis—but the energy is moving through the entire column of ocean water.

Speed: In the open ocean, most of a tsunami's energy goes into wave propagation (i.e., travel), and the wave moves at 500 to 600 miles per hour—about as fast as a jet. When tsunamis reach shallow water, they slow from jet speed to auto speed. On land they slow down still more, to about 20 mph.

CHARACTERISTICS OF TSUNAMIS

Visual 6.2.7



Key Points

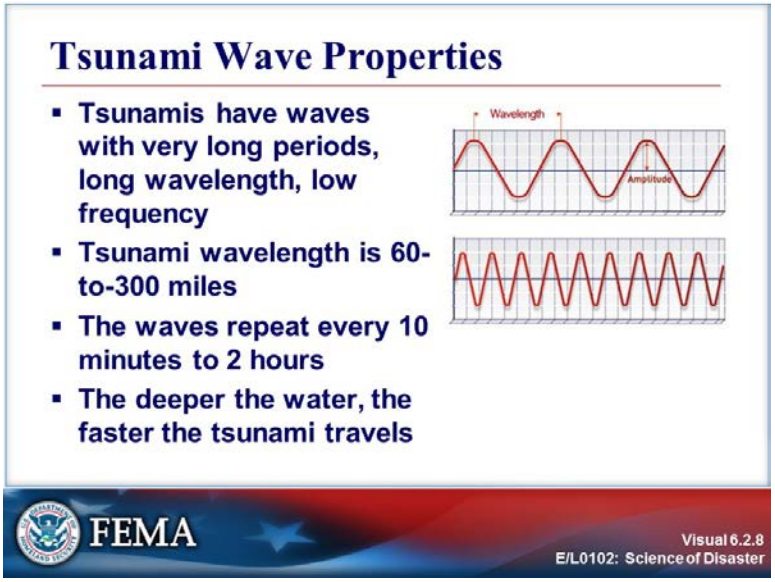
Video description:

This animation shows the evolution of tsunami waves caused by the December 26, 2004 Sumatra-Andaman earthquake.

Because it takes approximately eight (8) minutes for the entire fault to break, tsunami waves generated near the epicenter of the earthquake have propagated partway into the Bay of Bengal by the time the earthquake has just started to generate tsunami waves near the Andaman Islands. Tsunami waves then cross the Andaman Sea toward Thailand.

CHARACTERISTICS OF TSUNAMIS

Visual 6.2.8



Key Points

A tsunami, like an earthquake or any other wave phenomenon, is actually a series of waves called a wave train.

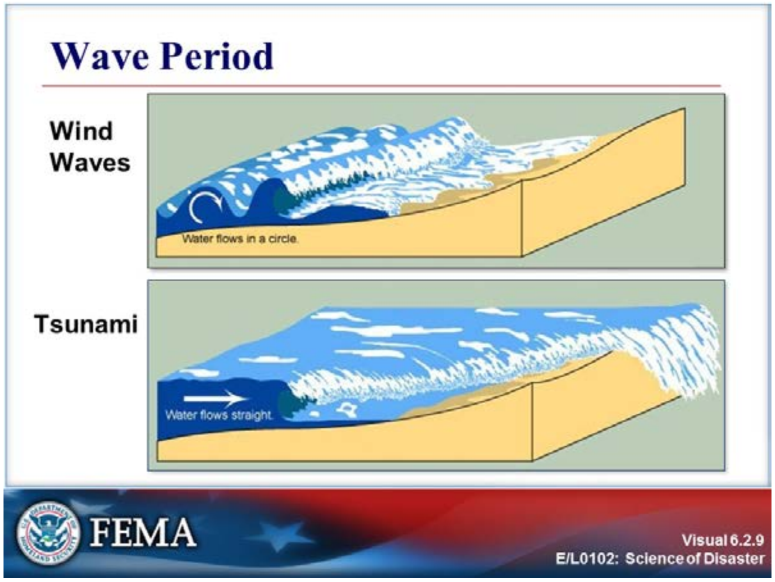
Period: The period measures the time it takes successive waves in the train to pass a given point. Tsunamis have waves with very long periods (also called low-frequency). The waves repeat every 10 minutes to 2 hours. In comparison, waves caused by tides or wind have periods of 5–20 seconds.

Wavelength: In a tsunami, the wavelength (distance from peak to peak) is 60–300 miles. In a wave from a tide or wind, the wavelength is 300–600 feet.

Speed: The speed of a tsunami varies as the square root of water depth. The deeper the water, the faster the tsunami travels.

CHARACTERISTICS OF TSUNAMIS

Visual 6.2.9



Key Points

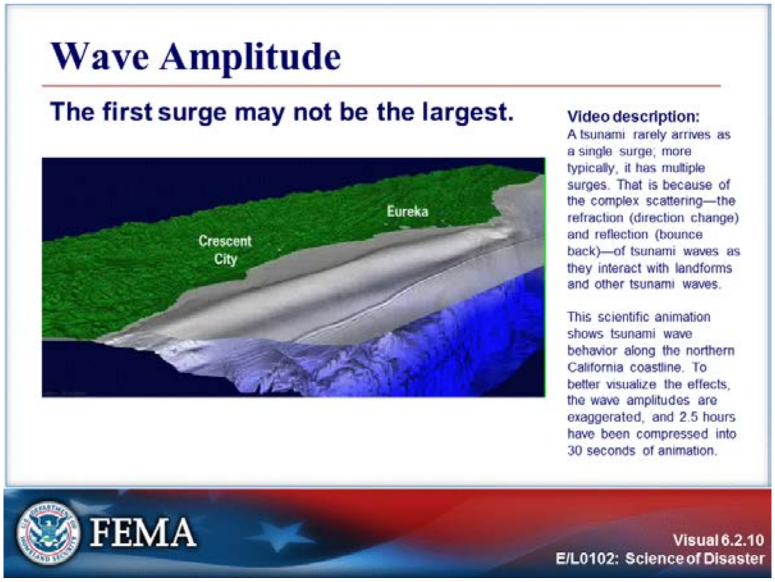
Why do tsunamis act differently than the ocean waves created by wind forces? The rate at which a wave loses energy is inversely related to its wavelength. Short-period, high-frequency waves lose energy more quickly than long-period, low-frequency waves.

- Wind waves are short-period waves. With wind waves, the water flows in a circular pattern, and the waves come and go without flooding higher areas.

- By contrast, tsunamis are long-period, low-frequency waves that move in a straight path as a great surge of water. Tsunamis come on land with enormous force, and recede with nearly equal force. Sometimes, tsunamis crest in shallow water and resemble waves made by tidal forces. More often they appear as walls of water or turbulent surge that resembles hurricane storm surge.

CHARACTERISTICS OF TSUNAMIS

Visual 6.2.10



Key Points

Video description:

A tsunami rarely arrives as a single surge; more typically, it has multiple surges. That is because of the complex scattering—the refraction (direction change) and reflection (bounce back)—of tsunami waves as they interact with landforms and other tsunami waves.

This scientific animation shows tsunami wave behavior along the northern California coastline. To better visualize the effects, the wave amplitudes are exaggerated, and 2.5 hours have been compressed into 30 seconds of animation.

A tsunami rarely arrives as a single surge; more typically, it has multiple surges. That is because of the complex scattering—the refraction (direction change) and reflection (bounce back)—of tsunami waves as they interact with landforms and other tsunami waves.

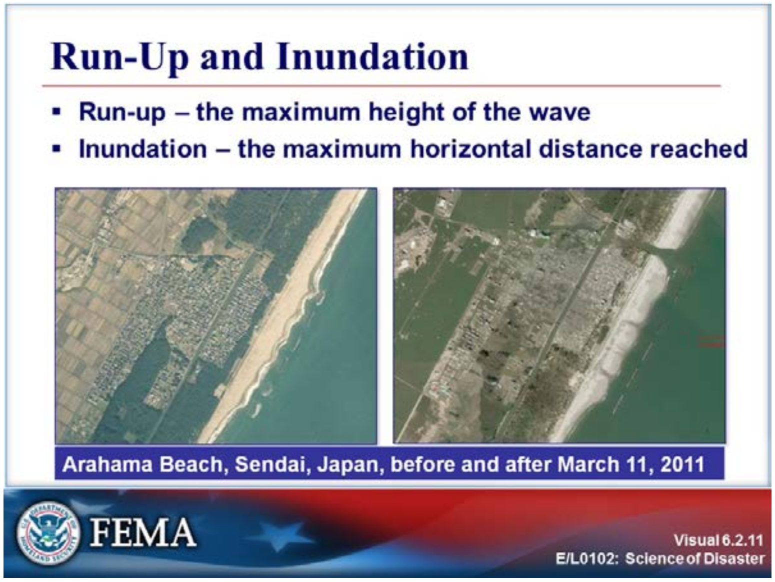
The scattering and wave interference processes are complicated in the open ocean and even more complicated near shore, where tsunami energy is scattered by sharp variations in the coastline.

In addition, a tsunami can generate a particular type of trapped wave called an edge wave, which travels back and forth parallel to shore. The effects of wave interference, scattering, and trapping combine to produce multiple arrivals of a tsunami.

The number of arrivals and the amplitudes of each wave will vary depending on the coastal properties, the exact travel direction, and other specifics of how the tsunami was generated. They will vary from place to place and event to event. In the largest tsunamis, surge can continue for many hours, even for more than a day.

CHARACTERISTICS OF TSUNAMIS

Visual 6.2.11



Key Points

How tsunami reach is measured: A tsunami's reach on shore is measured in two ways:

- **Run-up**, which is the height above sea level that the tsunami achieves, and
- **Inundation**, which is the maximum horizontal distance—that is, how far inland—the tsunami reaches

Factors that influence run-up and inundation: The run-up and the inundation depend on many factors, including:

- Energy of the tsunami
- Topography of the land
- Orientation of the land to the oncoming wave
- Tide

A tsunami that arrives at high tide will reach farther inland than a tsunami that arrives at low tide. The energy of the tsunami depends on how far it has traveled and how large the event was that created it.

The photos on this visual show a beach in Japan, before and after the 2011 tsunami. The white structure between the community and the ocean is a seawall, built for tsunami protection. However, it was not built for a tsunami as large as the one that occurred in 2011. Experts underestimated the possible size of earthquakes that could occur offshore in this region, and when the fault ruptured, the rock under Japan dropped down relative to the rock under the ocean, lowering the elevation along the coast. As a consequence, inundation extended as far as six (6) miles inland.

CHARACTERISTICS OF TSUNAMIS

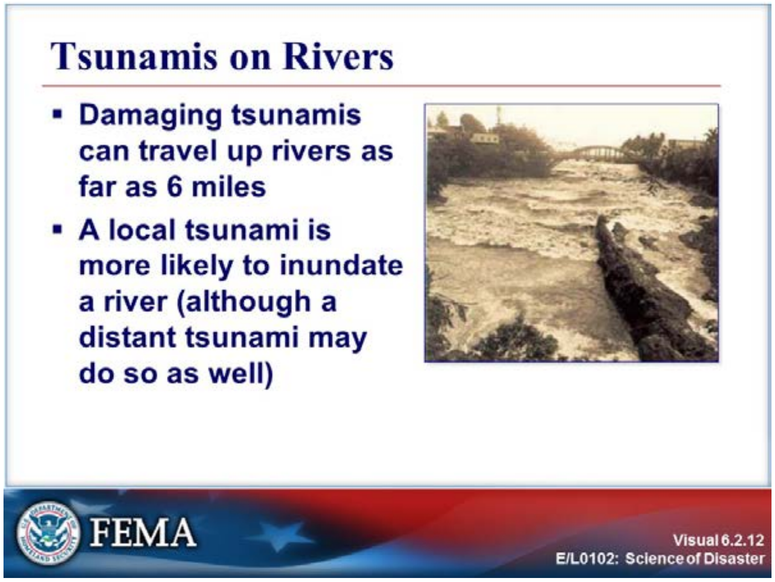
Visual 6.2.11 (Continued)

Many communities in Sendai province had seawalls that were overtopped by this tsunami, causing enormous devastation and resulting in tens of thousands of avoidable deaths. Residents did not flee to higher ground when they felt earthquake shaking, because they expected their seawalls to protect them, as had happened in previous, smaller tsunamis.

In the photo below, a researcher is measuring a tsunami's run-up, marked by a gouge in the tree made by floating debris.

TSUNAMI EFFECTS

Visual 6.2.12



Key Points

Tsunami inundation is a threat not just along coastlines. Damaging tsunamis also frequently travel up rivers, as far as six (6) miles and possibly more.

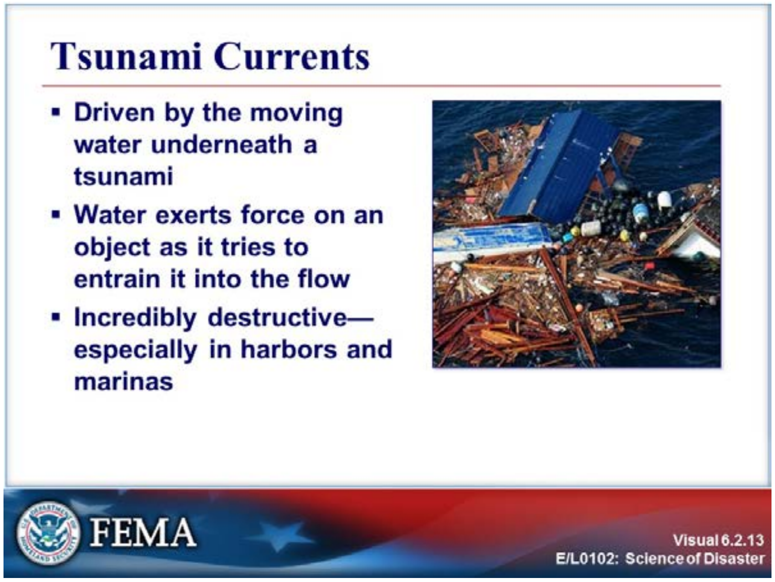
Factors that affect tsunami inundation on rivers include:

- The river’s depth, width, and bathymetry (underwater topography)
- Direction of the incoming waves relative to the orientation of the river and the amount of energy in the tsunami
- Local vs. distant: A local tsunami is more likely to cause extensive inundation on rivers, but distant tsunamis can also cause river inundation

The photo shows a tsunami wave advancing up the Wailuku River in Hilo, Hawaii in 1946, just before it tore a span from the railroad bridge in the distance. The tsunami was generated by an earthquake offshore of Alaska.

TSUNAMI EFFECTS

Visual 6.2.13



Key Points

Even in areas where inundation is trivial, tsunamis generate currents that can be incredibly destructive. Tsunami currents are driven by the moving water underneath a tsunami, and exert forces that can be very large, because water is heavy. Hazards include current force and whirlpools.

- **Current force:** Tsunamis have a current force (or drag force) that the water exerts on an object as it tries to entrain that object into the flow.
  - If the current is tripled, the force of the current is increased by a factor of nine (9)!
  - Just a small depth of moving water (e.g., ankle-deep) can be enough to knock a person over and to mobilize large objects.

- **Whirlpools:** Whirlpools are particularly dangerous in harbors and marinas, where breakwaters and other structures cause the flow to focus and converge into jets and eddies that create whirlpools. This creates very localized, very-high-energy areas with high damage potential.

In recent tsunamis, currents have broken nuclear submarines from moorings and sent a three-block-long container ship spinning in loops around a port. In a tsunami, boats at sea should never return to port. The safest place to be is offshore, if the boat can reach an area whose depth is 100 fathoms (600 feet).

TSUNAMI EFFECTS

Visual 6.2.14

Key Points

Tsunami currents can cause tremendous scour—a type of erosion—and have the ability to pick up and move very large objects.

In recent tsunamis, cars and trucks being pounded into buildings have been recurring causes of damage. Tsunami currents scour sediment and cement from foundations of buildings and bridges, unearth buried pipelines, and relocate sediment to bury intake valves and other structures that need to remain exposed.

PHOTO:

Scour effects in Sri Lanka, off the coast of India, in the 2004 tsunami that was generated in Sumatra on the other side of the Indian Ocean.

TSUNAMI EFFECTS

Visual 6.2.15

Alt Text for Visual 6.2.15
Direct Impacts on Health

- Drowning
- Injuries from debris
- Infection of wounds
- "Tsunami lung" from uncommon pathogens
- Damage to public health infrastructure
- Mass relocations
- Psychological impacts
- Exacerbation of chronic diseases

Handout 6.2.1: Tsunami Deaths by Cause of the Tsunami

Key Points

The recent tsunamis in Indonesia and Japan underscore the types of direct impact on public health that can occur.

Tsunami-related deaths and injuries: An impact that is relatively uncommon for other disasters, but more relevant during tsunamis, is the abundance of fatalities (including drowning), injuries, and wounds resulting from debris, and the post-disaster development of infections in the wounds from pathogens in sea water, soils, or debris.

Remember, tsunamis are secondary hazards, which means that they are created as a consequence of another hazard. The map on the next page shows the number of tsunami-related deaths in terms of the cause of the tsunami.

TSUNAMI EFFECTS

Visual 6.2.15 (Continued)

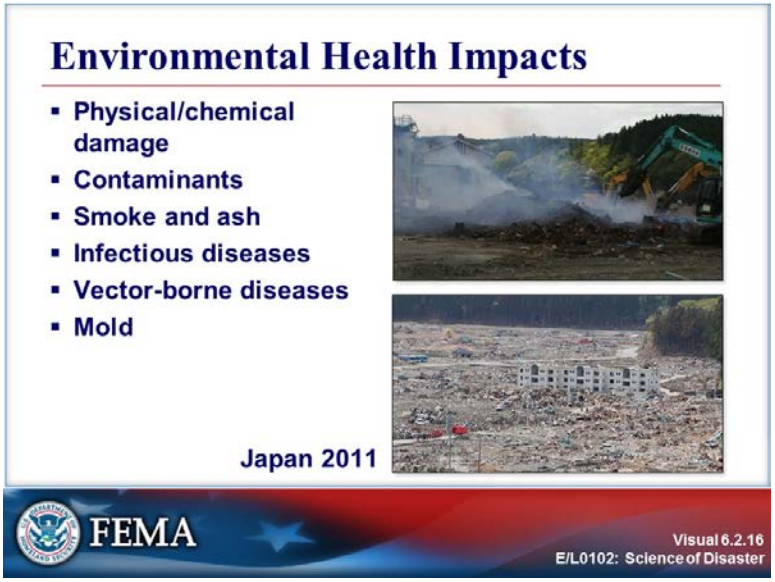
Other effects include:

- "Tsunami lung" in people who nearly drown (tsunami lung is an infection caused by relatively uncommon pathogens found in the seawater)
- Damage to public health infrastructure
- Relocation of thousands of people from affected areas into refugee camps
- Psychological impacts
- Disaster-related exacerbation of chronic diseases

See Color Handout 6.2.1 Tsunami Deaths by Cause of the Tsunami

TSUNAMI EFFECTS

Visual 6.2.16



Key Points

Tsunamis can also have severe impacts on the natural and built environments. For example, disposal of large volumes of debris has turned out to be a major challenge following both the 2004 Indonesian tsunami and the 2011 Japanese tsunami.

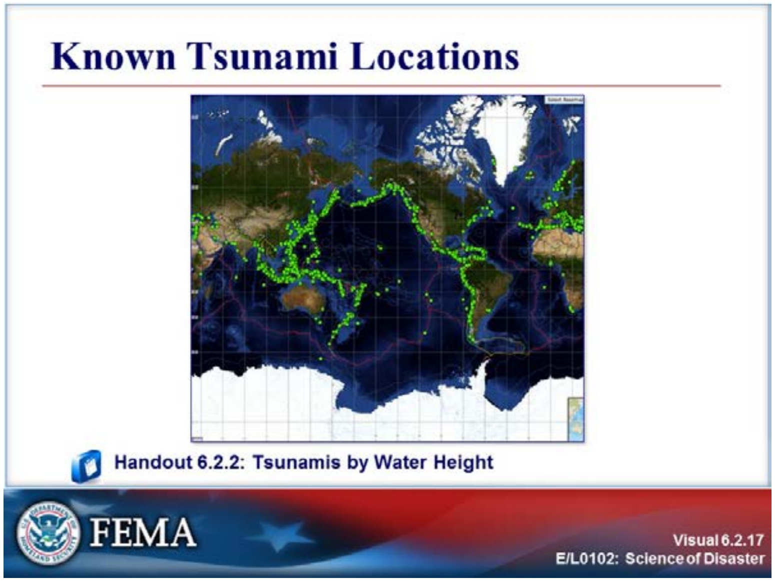
The debris can contain high levels of contaminants from the built environment, such as asbestos and lead. These contaminants can become windborne, and some can be leached from the debris by rainwater into ground and surface waters.

Environmental health impacts may include:

- Severe environmental damage, both physical and chemical (e.g., impacts of seawater on terrestrial vegetation)
- Exposures to smoke and ash from fires caused by tsunami, and from fires set intentionally as a debris-removal practice
- Infectious diseases from consumption of contaminated ground or surface waters
- Mosquito- and other vector-borne diseases
- Exposures to post-flood mold

TSUNAMI DISTRIBUTION AND WARNINGS

Visual 6.2.17



Key Points

This map shows locations where tsunamis are known to have made landfall. Green squares indicate known locations of tsunami events since 2000 B.C. The coastal areas along all oceans are at risk from tsunamis. (As with any scientific dataset, the recent portions will be the most complete. The coastlines without green squares are more likely to be lacking data than lacking tsunamis.)

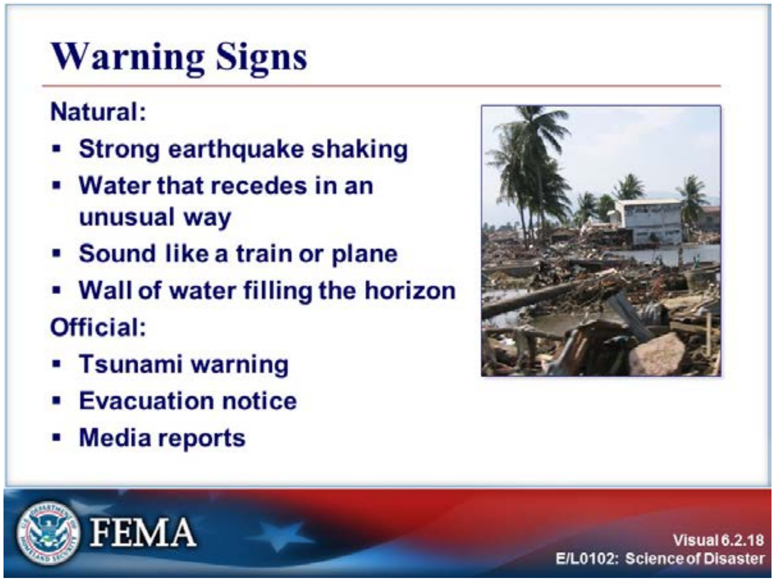
The map on the next page shows the locations where tsunami wave heights have been measured.

- The **height of the bar** changes with the height of the observation.
- The color of the bar indicates how the measurement was estimated.
  - **Blue bars** are made with scientific instruments; thus, this dataset spans several decades.
  - **Brown measurements** indicate measurements estimated from eyewitness observations or post-tsunami surveys. (The surveys are scientific fieldwork that can be done decades or centuries after the event, if the evidence has not been obliterated by changes to the Earth's surface. In some cases, the tsunami site may no longer be near an ocean.)

See Color Handout 6.2.2: Tsunamis by Water Height

TSUNAMI DISTRIBUTION AND WARNINGS

Visual 6.2.18



Key Points

A tsunami may arrive without any warning. However, in some cases, there may be signs that a tsunami is approaching.

Natural signs: Signs created by the physical characteristics of the event may include:

- **Strong earthquake shaking** (only if the tsunami is generated locally)
- **Water that recedes in an unusual way.** Depending on exactly how the water is initially displaced, about half the time the first wave motion will be away from shore, and in this case the water will recede far from shore when the tsunami first arrives. This can happen for both local and distant tsunamis
- **A sound** like a train or plane coming from the ocean. This has been experienced in both local and distantly generated tsunamis, but not in all tsunamis
- **The appearance of a long wall of water advancing toward land.** However, by the time a tsunami can be seen or heard it is often too late to get away

Human-created warnings: Other signs are human-created because a tsunami has been detected in the open ocean, or an undersea event has been detected that is capable of producing a tsunami. Human-created warnings may include:

- Sirens
- Evacuation efforts
- Word that a tsunami has struck another coastline

TSUNAMI DISTRIBUTION AND WARNINGS

Visual 6.2.18 (Continued)

Hundreds of thousands of people died in the December 26, 2004 Indian Ocean tsunami. But as described in these news reports, others saw warning signs, and escaped with their lives.

Girl saves tourists after raising tsunami warning

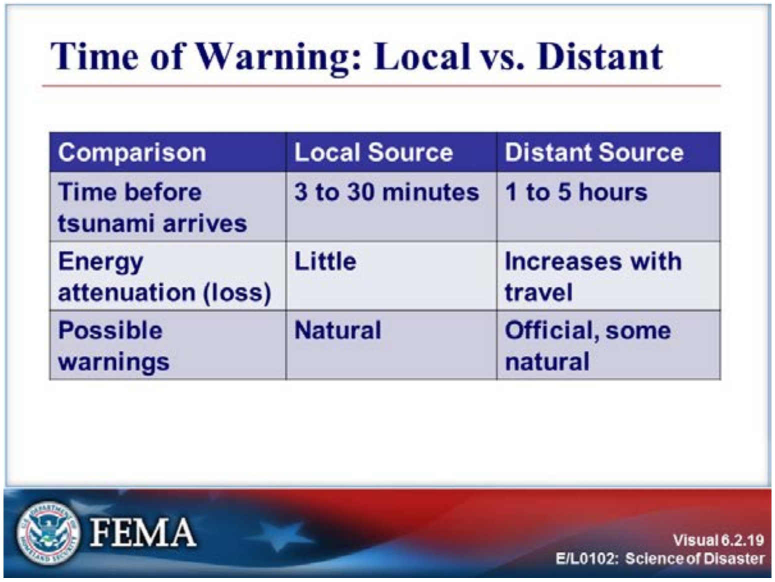
Thousands died on the beaches of Thailand in the December 2004 tsunami. But a 10-year-old British girl saved more than 100 people because she had just studied the killer waves in school. When the sea suddenly began to boil, then pulled away from the resort she was visiting, leaving fish and boats stranded high and dry, Tilly Smith recognized that a tsunami was approaching. Fortunately, her frantic warnings were heeded, and the beach was evacuated just moments before the huge waves crashed ashore.

Kalutara Beach Detail
Imagery collected December 26, 2004. Description: Receding waters and beach damage from tsunami

(Source of article: This link can also be accessed at the following URL: http://oceanexplorer.noaa.gov/edu/learning/player/lesson09/l9la2_a.html)

TSUNAMI DISTRIBUTION AND WARNINGS

Visual 6.2.19



Alt Text for Visual 6.2.19

Comparison	Local Source	Distant Source
Time before tsunami arrives	3 to 30 minutes	1 to 5 hours
Energy attenuation (loss)	Little	Increases with travel
Possible warnings	Natural	Official, some natural

Key Points

For public safety, it is important to distinguish between tsunamis that have a nearby or local source and tsunamis that are generated far away, as shown in the table on the visual.

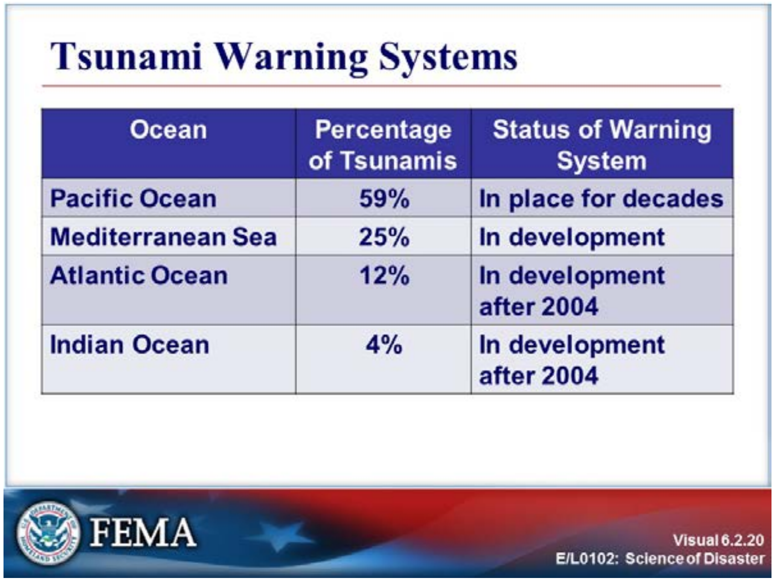
Local tsunamis: Local tsunamis are generated just offshore. Depending on how close to shore they are created, the first wave will arrive in 3 to 30 minutes, with the most typical time being 15 to 20 minutes. The waves will retain most of their initial energy and thus will have enormous force. **Tsunami detection instruments cannot detect local tsunamis, and official warnings cannot be issued before locally generated waves reach shore.**

Distant tsunamis: For distant-source tsunamis, the arrival time depends on how far away the tsunami was created and thus how long it has to travel. Recall that all waves lose energy as they travel. Therefore, the energy of a distantly generated tsunami will lessen, but it can still be enough to cause substantial death and damage. As a distantly generated tsunami travels across an ocean, if there are instruments in place they will detect the tsunami and there will be time for official warnings to be issued.

Again, only the largest earthquakes create tsunamis with enough energy to cause destruction at great distances.

TSUNAMI DISTRIBUTION AND WARNINGS

Visual 6.2.20



Alt Text for Visual 6.2.20

Ocean	Percentage of Tsunamis	Status of Warning System
Pacific Ocean	59%	In place for decades
Mediterranean Sea	25%	In development
Atlantic Ocean	12%	In development after 2004
Indian Ocean	4%	In development after 2004

Key Points

Looking at long-term averages, the Pacific Ocean has the most tsunamis of any body of water, and the Indian Ocean has about 4 percent of all tsunamis. On the Pacific Ocean there is an established system of deep ocean and tidal gauges to detect and track tsunamis, and a system to provide warnings.

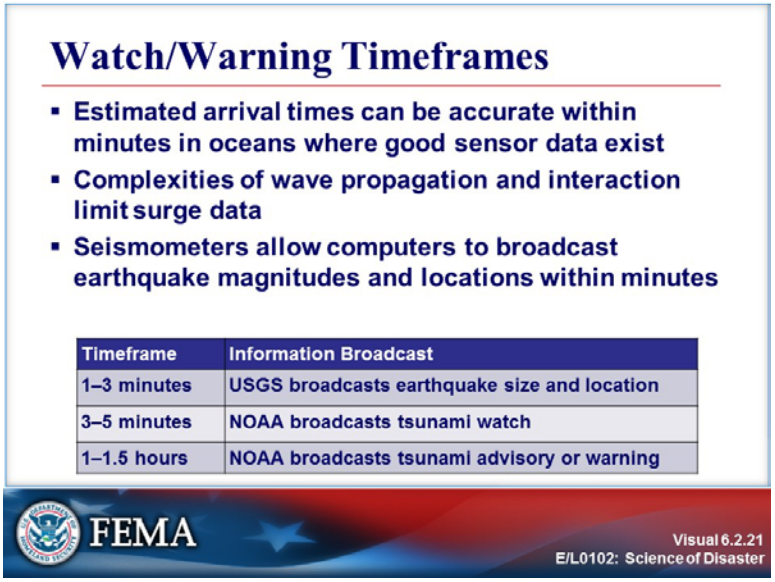
Tsunami frequency: Major tsunamis occur about once per decade, looking at long-term averages. But there is variation from year to year and decade to decade.

In 1964, the whole world paid attention to tsunamis when the Great Alaskan “Good Friday” earthquake created a particularly destructive tsunami in the Pacific Ocean. However, 40 years elapsed until the next really large tsunami in 2004 in the Indian Ocean. When more than a generation elapses between events, society’s readiness for those events inevitably lessens.

Development of monitoring systems: Before 2004, there was little or no money available to deploy monitoring equipment in areas where tsunamis are particularly rare. This situation has slowly been changing since that time.

TSUNAMI DISTRIBUTION AND WARNINGS

Visual 6.2.21



Alt Text for Visual 6.2.21

Watch/Warning Timeframes

- Estimated arrival times can be accurate within minutes in oceans where good sensor data exist
- Complexities of wave propagation and interaction limit surge data
- Seismometers allow computers to broadcast earthquake magnitudes and locations within minutes

Timeframe	Information Broadcast
1–3 minutes	USGS broadcasts earthquake size and location
3–5 minutes	NOAA broadcasts tsunami watch
1–1.5 hours	NOAA broadcasts tsunami advisory or warning

Key Points

After large earthquakes occur undersea, the National Oceanic and Atmospheric Administration (NOAA) monitors ocean sensors to detect whether a tsunami has been generated, and if so, issues estimates of tsunami arrival times for different locations. NOAA uses the sensor data to refine estimates for the time at which the first tsunami surge will arrive. Estimated arrival times can be accurate within minutes in oceans where good sensor data exist. Typically, information about the event gets conveyed according to the timeline shown on the visual.

- **Watch:** Initially, after the earthquake, NOAA will declare a Tsunami Watch, normally just a few minutes after the earthquake has occurred. The worldwide network of seismometers allows computers to broadcast earthquake magnitudes and locations within minutes of the event.
- **Advisory and warning:** A watch gets upgraded to an **advisory** and then a **warning** if a tsunami is detected by sensors or humans. Typically, a warning is issued 1 to 1.5 hours after the event.

TSUNAMI DISTRIBUTION AND WARNINGS

Visual 6.2.21

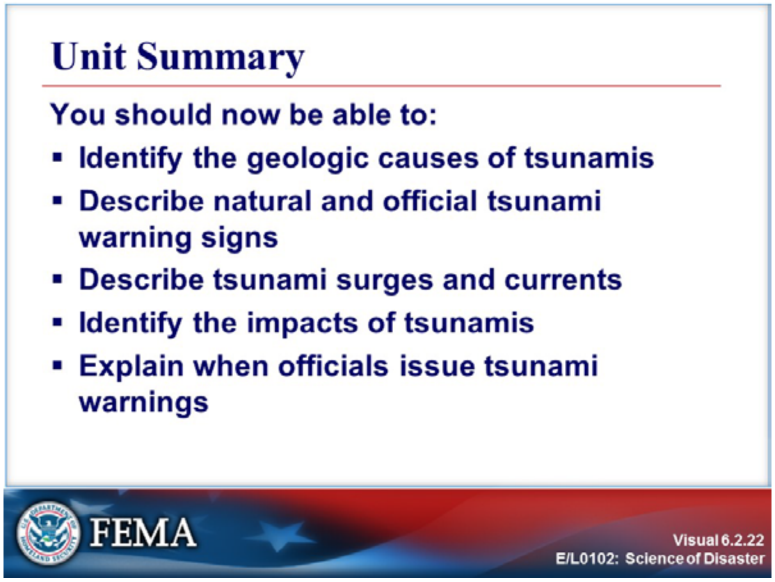
- **Updates:** NOAA updates and continues to issue information bulletins, watches, and warnings, for specific areas, until all tsunami danger is past.

Not all oceans have sensors to detect tsunamis, so some advisories must be based on past scientific experience of the ways in which earthquakes of different magnitudes create tsunamis.

The complexities of tsunami wave propagation and interaction limit the ability to rapidly model and relay high-resolution, locally specific surge data as part of a warning system.

UNIT SUMMARY

Visual 6.2.22



Key Points

Do you have any questions about the material covered in this unit?

MODULE 7: VOLCANOES

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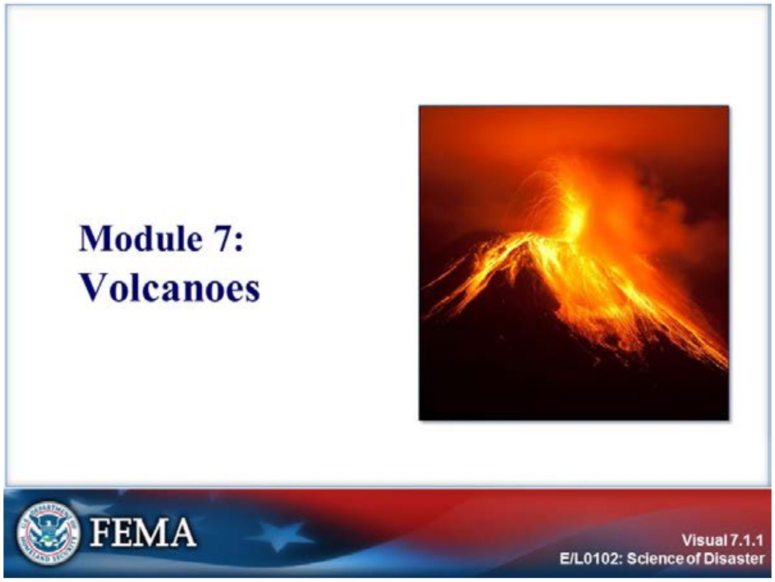
INTRODUCTION

Visual 7.1.1



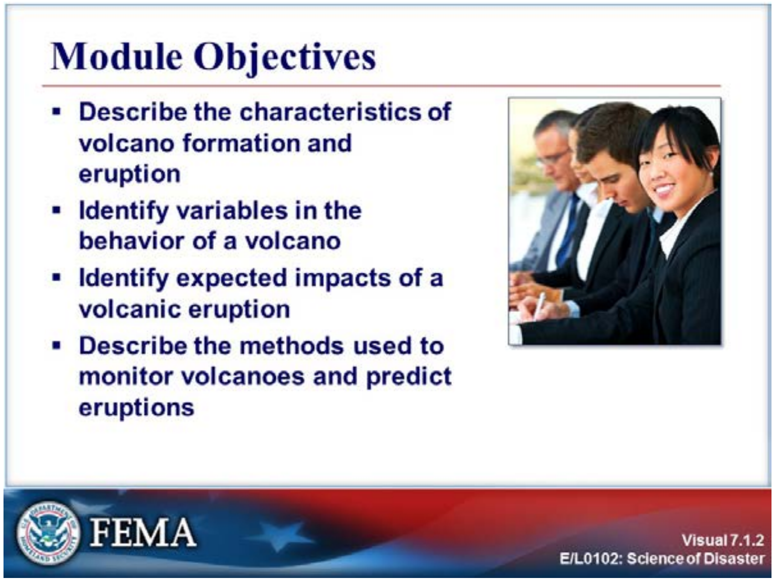
Key Points

A suggested time plan for this module is shown below.

Topic	Time
Introduction	5 minutes
Plate Tectonics	3 minutes
Molten Rock	2 minutes
Volcano Geography	5 minutes
Eruption Characteristics • Activity 7.1 – Analyzing Eruptions	20 minutes
Magma Variables	5 minutes
Precursors	10 minutes
Volcano Impacts	5 minutes
Volcanic Monitoring • Activity 7.2 – Hazard Maps	45 minutes
Module Summary	5 minutes
Total Time	**1 hour, 45 minutes**

INTRODUCTION

Visual 7.1.2

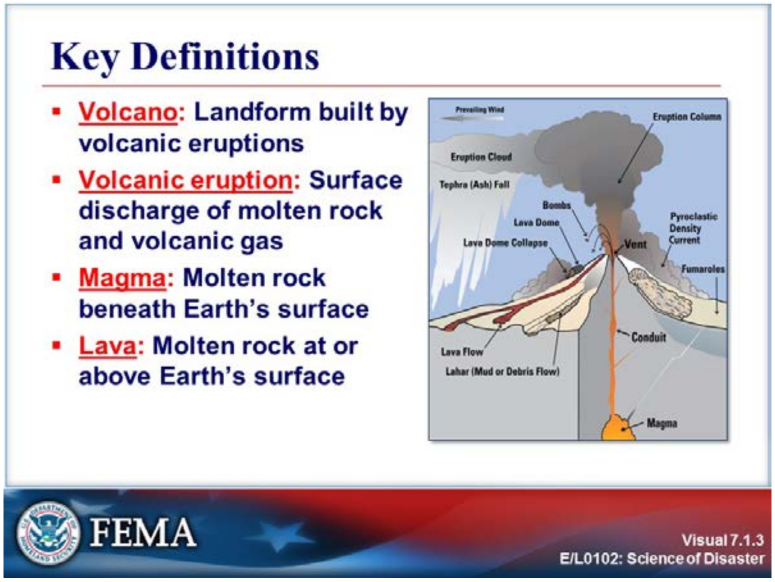


Key Points

Review the module objectives as shown on the visual.

INTRODUCTION

Visual 7.1.3



Alt Text for Visual 7.1.3
Key Definitions

- Volcano: Landform built by volcanic eruptions
- Volcanic eruption: Surface discharge of molten rock and volcanic gas
- Magma: Molten rock beneath Earth's surface
- Lava: Molten rock at or above Earth's surface

Graphic of a volcano cutoff with the following noted: prevailing wind, eruption column, eruption cloud, tephra (ash) fall, bombs, lava dome, lava dome collapse, vent, pyroclastic density current, fumaroles, conduit, lava flow, lahar (mud or debris flow), and magma.

Key Points

Volcanoes and eruptions are complex and varied. As scientists strive to understand volcanic processes, they have had to develop a large number of terms and concepts. Just a few of the basic terms are shown on this visual. We will return to some of these terms later in the module.

- A **volcano** is a landform—a geographic feature—that exists because of volcanic eruptions.

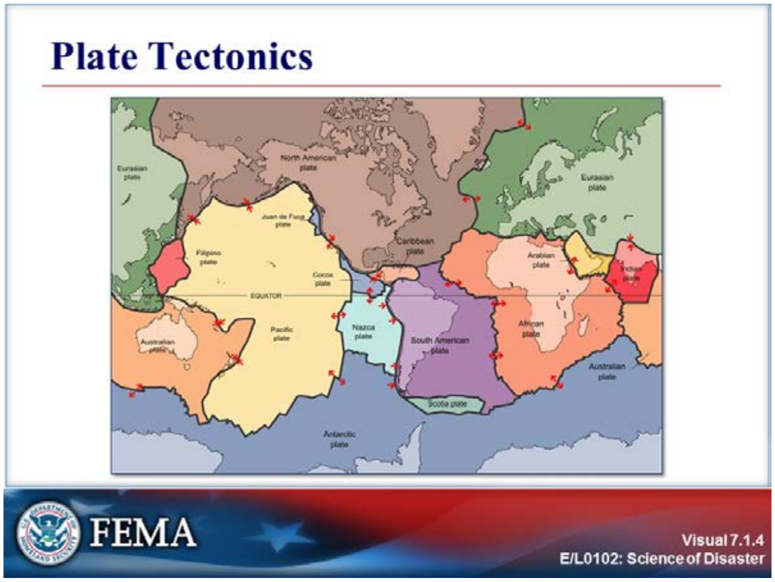
- A **volcanic eruption** is a surface discharge from a volcano. Note the word "surface." Often, young volcanoes will have subsurface discharges and the subsurface activity may herald a period of unrest. But if nothing reaches the surface, the unrest is a **volcanic crisis**, not an eruption.

- **Molten rock** is a key ingredient in volcanic processes. Volcano scientists need to know whether molten rock has reached the surface or not, and so have two terms:
  - **Magma** is the molten rock beneath the Earth's surface.
  - **Lava** is molten rock at or above the Earth's surface.

Also, it is important to note that although most volcano hazards are associated with eruptions, some hazards can occur even when a volcano is not erupting.

PLATE TECTONICS

Visual 7.1.4



Key Points

Plate tectonics account for much of what happens at the Earth's surface and creates natural hazards. The theory of plate tectonics states that the Earth's lithosphere is fragmented into enormous blocks of rock called **plates** that are moving relative to one another as they ride atop hotter, more mobile material.

Plate boundaries: There are three types of plate boundaries:

- Divergent boundaries—where new crust is generated as the plates pull away from each other
- Convergent boundaries—where crust is destroyed as one plate dives under another
- Transform boundaries—where crust is neither produced nor destroyed as the plates slide horizontally past each other

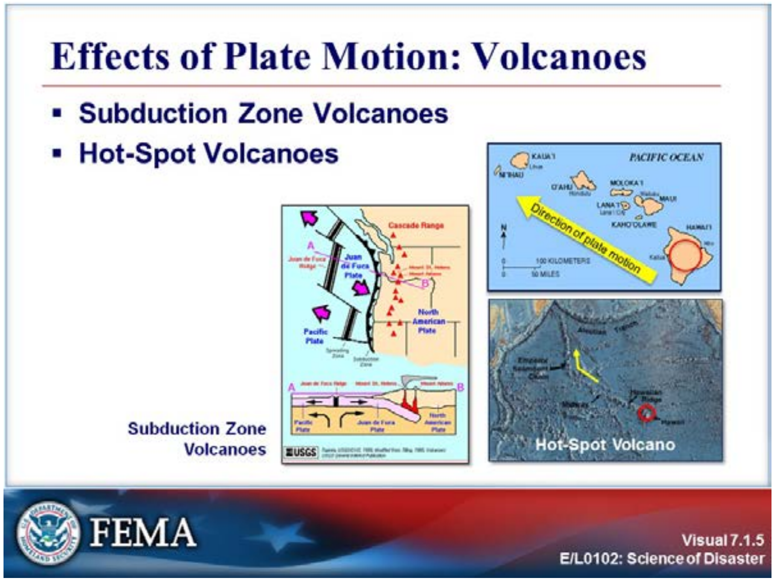
The number and sizes of plates, their directions of motion, and their styles of motion change over time, but there is no net change in size (i.e., the circumference of the Earth remains the same).

Plate locations: The map on the visual shows the current plates and their boundaries. Take note of the following:

- Most of the contiguous United States and Alaska sit on the North American plate.
- Westernmost southern California is along the boundary of the Pacific plate. Hawaii lies on the Pacific plate.
- The Pacific and North American plates slide past each other at about 50 millimeters a year—about the rate that fingernails grow.

PLATE TECTONICS

Visual 7.1.5



Key Points

Plate tectonics aids in our understanding of why the Earth's surface is dynamic and always changing. We have seen several ways in which plate motion affects Earth formations and hazards. The first is volcanoes. Plate motion can create two types of volcanoes:

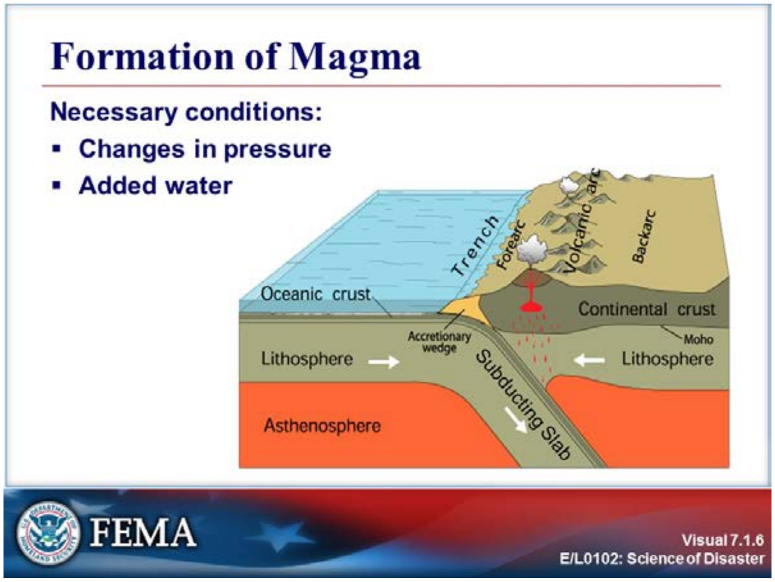
- **Subduction zone volcanoes:** Plate movement creates volcanoes over subduction zones. The subduction process melts some of the rock, which then rises as magma, forming long lines of volcanoes above the subducting plate. About 90 percent of the Earth's volcanoes result from subduction. The Juan de Fuca plate in the U.S. Pacific Northwest is subducting under the North American plate. The Cascade Volcanic range is a result of this process.
- **Hot-spot volcanoes:** Hot spots are fixed points in the mantle. (The plate moves over the hot spot.) Hot-spot volcanoes are formed when magma flows to the surface and burns a hole in the plate that moves over it. On the visual is a map of the Hawaiian Islands and a corresponding map of the Pacific Ocean floor.

  The red circle indicates a hot spot, on which Hawaii currently sits. Other islands in the chain previously sat atop the hot spot and have been moved away as the Pacific plate has moved to the northwest. All of the Hawaiian Islands are composed of volcanoes that at one time erupted with magma originating from the hot spot.

  Yellowstone is a hot-spot volcano that erupts rarely, with hundreds of thousands of years between eruptions. Its eruptions are enormous and violently explosive.

MOLTEN ROCK

Visual 7.1.6



Alt Text for Visual 7.1.6
Formation of Magma
Necessary conditions:
- Changes in pressure
- Added water

Cut off graphic showing the oceanic crust, trench, forearc, volcanic arc, backarc, continental crust, moho, litosphere, lithosphere, accredtionary wedge, subducting slab and asthenosphere

Key Points

Recall from an earlier module that most of the Earth's mantle consists of solid rock, but there is some liquid derived from the melting of rock. It is this molten rock that provides magma to volcanoes. The following conditions are needed to melt rock into magma:

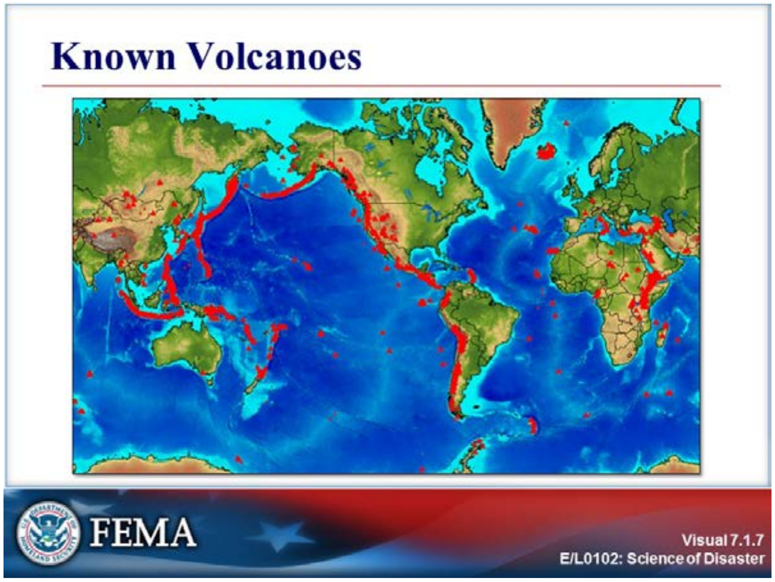
- **Changes in pressure:** Pressure changes around the rock are also needed to make the rock melt. Interestingly, in some situations a <u>decrease</u> in pressure produces melting (called "decompression melting"), while in other situations an <u>increase</u> in pressure causes melting.

- **Added water:** Because water changes many chemical reactions, including melting, adding water to a rock environment can enhance melting under suitable temperature and pressure conditions.

Fluctuations are inevitable on this ever-changing planet, and the fluctuations in temperature, pressure, or water content can be enough to melt rock inside the Earth.

VOLCANO GEOGRAPHY

Visual 7.1.7



Key Points

Volcanoes pose a threat to many places in the world, and the largest eruptions have global consequences.

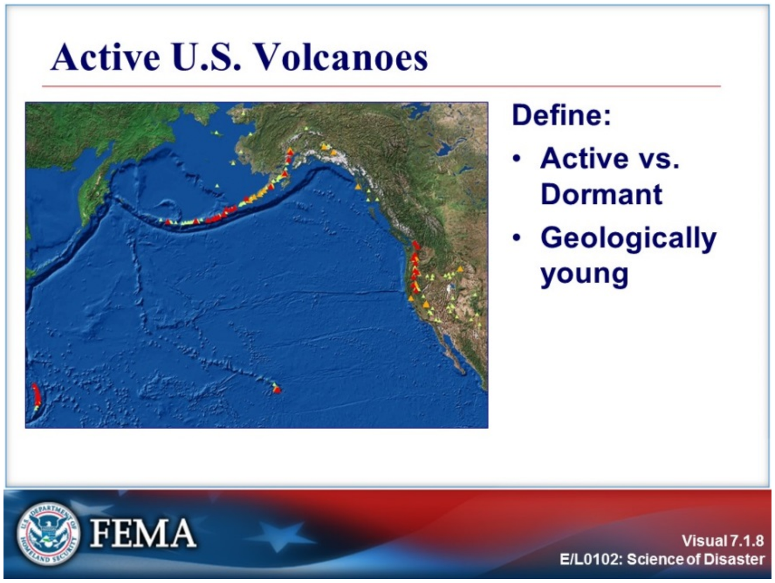
In the last 10,000 years, 1,500 volcanoes have erupted. In recent decades, 50 to 70 different volcanoes have erupted around the world each year. At any one time, about 20 volcanoes are actively erupting. Although the chance is small that any particular volcano will erupt on a given day, it is essentially guaranteed that a volcano will be erupting on any given day.

Even more often, volcanoes show signs that eruption may be imminent, resulting in volcanic crises where communities and government entities have to take action or prepare to take action. Unrest periods can go on for years and may or may not lead to eruptions. A single period of unrest may be punctuated with more than one eruption of varying severities and durations.

Triangles on this map indicate locations of known volcanoes in the world. (Remember that “known” does not necessarily mean active.) Recall that volcanoes occur at certain kinds of plate boundaries (and also where there are hot spots). Volcano locations thus tend to delineate plate boundaries; however, volcanoes are hard to count unambiguously.

VOLCANO GEOGRAPHY

Visual 7.1.8



Key Points

A total of 169 volcanoes exist in the United States that are **active**—i.e., capable of eruption. This means that the volcano has erupted within the last 10,000 years. These are shown by the small red triangles on the map. Some are much more likely to erupt than others, and are shown in red.

Another common term associated with volcanoes is **dormant**. Dormant volcanoes are those that have not erupted in the last 10,000 years, but could erupt again. In other words, the geologic processes that form magma are still active in the region and an eruption could occur. Extinct volcanoes are those that will not erupt again because the geological processes that formed them are no longer supplying necessary magma.

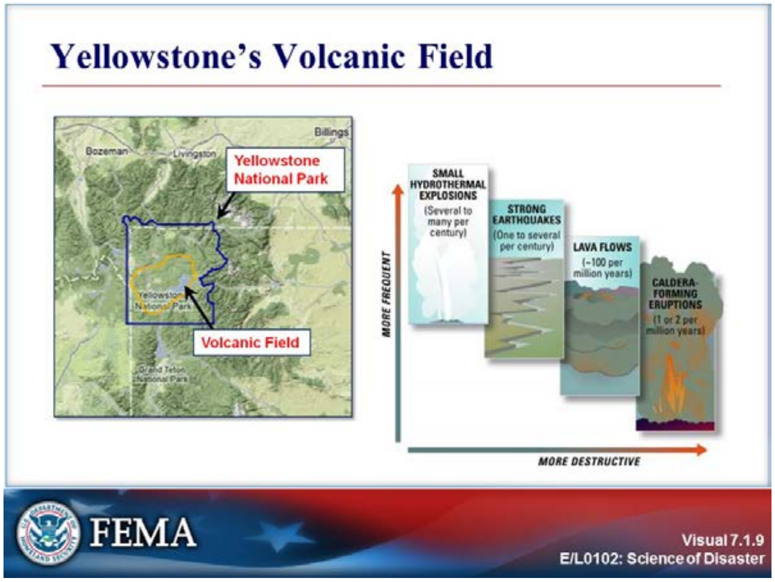
Many scientists, however, are uncomfortable calling a volcano "inactive" because there is no agreed-upon definition of an "active" volcano. Some prefer to identify volcanoes that are **geologically young**—i.e., those that have been active in the last 10,000 years. (The Smithsonian Institution's Global Volcanism Program database can be used as a resource for these designations. It is updated with ongoing geologic discoveries and improvements to scientific dating of past eruptions.)

In addition, there are areas called **volcanic fields** where an eruption can occur from many sites, rather than from a single distinct structure. Volcanic fields exist in many locations in the United States, including Arizona, New Mexico, and within the city limits of Portland, OR.

Pauses between eruptions can be as short as months or as long as thousands of years. Some volcanoes erupt only once; most erupt multiple times and result in a large landform.

VOLCANO GEOGRAPHY

Visual 7.1.9



Alt Text for Visual 7.1.9
Yellowstone's Volcanic Field
From more frequent to more destructive:

- Small hydrothermal explosions (Several to many per century)
- Strong earthquakes (One to several per century)
- Lava flows (-100 per million years)
- Caldera-forming eruptions (1 or 2 per million years)

Key Points

There is no volcanic mountain in Yellowstone, WY. However, there is a volcanic field that produces the largest eruptions in the United States. Yellowstone is a massive hot-spot volcano.

Evidence of ancient hot-spot eruptions exist to the southwest of Yellowstone. These hot spots burned a hole through the North American plate, resulting in the volcanic field. If plate motion does not shift direction, there will eventually be eruptions northeast of Yellowstone.

PHOTOS:
The map on the left shows northwestern Wyoming, with the perimeter of Yellowstone National Park (Link can also be found at this URL: https://volcanoes.usgs.gov/volcanoes/yellowstone/) outlined in blue, and the perimeter of the current Yellowstone caldera in orange.

VOLCANO GEOGRAPHY

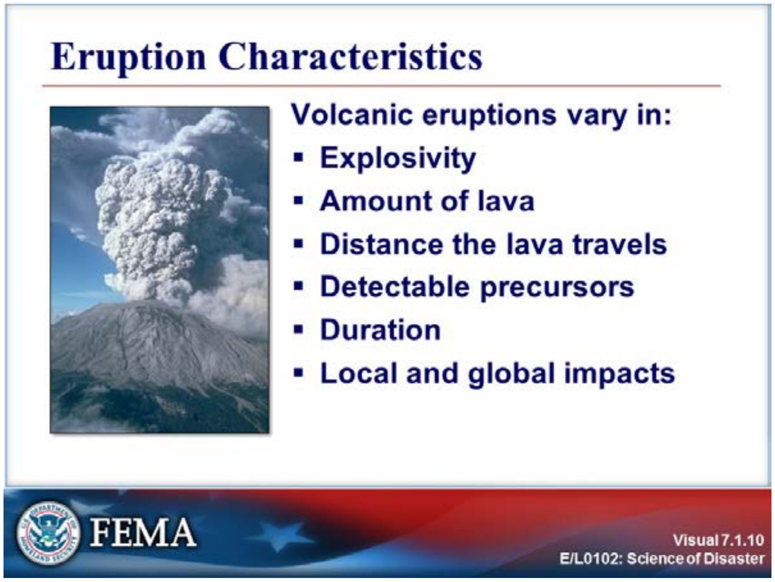
Visual 7.1.9 (Continued)

At some point, a volcano stops producing eruptions, but a volcano can erupt after being inactive for millennia. In fact, the biggest eruptions are the most rare, and as the chart on the right indicates, a supervolcano like Yellowstone keeps active with small steam eruptions, but waits tens of thousands of years between lava flows, and waits a million years between eruptions large enough to form volcanic craters called calderas.

Yellowstone is a good representative of the opposing factors that volcano scientists must juggle in helping society prepare for volcanic eruptions, which are low-probability, high-consequence events. A Yellowstone eruption is a very low-likelihood event, but there is no indication that Yellowstone is “done.” At some point, an eruption will occur, and when it does, it will affect the health and economy of the entire Nation and the world.

ERUPTION CHARACTERISTICS

Visual 7.1.10



Key Points

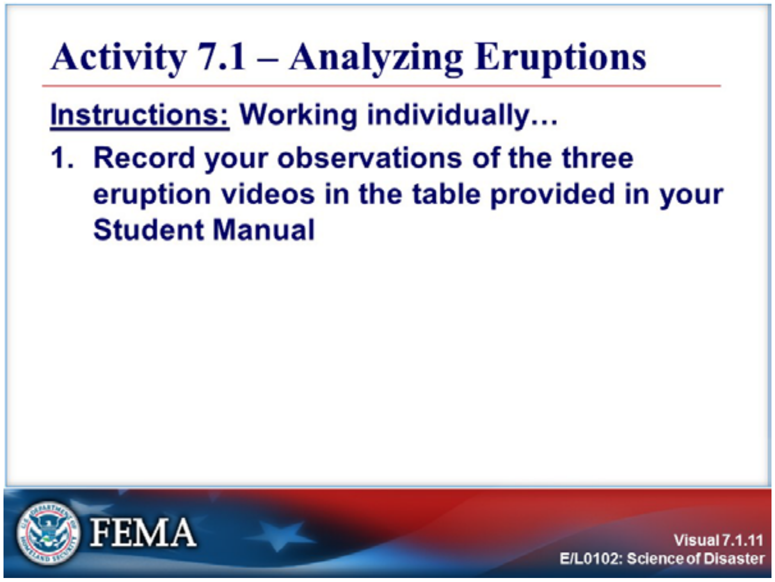
There are several characteristics of volcanic eruptions, including:

- Explosivity
- Amount of lava
- How far the lava travels
- Detectable precursors
- Duration
- Local and global impacts

In this part of the module, we will look at how variations in molten rock, or magma, influence volcano formation and behavior.

ACTIVITY 7.1 – ANALYZING ERUPTIONS

Visual 7.1.11



Key Points

Instructions:

Working individually….

1. Record your observations of the three eruption videos in the table provided in your Student Manual.

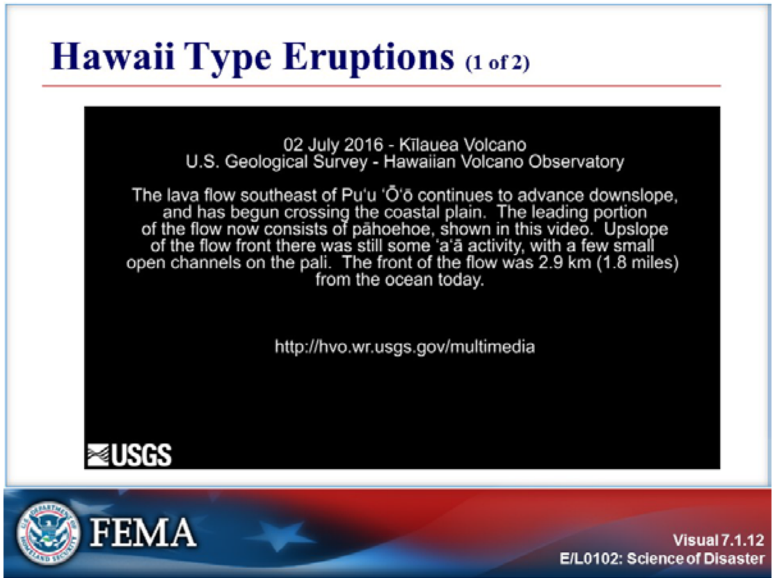
ACTIVITY 7.1 – ANALYZING ERUPTIONS

Visual 7.1.11 (Continued)

	Hawaii Eruptions	Mount St. Helen Eruptions
Lava	Yes / No	Yes / No
Ash Column	Yes / No	Yes / No
Height of Eruption		
Surface Area Affected by Eruption		
Other Characteristics		

HAWAII ERUPTIONS

Visual 7.1.12



Alt Text for Visual 7.1.12
Hawaii Type Eruptions (1 of 2)
02 July 2016 - Kilauea Volcano
U.S. Geological Survey - Hawaiian Volcano Observatory
The lava flow southeast of Puʻu ʻŌʻō continues to advance downslope, and has begun crossing the coastal plain. The leading portion of the flow now consists of pãhoehoe, shown in this video. Upslope of the flow front there was still some ʻaʼã activity, with a few small open channels on the palí. The front of the flow was 2.9 km (1.8 miles) from the ocean today. http://hbo.wr.usgs.gov/multimedia

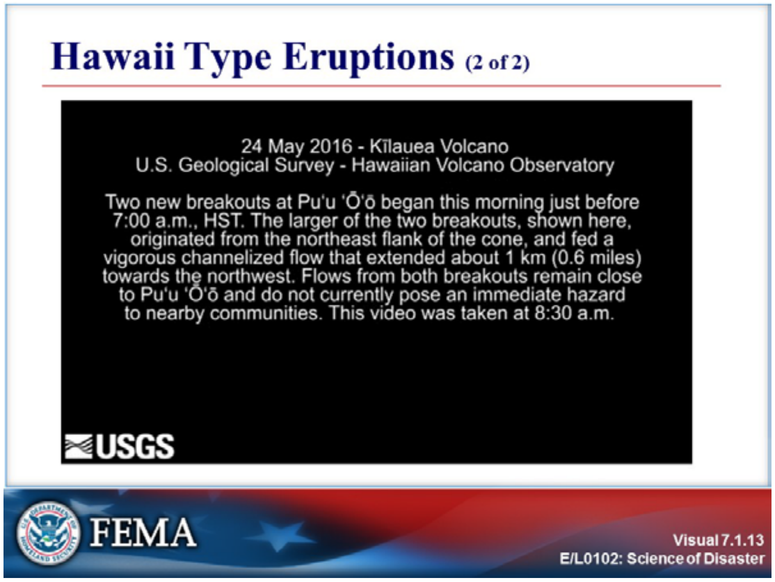
Key Points

Video Transcript:

Two new breakouts at Puʻu ʻŌʻō began this morning just before 7:00 a.m., HST. The larger of the two breakouts, shown here, originated from the northeast flank of the cone, and fed a vigorous channelized flow that extended about 1 km (0.6 miles) towards the northwest. Flows from both breakouts remain close to Puʻu ʻŌʻō and do not currently pose an immediate hazard to nearby communities. This video was taken at 8:30 a.m.

HAWAII ERUPTIONS

Visual 7.1.13



Alt Text for Visual 7.1.13
Hawaii Type Eruptions (2 of 2)
24 May 2016 – Kilauea Volcano
U.S. Geological Survey – Hawaiian Volcano Observatory
Two new breakouts at Puʻu ʻŌʻō began this morning just before 7:00 a.m., HST. The larger of the two breakouts, shown here, originated from the northeast flank of the cone, and fed a vigorous channelized flow that extended about 1 km (0.6 miles) towards the northwest. Flows from both breakouts remain close to Puʻu ʻŌʻō and do not currently pose an immediate hazard to nearby communities. This video was taken at 8:30 a.m.

Key Points

Video Transcript:

The two breakouts that began at Puʻu ʻŌʻō yesterday (May 24) are still active. This morning, the active portions of both flows remained relatively short, extending no more than 1 km (0.6 miles) from their breakout points. The northern breakout, shown here, changed course slightly overnight, but is still directed towards the northwest in an impressive channel, with lava spreading out at the flow front. This video was taken at 8:30 a.m., HST, today (May 25).

MOUNT ST. HELENS ERUPTION

Visual 7.1.14

Key Points

The eruption of Mount St. Helens in Washington State in 1980 was a pivotal event for improving scientific understanding of explosive volcano processes and for coordinating scientific understanding with emergency response.

For more than 4,000 years, Mount St. Helens has been the most active among a chain of volcanoes in the Pacific Northwest, but it had not erupted since the mid-1800s. Its recent eruption timelines offer a good lesson in how suddenly a volcano can become restless, how difficult it can be to have certainty that an eruption is about to start (or end), and how far an eruption's effects can reach.

In this video, U.S. Geological Survey (USGS) scientists recount their experiences during the eruption of Mount St. Helens, which was one of the most dramatic geologic moments in the history of the United States.

MOUNT ST. HELENS ERUPTION

Visual 7.1.14 (Continued)

Video Transcript:

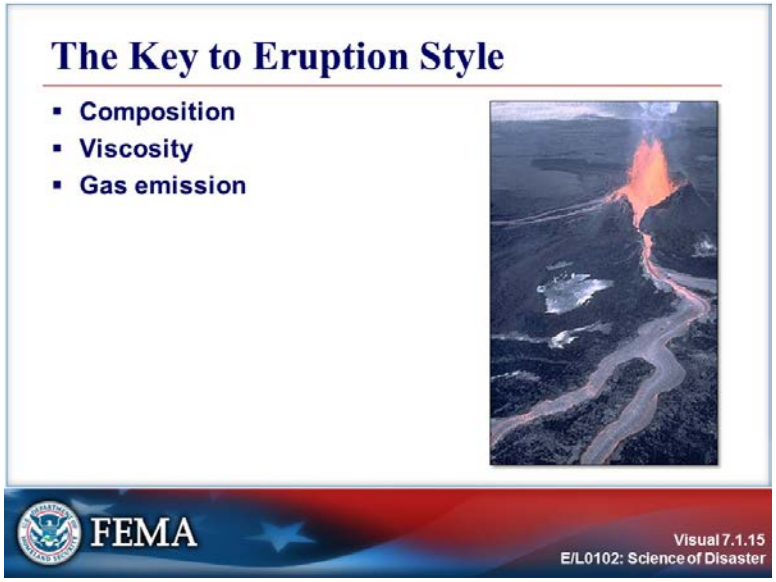
Don Swanson: And we were off the ground probably at 9:05 or something like that. It was really, really rapid. And got up to the point where we could really see the mountain well, I suppose, between 9:20 and 9:25. Something like that.

There was this terrific, very vigorous vertical eruption column that was the stem of the mushroom or the toadstool. It then blossomed out at greater height. And, for most of the morning we saw this tremendous ash cloud roiling out toward the northwest, and I can only assume that that was coming off of the big pyroclastic flows that were going off in that direction that later built the pumice plane. It was a very eventful morning, but it was sobering because I remember thinking up in the airplane that Dave just couldn't have survived this. Especially when we got around to the west side and saw all the ash heading in his direction.

C. Dan Miller: On the morning of May 18, what actually happened . . . the landslide basically uncorked this pressurized body of magma and allowed it to explode or expand out toward the north very rapidly. This is what we call the "lateral blast." It was a horizontally directed explosion of incredible magnitude. It caused this expanding cloud of ash, rocks, and gases to move out across the countryside to the north at speeds of several hundred miles an hour. The directed blast was really the most destructive event that occurred on the morning of May 18. It completely destroyed an area of 230 square miles in the matter of somewhere between 5 and 9 minutes. It essentially killed every living thing within an area of 230 square miles. And it destroyed hundreds of acres of virgin forest and was an incredibly spectacular event

MAGMA VARIABLES

Visual 7.1.15

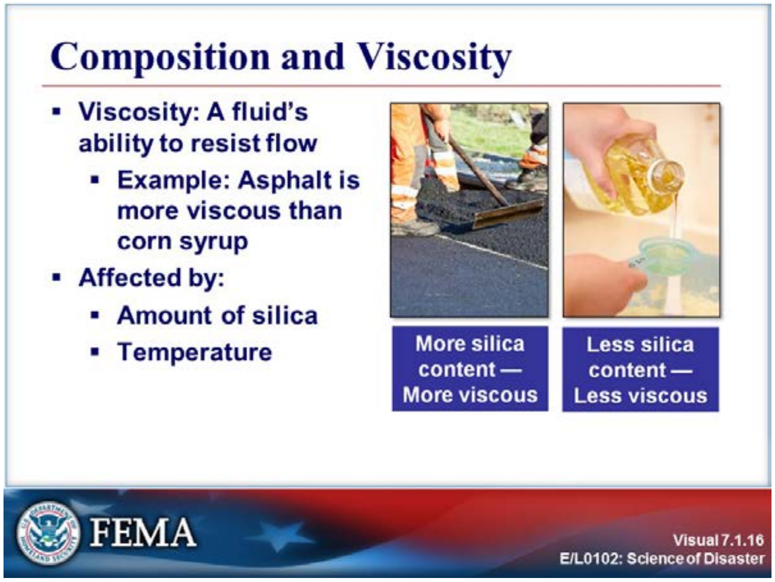


Key Points

Key variables of magma that can change an eruption include composition, viscosity, and dissolved gas content (gas emission).

MAGMA VARIABLES

Visual 7.1.16



Alt Text for Visual 7.1.16
Composition and Viscosity

- Viscosity: A fluid's ability to resist flow
- Example: Asphalt is more viscous than corn syrup
- Affected by:
- Amount of silica
- Temperature

A photo of workmen laying asphalt – More silica content – More viscous
A photo of someone measuring corn syrup – Less silica content – Less viscous

Key Points

Viscosity is a measure of a fluid's ability to resist flow. If you increase a fluid's viscosity, then you decrease that fluid's ability to flow. For example, at the same temperature corn syrup is less viscous than asphalt, so it flows more easily. With volcanic fluids, viscosity is affected by the amount of silica and by temperature.

Silica. Different magmas have different amounts of silica. Higher silica rocks—and hence, magmas—occur in the continental crust and oceanic sediments. So, high silica magmas commonly occur in subduction zones because continental rock melts to form the magma.

Different concentrations of silica produce different magma types that when cooled, form different types of rock:

Silica Content	Magma Type	Volcanic Rock
~50%	Mafic	Basalt
~60%	Intermediate	Andesite
~65%	Felsic (low silica)	Dacite
~70%	Felsic (high silica)	Rhyolite

MAGMA VARIABLES

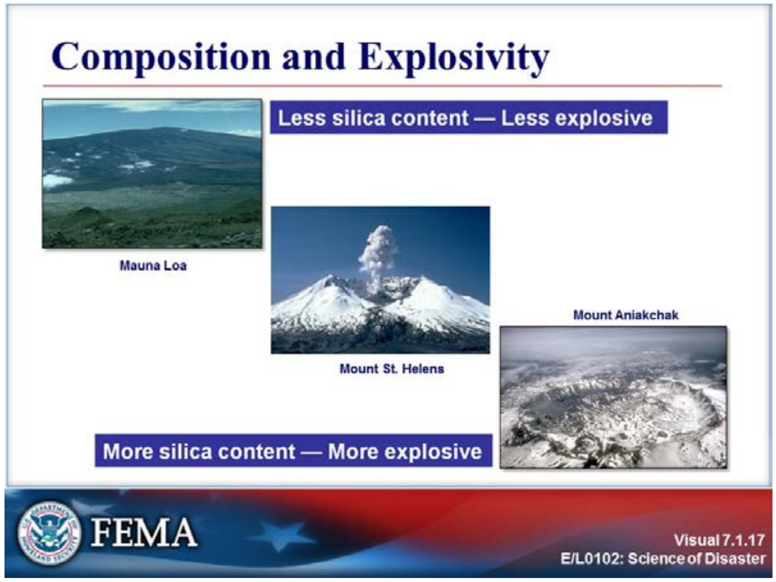
Visual 7.1.16 (Continued)

Oceanic hot spots such as Hawaii are lower in silica and have a lower viscosity magma. This means that the magmas de-gas more easily, and produce eruptions that are more effusive. An effusive lava is comparatively “runny” and likely to flow longer distances. Oceanic hot spots rarely exhibit cataclysmic eruptions.

Temperature also affects viscosity because higher temperatures decrease viscosity (make the magma runnier) and increase flow. (Example: Syrup just out of the refrigerator is more viscous than syrup at room temperature.) Basaltic magmas like those in Hawaii and Iceland form at higher temperatures than granitic magmas like those at Mount St. Helens. Therefore, not only are the oceanic hot-spot lavas less viscous because of their lower silica content, but they are less viscous because of their higher temperature.

MAGMA VARIABLES

Visual 7.1.17



Key Points

Why is viscosity important?

Explosivity: More viscous magmas and lavas that cannot flow or de-gas easily are more explosive. Therefore, the less silica content, the less explosive the volcano. The more silica content, the more explosive the volcano.

There is a great range in the explosivity of volcanic eruptions. Many eruptions are relatively calm, with nonviolent extrusion of lava flows. Others are highly explosive and are characterized by the violent ejection of fragmented volcanic debris. This variation depends on the magma's composition, and in particular on the amount of silica in the melt.

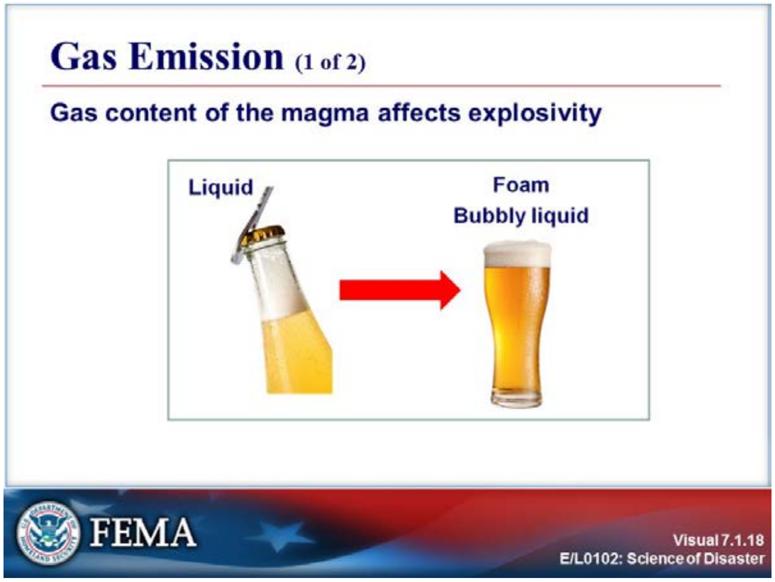
Volcano shape and size: The factors that affect explosivity, how much lava will erupt, and how far lava will travel, also influence the volcano's shape and size. Most volcanoes have characteristic eruptive styles and thus a characteristic shape. This visual provides three examples of distinctly shaped volcanoes. Moving from left to right goes from least to most explosive, and from less to more silica content.

- At the left is Mauna Loa in Hawaii.
- In the middle is Mount St. Helens.
- On the right is what is left of Mount Aniakchak in Alaska after the volcano blew itself apart in an explosive eruption some 3,700 years ago. (Such an eruption today would affect air traffic worldwide for months.)

Although a volcano's shape tells scientists important information about past eruptions, any volcano can change its eruptive style during the next eruption. A single volcano can (and often does) have mixtures of magma types, and thus many eruption styles.

MAGMA VARIABLES

Visual 7.1.18



Key Points

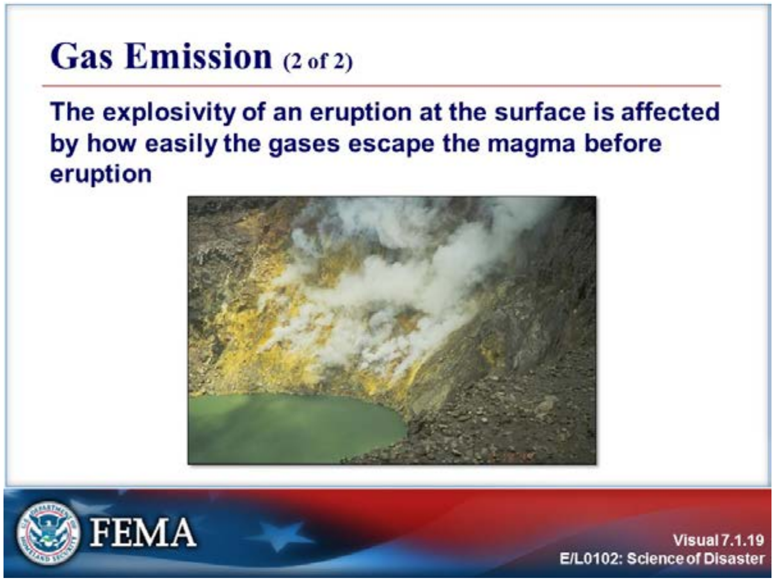
Gas emission is another variable that affects volcanic behavior. Magmas include varying degrees of volcanic gases such as water vapor, carbon dioxide, and sulfur dioxide.

Deeper in the Earth where pressure is higher, the gas is contained in the liquid, much like gas is contained in a carbonated liquid within a pressurized container. If the pressure is released on a bottle by opening the cap, the liquid degasses quickly. First, the foamier and gassy contents will be released, and then the liquid will follow.

Similarly, in a volcanic eruption, there can be rapid changes in pressure as the magma ascends, allowing trapped gas to escape explosively. Although the magma is not always shaken in a volcanic eruption, the escape of gas can be explosive depending on the amount of gas present and the buildup of pressure.

MAGMA VARIABLES

Visual 7.1.19



Key Points

The extent to which the liquid magma and gas can separate before the eruption starts affects eruption behavior. This separation occurs as a result of the following process:

1. As magma rises toward the surface where pressure is lower, gases begin to form tiny bubbles. These take up more volume than the gas did previously, making the magma less dense, more buoyant, and allowing it to continue its upward journey.

2. Closer to the surface, the bubbles increase in size and number. Sometimes, the gas volume exceeds the melt volume, creating a magma foam.

3. Dissolved gases in the magma are released into the atmosphere during eruptions. Water vapor, carbon dioxide, and sulfur dioxide are the most common gases released.

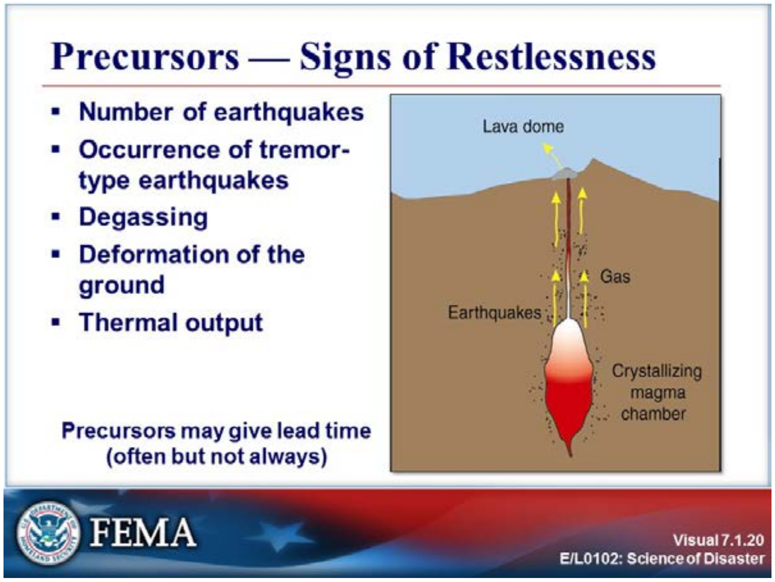
PHOTOS:
Steam plumes and a sulfur-encrusted crater wall, both evidence of gas escaping between eruptions at El Salvador’s Santa Ana volcano

It is more difficult for gas to escape a viscous lava, making explosion more likely when the gas-filled magma reaches the surface.

Although the explanation for why volcanoes stop erupting is complex, the simple answer is that as magma reservoirs become depleted of hot gassy magma, they lose their driving force—excess buoyancy.

PRECURSORS

Visual 7.1.20



Alt Text for Visual 7.1.20
Precursors – Signs of Restlessness

- Number of earthquakes
- Occurrence of tremor-type earthquakes
- Degassing
- Deformation of the ground
- Thermal output

Precursors may give lead time (often but not always)
Graphic of a volcano cutout with lava dome, gas, earthquakes, and crystallizing magma chamber labeled

Key Points

Precursors help scientists predict volcanic eruptions. There are several important eruption precursors, including:

- Number of earthquakes
- Occurrence of a style of earthquake called “tremor”
- Degassing
- Deformation of the ground
- Thermal output

All of these precursory signals are caused by processes associated with magma migration toward the surface.

Magma accumulates a few miles below a volcano. Before an eruption, magma ascends toward the surface through narrow conduits. The magma changes the volume of the rock, and breaks rock, producing earthquakes. Moving magma and escaping gas can also produce distinctive earthquake styles, together called “volcanic tremor.”

PRECURSORS

Visual 7.1.20 (Continued)

As magma migrates, it often deforms the volcano or nearby land because of increases and decreases in volume. An increasing volume of hot material will heat groundwater and can change spring water chemistry. Then, gases escape from the magma when the magma reaches lower pressures near the surface.

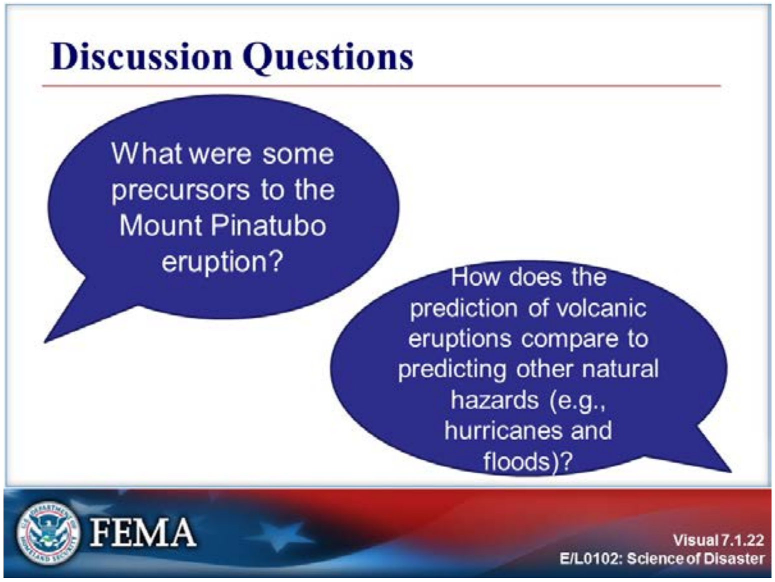
MOUNT PINATUBO

Visual 7.1.21

Key Points

PRECURSORS: DISCUSSION

Visual 7.1.22



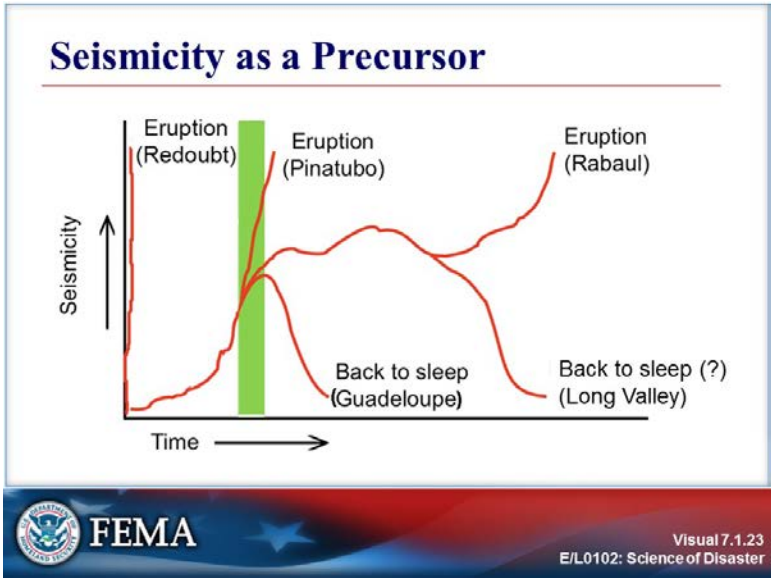
Key Points

<u>Discussion Question</u>: What were some precursors to the Mount Pinatubo eruption?

<u>Discussion Question</u>: How does the prediction of volcanic eruptions compare to predicting other natural hazards (i.e., hurricanes and floods)?

PRECURSORS

Visual 7.1.23



Key Points

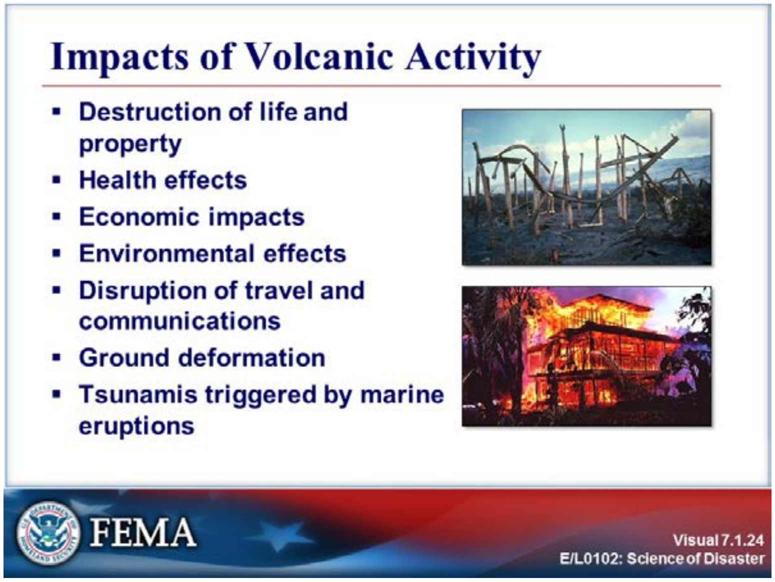
Seismicity—the number and characteristics of earthquakes near the volcano—is a key indicator.

As magma rises it often causes small earthquakes. Sometimes an increase in the seismicity indicates that eruption is imminent.

What the graphic shows: This plot shows the behavior of five recently restless volcanoes (Redoubt, Pinatubo, Rebaul, Guadeloupe, and Long Valley) vs. the number of earthquakes near the volcano over time. (Similar plots could be made for other indicators of volcanic unrest, such as gas emission.) In this case the timeframe is months to years, but other examples could be shown that would be in hours, days, or decades.

VOLCANO IMPACTS

Visual 7.1.24



Key Points

Although eruption styles and intensities vary, a wide array of impacts can be seen, including:

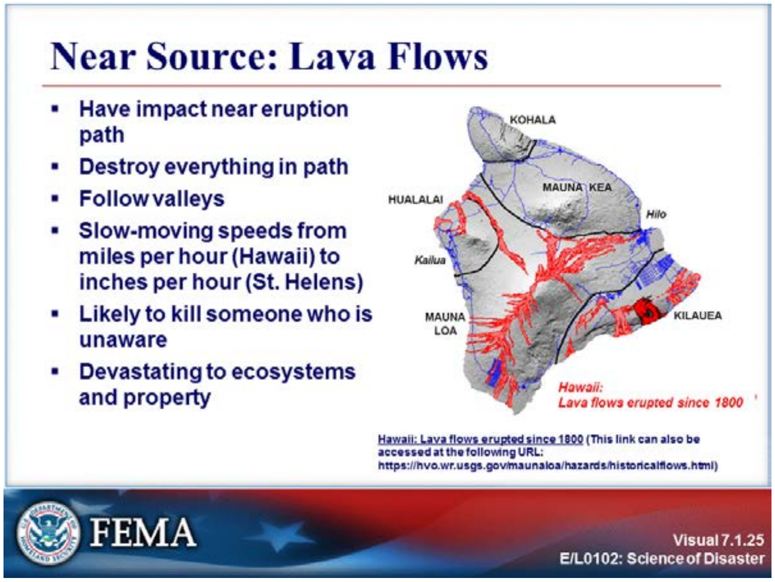
- Destruction of life and property
- Health effects
- Economic impacts
- Environmental effects
- Disruption of travel and communications
- Ground deformation
- Tsunamis triggered by marine eruptions

Long durations of volcanic events (extended eruptions or long periods of unrest) can create significant economic and health impacts. Among the health impacts are mental and physical fatigue, which can impede good decision making and appropriate action.

In addition, a psychological reaction to extended periods of official alert is to redefine what “normal” is and accept the new conditions as average.

VOLCANO IMPACTS

Visual 7.1.25



Alt Text for Visual 7.1.25
Near Source: Lava Flows

- Have impact near eruption path
- Destroy everything in path
- Follow valleys
- Slow-moving speeds from miles per hour (Hawaii) to inches per hour (St. Helens)
- Likely to kill someone who is unaware
- Devastating to ecosystems and property

Graphic of a Hawaiian island with Kohala, Hualalai, Mauna Kea, Hilo, Kailua, Mauna Loa, and Kilauea labeled.
Hawaii: Lava flows erupted since 1800 (This link can also be accessed at the following URL: https://hvo.wr.usgs.gov/maunaloa/hazards/historicalflows.html)

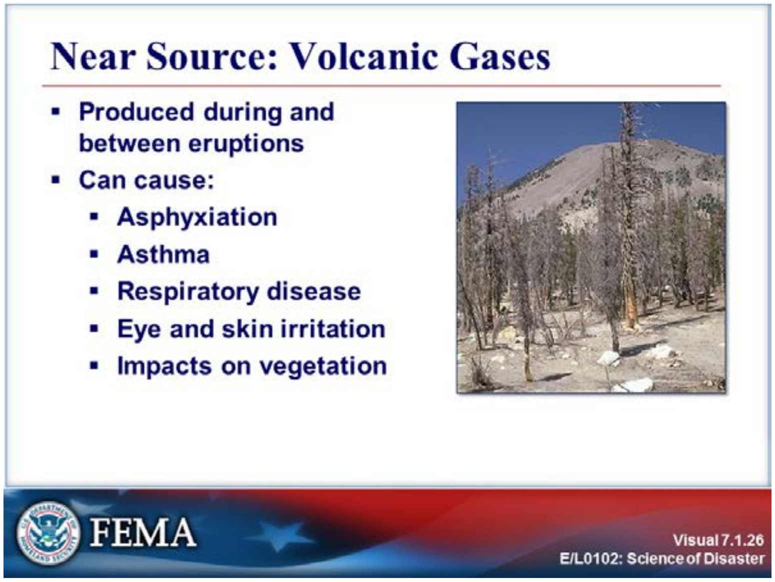
Key Points

Lava flows:

- Have impact near the eruption source
- Destroy everything in their path
- Follow paths that can be anticipated—typically through valleys
- Are relatively slow moving
  - Less viscous lava flows, such as those on Hawaii, move at speeds of miles per hour.
  - Viscous, high-silica lava travels inches per hour.
- Are most likely to kill someone who is caught unaware.
- Are devastating to ecosystems and property because their high temperatures (often 800 degrees Fahrenheit) destroy everything in their path

VOLCANO IMPACTS

Visual 7.1.26



Key Points

During and between eruptions, volcanoes produce several different acidic gases, including sulfur dioxide and hydrogen chloride. Volcanic gases occur in highest levels near volcanoes that are actively degassing, and can cause a variety of health problems, including:

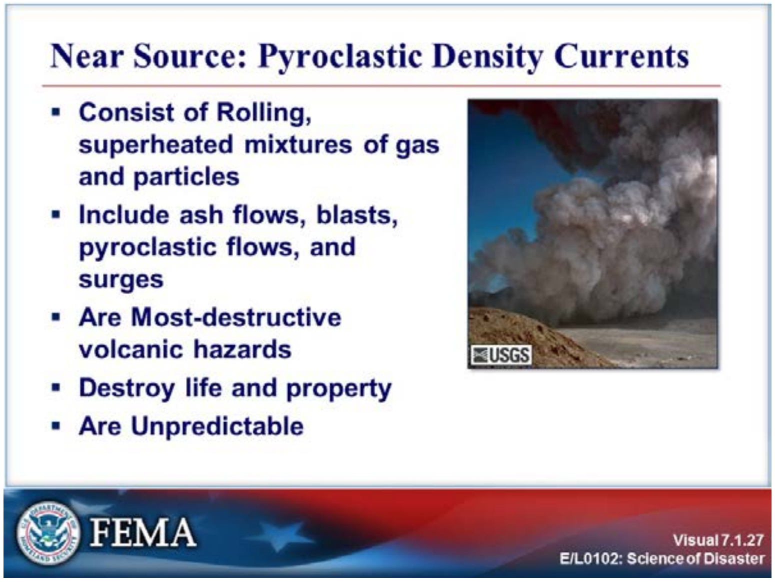
- Asphyxiation
- Asthma
- Respiratory disease
- Eye and skin irritation
- Impacts on vegetation

For example, the trees in this photo are dying from high concentrations of carbon dioxide gas in the soil from subsurface volcanic activity at Long Valley Caldera, also known as Mammoth Mountain.

The only protection from these gases is relocation.

VOLCANO IMPACTS

Visual 7.1.27



Alt Text for Visual 7.1.27
Near Source: Pyroclastic Density Currents

- Consist of Rolling, superheated mixtures of gas and particles
- Include ash flows, blasts, pyroclastic flows, and surges
- Are Most-destructive volcanic hazards
- Destroy life and property
- Are Unpredictable

USGS Photo of a pyroclastic density currents

Key Points

Pyroclastic density currents (PDCs), also called pyroclastic flows, are another near-source hazard.

PDCs:

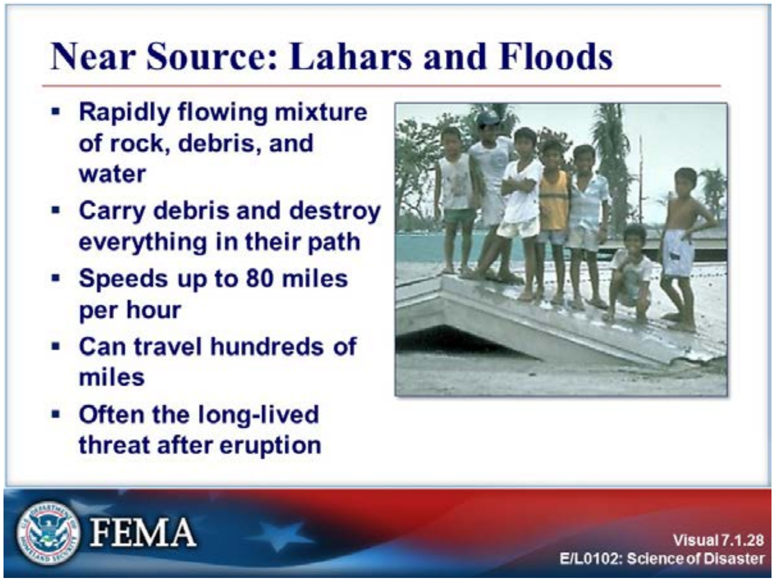
- Are roiling, superheated mixtures of gas and particles that move faster than 100 miles per hour and can blanket a landscape, obliterating everything in their path
- Include ash flows, blasts, pyroclastic flows, and surges
- Are the most devastating of all volcanic hazards, with a long history of destruction of life and property
- Are unpredictable in their path and occurrence

Ancient Pompeii was destroyed by a PDC during an eruption of Mount Vesuvius.

The photo shows a pyroclastic flow during the Mount St. Helens eruption of 1980, which we looked at earlier in this module.

VOLCANO IMPACTS

Visual 7.1.28



Alt Text for Visual 7.1.28
Near Source: Lahars and Floods
- Rapidly flowing mixture of rock, debris, and water
- Carry debris and destroy everything in their path
- Speeds up to 80 miles per hour
- Can travel hundreds of miles
- Often the long-lived threat after eruption

Key Points

A lahar is a rapid volcanic mudflow of up to 80 miles per hour.

Lahars:
- Carry a mixture of rock, debris and water, destroying everything in their path
- Are the volcanic equivalent of a debris flow; in fact, scientists who study one hazard sometimes collaborate with those who study the other
- Can occur during or between eruptions
- Are the most far-reaching of volcanic hazards that are ground-based (as opposed to air-based) and can travel hundreds of miles
- Are often the long-term threat after eruption

PHOTO:
Children on the roof of a school that was buried by a lahar after the eruption of Mount Pinatubo in 1991. Thousands of lahars have occurred there since 1991, nearly all of them triggered by intense rainfall.

VOLCANO IMPACTS

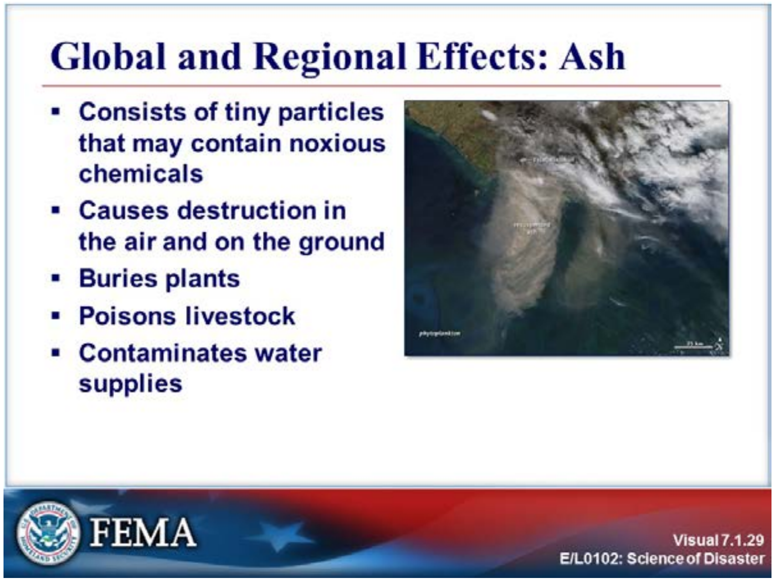
Visual 7.1.28 (Continued)

Lahars can form in a variety of ways, such as:

- When a pyroclastic flow or steam eruption melts snow and ice on a volcano
- By breakout of a lake dammed by volcanic deposits
- During intense rainfall on loose volcanic deposits

VOLCANO IMPACTS

Visual 7.1.29



Alt Text for Visual 7.1.29
Global and Regional Effects: Ash
- Consists of tiny particles that may contain noxious chemicals
- Cause destruction in the air and on the ground
- Buries plants
- Poisons livestock
- Contaminates water supplies

Key Points

An effect that reaches beyond the Local hazard area is ash generated by an explosive volcanic eruption.

PHOTO:
NASA image of the ash plume from an Icelandic eruption in 2010 that disrupted worldwide aviation for weeks

Ash:
- Consists of tiny particles, fractions of an inch in size

Is typically composed of silica—essentially microscopic glass—and may also contain noxious chemical substances.
- Can cause destruction while in the air and when it reaches ground. Even minor amounts cause significant impacts on infrastructure, lifelines, and industry including aviation, ground transportation, communications, utilities, and farming.
- Buries plants, poisons livestock, and contaminates water supplies. In water it becomes extremely abrasive.

VOLCANO IMPACTS

Visual 7.1.29 (Continued)

Ash inhalation and contact have many health consequences for animals and humans.

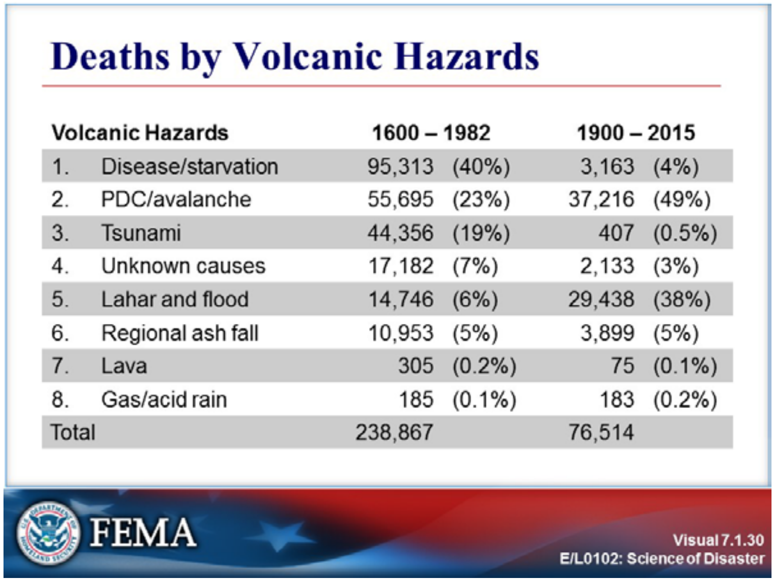
- Short-term effects include:
  - Asthma, bronchitis, and irritation of airways
  - Increased risk of stroke or heart attack
  - Skin and eye irritation

Long-term effects include:

- Chronic obstructive pulmonary disease
- Tuberculosis
- Pneumoconiosis
- Fluorosis
- Silicosis and other lung fibrotic diseases

VOLCANO IMPACTS

Visual 7.1.30



Volcanic Hazards		1600 – 1982		1900 – 2015	
1.	Disease/starvation	95,313	(40%)	3,163	(4%)
2.	PDC/avalanche	55,695	(23%)	37,216	(49%)
3.	Tsunami	44,356	(19%)	407	(0.5%)
4.	Unknown causes	17,182	(7%)	2,133	(3%)
5.	Lahar and flood	14,746	(6%)	29,438	(38%)
6.	Regional ash fall	10,953	(5%)	3,899	(5%)
7.	Lava	305	(0.2%)	75	(0.1%)
8.	Gas/acid rain	185	(0.1%)	183	(0.2%)
Total		238,867		76,514	

Key Points

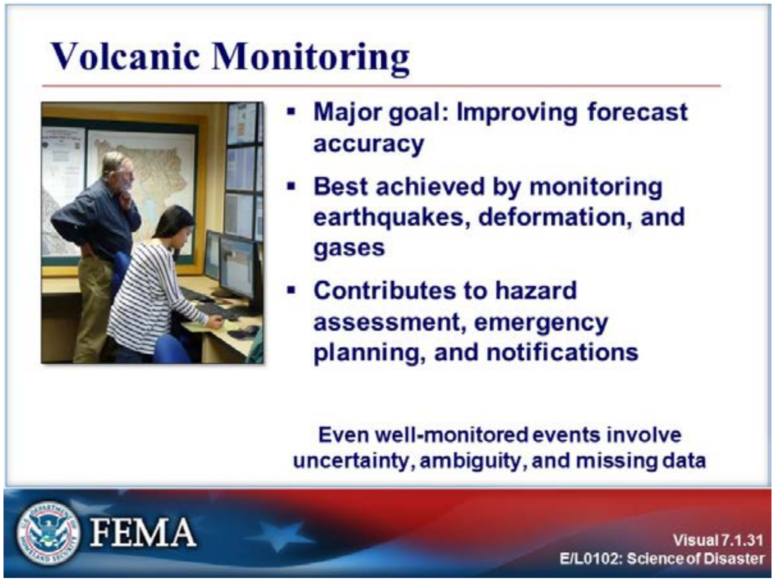
Deaths from volcanoes can result from many different hazards.

This table shows a breakdown of deaths by volcanic hazards for eruptions between 1600 and 1982 and between 1900 and 2015. Notice that for both time periods, PDC/avalanche was one of the top two causes of fatalities.

Volcanic Hazards		1600 – 1982		1900 – 2015	
1.	Disease/starvation	95,313	(40%)	3,163	(4%)
2.	PDC/avalanche	55,695	(23%)	37,216	(49%)
3.	Tsunami	44,356	(19%)	407	(0.5%)
4.	Unknown causes	17,182	(7%)	2,133	(3%)
5.	Lahar and flood	14,746	(6%)	29,438	(38%)
6.	Regional ash fall	10,953	(5%)	3,899	(5%)
7.	Lava	305	(0.2%)	75	(0.1%)
8.	Gas/acid rain	185	(0.1%)	183	(0.2%)
	Total	238,867		76,514	

VOLCANIC MONITORING

Visual 7.1.31



Alt Text for Visual 7.1.31
Volcanic Monitoring
- Major goal: Improving forecast accuracy
- Best achieved by monitoring earthquakes, deformation, and gases
- Contributes to hazard assessment, emergency planning, and notifications

Even well-monitored events involve uncertainty, ambiguity, and missing data

Key Points

How volcanoes are monitored: Volcanology is the study of volcanoes. A major goal of volcanology is to improve the accuracy of forecasting. Because most volcanoes enter periods of unrest before eruption, monitoring volcanoes for signs of activity provides the best chance of reducing eruption impacts. Signs of activity can vary, and monitoring is best achieved by looking at earthquakes, ground deformation, and volcanic gases. Scientists employ an arsenal of skills and methods to observe and detect the great variety and wide scale of changes volcanoes can make to Earth, air, and water.

- **Earthquake seismometers** must detect energy of different wavelengths.
- **Ground deformation detection** includes techniques from satellite radar, to real-time GPS, to leveling surveys.
- **Satellite, airborne, and in-person methods** are used to sample gas emissions.
- During eruptions, volcanoes generate their own weather, so **worldwide lightning detection** is also a method employed for situational awareness.

Monitoring in the United States: During an eruption, monitoring remains a critical tool to understand what will happen next. In the United States, the USGS has statutory responsibility to monitor U.S. volcanoes and to issue alerts and warnings about volcanic unrest and eruption. It is currently developing a volcano early warning system. However, not all active volcanoes are currently monitored, including some that pose high risk.

VOLCANIC MONITORING

Visual 7.1.31 (Continued)

Forecasting: For an eruption forecast to be useful, it needs to identify:

- When the eruption will begin
- How long it will last
- How severe it will be
- Then the eruption is over (although unrest might continue)

However, it is important to keep in mind that even well-monitored events involve uncertainty, ambiguity, and missing data.

VOLCANIC MONITORING

Visual 7.1.32

Alt Text for Visual 7.1.32
Volcanic Monitoring and Emergency Management

- Hazard assessment
- Emergency planning
- Notifications

Ground-based Volcano Alert Levels and Aviation Color Codes (This link can also be accessed at the following URL: https://volcanoes.usgs.gov/vhp/alert_icons.html)

Key Points

Contributions to emergency management: Volcanic monitoring contributes to emergency management in several ways:

- **Hazard assessment:** Before unrest, scientists focus on an individual volcano or hazardous process to develop a hazard assessment, which is based on an understanding of volcanic processes in general and on the history and likely behavior of a particular volcano or process. To fully quantify the hazard in space and time, a hazard assessment will include:
  - Geologic mapping of the volcano
  - Accurate topography from a digital elevation model
  - Analyses of past eruptions at that volcano
  - Knowledge of Local wind directions and other weather features

  Hazard assessments will change as conditions change, including landscape changes and increases in understanding.

VOLCANIC MONITORING

Visual 7.1.32 (Continued)

- **Emergency planning:** Response plans are in place at the national and regional levels to deal with the widespread potential effects of ash eruptions.

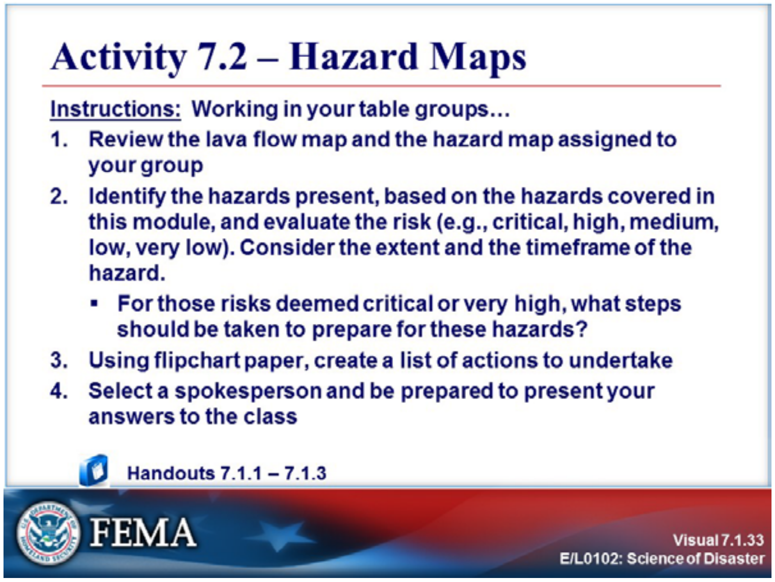
  Developing such plans requires the combination of scientific and emergency management expertise, and the participation of numerous agencies and organizations to delineate interagency roles and coordination requirements for events that can have Local, regional, and national impacts. There exist scattered Local plans for individual volcanoes, but as is true with other hazards, it is difficult to engage communities in preparations for rare events.

- **Notifications:** When a volcano becomes restless, or finally erupts, scientific scrutiny greatly increases. Monitoring of that volcano, its hazard assessment, and understanding of volcanic processes are all more generally brought to bear, quickly, to produce Volcano Activity notifications. These notifications are available by subscription and on the web. Weather science is combined with Earth science to produce special weather statements from the National Weather Service.

During an eruption or crisis, the scientists who create these messages, and those who receive them, must grapple with the difficulty of communicating information and making decisions in a situation with great inherent uncertainty.

ACTIVITY 7.2 – HAZARD MAPS

Visual 7.1.33



Alt Text for Visual 7.1.33
Activity 7.2 – Hazard Maps
Instructions: Working in your table groups…
1. Review the lava flow map and hazard map assigned to your group
2. Identify the hazards present, based on the hazards covered in this module, and evaluate the risk (e.g., critical, high, medium, low, very low). Consider the extent and the timeframe of the hazard.
    - For those risks deemed critical or high, what steps should be taken to prepare for these hazards?
3. Using flipchart paper, create a list of actions to undertake
4. Select a spokesperson and be prepared to present your answers to the class

Job Aid: Handouts 7.1.1 – 7.1.3

Key Points

Instructions: Working in your table groups…

See:

- Handout 7.1.1: Lava Flow Map
- Handout 7.1.2: Hawaii
- Handout 7.1.3: Mount Rainier

1. Review the lava flow map and the hazard map assigned to your group.
2. Identify the hazards present, based on the hazards covered in this module, and evaluate the risk (e.g., critical, high, medium, low, very low). Consider the extent and the timeframe of the hazard.
    - For those risks deemed critical or very high, what steps should be taken to prepare for these hazards?
3. Using flipchart paper, create a list of actions to undertake.
4. Select a spokesperson and be prepared to present your answers to the class.

ACTIVITY 7.2 – HAZARD MAPS

Visual 7.1.33 (Continued)

HAWAII – RISK ASSESSMENT				
Hazard	Kailua-Kona	Ocean View	Pãhoa	Waimea
Ash Fall				
Explosive Eruptions				
Ground Cracks and Settling				
Lava Flows				
Lahars				
Pyroclastic Flows				
Tephra				
Volcanic Gasses				

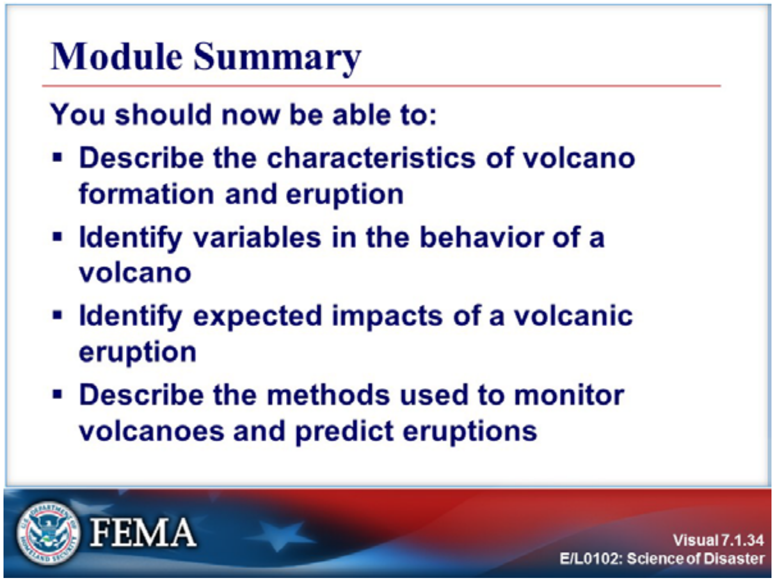
ACTIVITY 7.2 – HAZARD MAPS

Visual 7.1.33 (Continued)

MOUNT RANIER – RISK ASSESSMENT				
Hazard	Ashford	Morton	Paradise	50 miles due east of Ranier
Ash Fall				
Explosive Eruptions				
Ground Cracks and Settling				
Lava Flows				
Lahars				
Pyroclastic Flows				
Tephra				
Volcanic Gasses				

MODULE SUMMARY

Visual 7.1.34



Alt Text for Visual 7.1.34
Module Summary
You should now be able to:

- Describe the characteristics of volcano formation and eruption
- Identify variables in the behavior of a volcano
- Identify expected impacts of a volcanic eruption
- Describe the methods used to monitor volcanoes and predict eruptions

Key Points

Do you have any questions about the material covered in this module?

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MODULE 8: HUMAN-INDUCED DISASTERS

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UNIT 1. INTRODUCTION TO HUMAN-INDUCED DISASTERS

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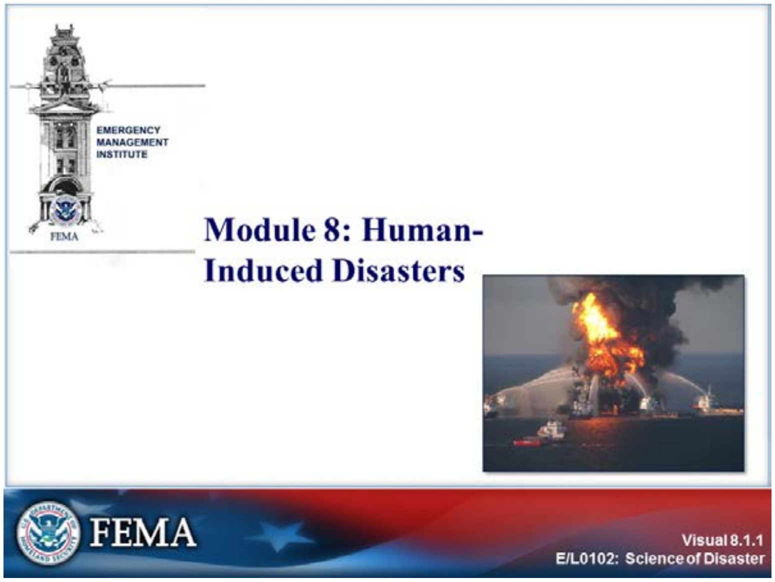
INTRODUCTION

Visual 8.1.1

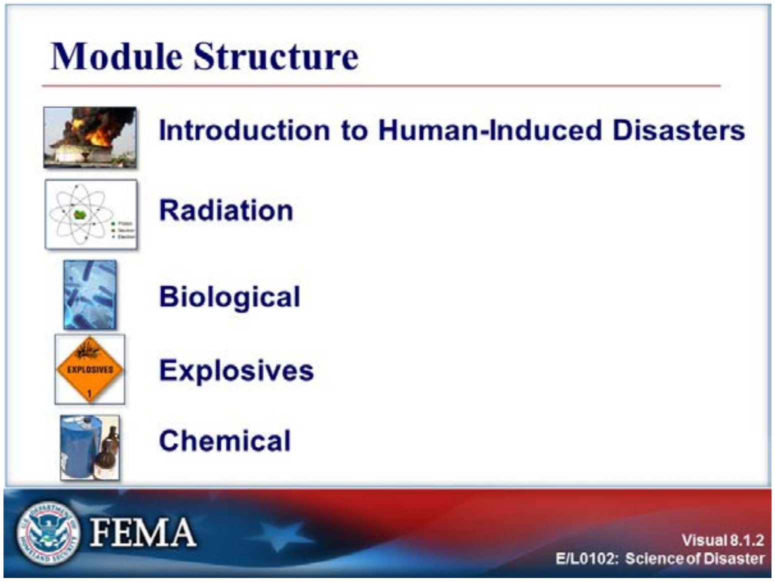


Key Points

As you have learned, hazards are typically categorized as natural, human-induced, and technological. We have spent the first two days of the course learning the science of the natural hazards. Today, we will learn the science behind some human-induced and technological hazards.

INTRODUCTION

Visual 8.1.2



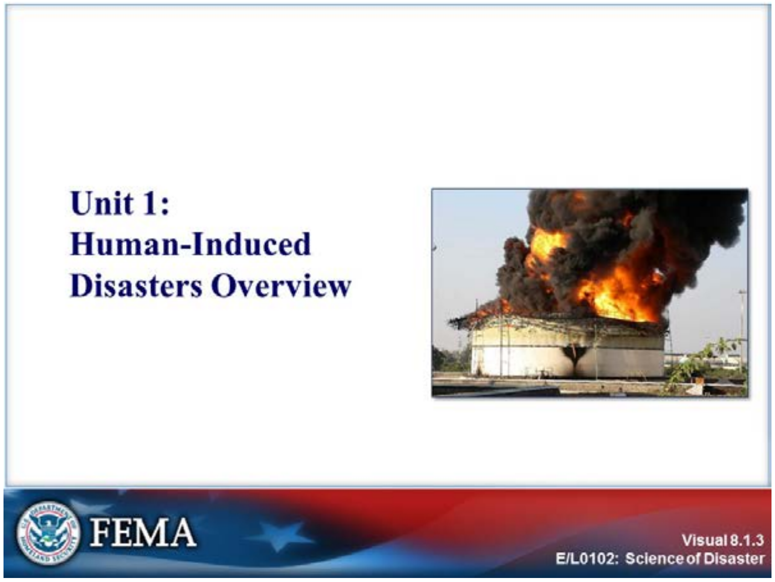
Key Points

This module consists of the following units:

Unit	Time
Unit 1: Human-Induced Disasters Overview	
Unit 2: Radiation • Activity 8.1 – Goiânia Contamination (Visual 8.2.51) • Activity 8.2 – Assessing Radiological Exposure Risk for Your Community (Visual 8.2.54)	1 hour 40 minutes
Unit 3: Biological • Activity 8.3 – Hurricane Sandy (Visual 8.3.20) • Activity 8.4 – Bioterrorism Tabletop (Visual 8.3.36)	2 hours 30 minutes
Unit 4: Explosives • Activity 8.5 – Prevention and Mitigation of Explosives (Visual 8.4.44) • Activity 8.6 – Module 8 IAW (Visual 8.4.46)	1 hour 40 minutes
Unit 5: Chemical • Activity 8.7 – Chemical Response Resources (Visual 8.5.38) • Activity 8.8 – Chemical Response in Your Community (Visual 8.5.40)	2 hours 10 minutes
Total Module Time:	**8 hours**

INTRODUCTION

Visual 8.1.3



Key Points

This unit will give an introduction to Human-Induced Disasters.

INTRODUCTION

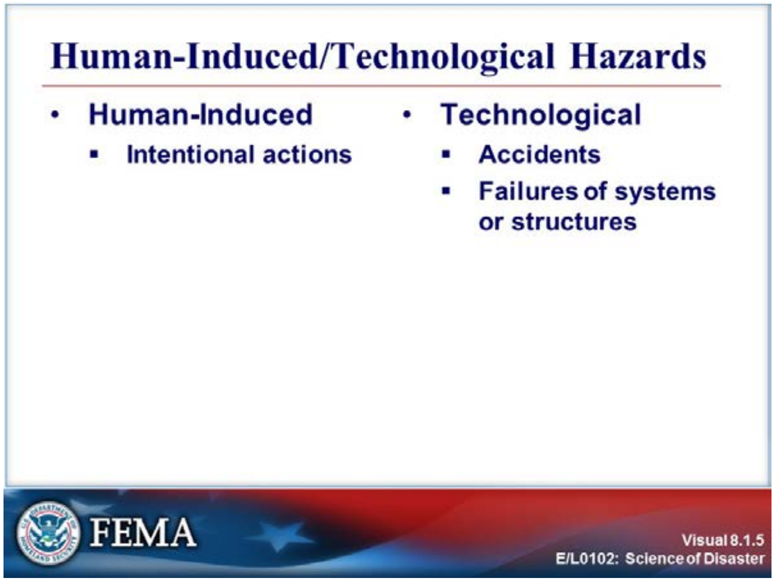
Visual 8.1.4

Key Points

Review the unit objectives.

HUMAN-INDUCED/TECHNOLOGICAL HAZARDS

Visual 8.1.5



Key Points

Human-Induced Hazards are those hazards that result from the intentional actions of an adversary, such as a chemical attack, biological attack, or cyber-attack. (*Comprehensive Preparedness Guide* (CPG) 201)

Technological Hazards are those hazards that result from accidents or the failures of systems and structures, such as hazardous materials spills or dam failures. (CPG 201).

These hazards are often referred to as “man-made” hazards.

HUMAN-INDUCED/TECHNOLOGICAL HAZARDS

Visual 8.1.6

Alt Text for Visual 8.1.6
Human-Induced/Technological Hazards (cont.)

- Inevitable product of human development
- Less understood compared to natural hazards
- Technology increases in complexity
- Increases in the complexity of technological hazards

What are some examples of complex technological hazards that didn't exist 100 years ago?

Key Points

In the realm of possible disasters in the field of emergency management, human-induced and technological hazards are definitely ones to consider. These types of disasters are

- Inevitable products of human development
- Often less understood, when compared to natural hazards
- As technology increases in complexity, so does the complexity of technological hazards

Discussion Question: What are some examples of complex human-induced and technological hazards that didn't exist 100 years ago?

TYPES OF INCIDENTS

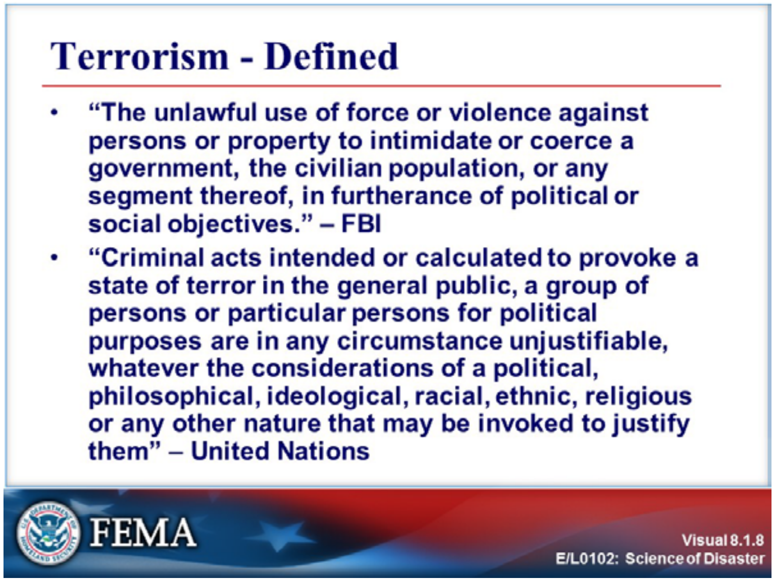
Visual 8.1.7

Key Points

Review the different types of human-induced incidents on the visual.

TERRORISM

Visual 8.1.8



Alt Text for Visual 8.1.8
Terrorism - Defined

- "The unlawful use of force or violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof, in furtherance of political or social objectives." – FBI
- "Criminal acts intended or calculated to provoke a state of terror in the general public, a group of persons or particular persons for political purposes are in any circumstance unjustifiable, whatever the considerations of a political, philosophical, ideological, racial, ethnic, religious or any other nature that may be invoked to justify them" – United Nations

Key Points

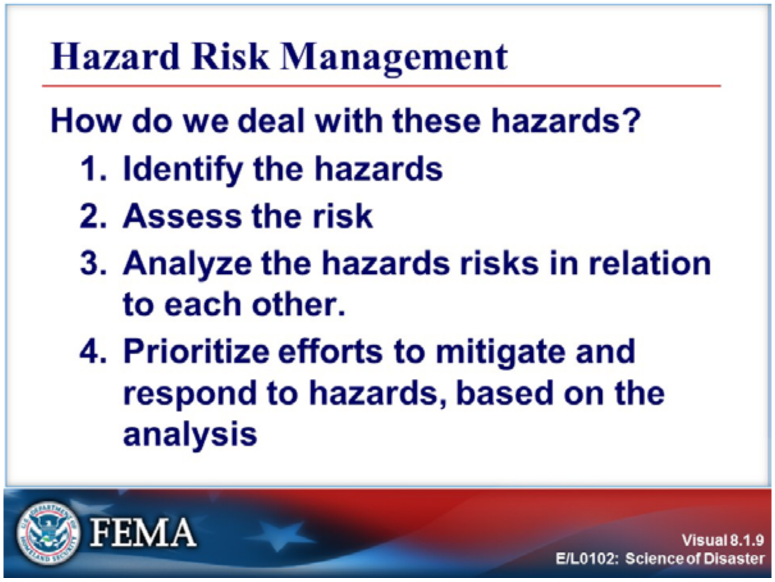
To get a better understanding of human-induced incidents, it is important to have an understanding of terrorism.

Terrorism is defined as "the unlawful use of force or violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof, in furtherance of political or social objectives" – FBI

"Criminal acts intended or calculated to provoke a state of terror in the general public, a group of persons or particular persons for political purposes are in any circumstance unjustifiable, whatever the considerations of a political, philosophical, ideological, racial, ethnic, religious or any other nature that may be invoked to justify them" – United Nations

HAZARD RISK MANAGEMENT

Visual 8.1.9

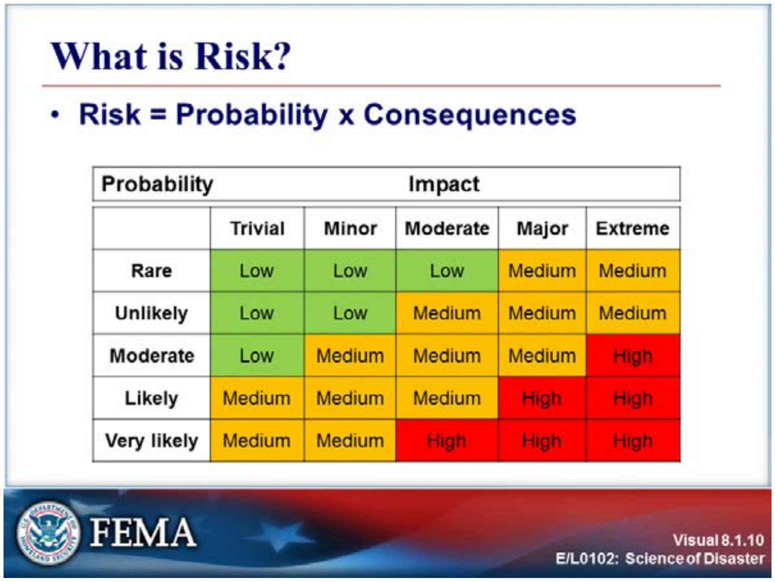


Key Points

This is the general hazard risk management process, as defined by George Haddow in *Introduction to Emergency Management.* There are other more defined processes, such as the Threat and Hazard Identification and Risk Assessment (THIRA) process. We will not be discussing a specific process.

WHAT IS RISK?

Visual 8.1.10



Key Points

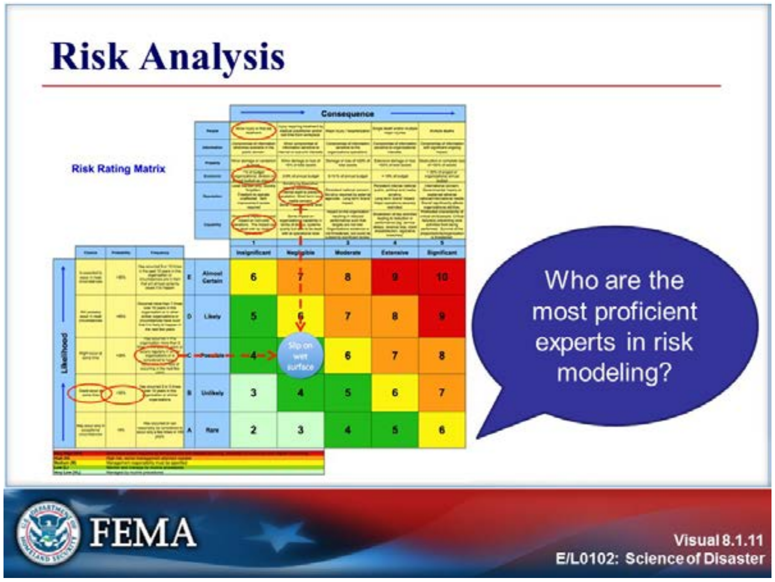
Once the potential risks to your community have been identified, you will need to determine the likelihood (probability) of the hazard occurring and the impact (severity of consequences to life and health, property, and infrastructure, and the environment).

Using a matrix like the one in the visual can help you organize and determine your risk.

Probability	Impact				
	Trivial	**Minor**	**Moderate**	**Major**	**Extreme**
Rare	Low	Low	Low	Medium	Medium
Unlikely	Low	Low	Medium	Medium	Medium
Moderate	Low	Medium	Medium	Medium	High
Likely	Medium	Medium	Medium	High	High
Very likely	Medium	Medium	High	High	High

RISK ANALYSIS

Visual 8.1.11



Key Points

Risk analysis and modeling is a science onto itself.

The harm severity on a risk analysis matrix can be categorized as:

- Catastrophic – Multiple Deaths
- Critical – One Death or Multiple Severe Injuries
- Marginal – One Severe Injury or Multiple Minor Injuries
- Negligible – One Minor Injury

The probability of harm occurring or consequence might be categorized as 'Certain', 'Likely', 'Possible', 'Unlikely' and 'Rare'. However, it must be considered that very low probabilities may not be very reliable.

RISK ANALYSIS

Visual 8.1.11 (Continued)

The resulting Risk Matrix could be:

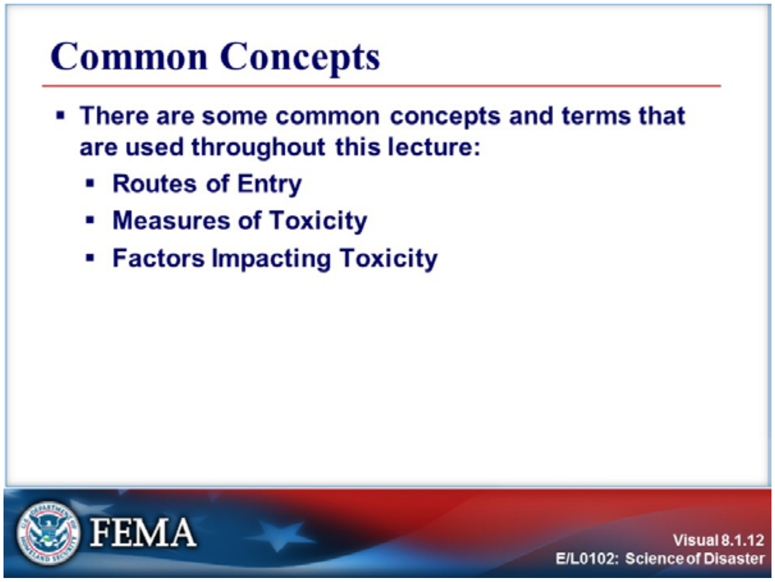
	Negligible	Marginal	Critical	Catastrophic
Certain	High	High	Extreme	Extreme
Likely	Moderate	High	High	Extreme
Possible	Low	Moderate	High	Extreme
Unlikely	Low	Low	Moderate	Extreme
Rare	Low	Low	Moderate	High

Discussion Question: Who are the most proficient experts in risk modeling and prediction?

Risk Rating Matrix Source (This link can also be accessed at the following URL: http://www.jakeman.com.au/sb_cache/media/id/38/f/figure1.png

COMMON CONCEPTS

Visual 8.1.12

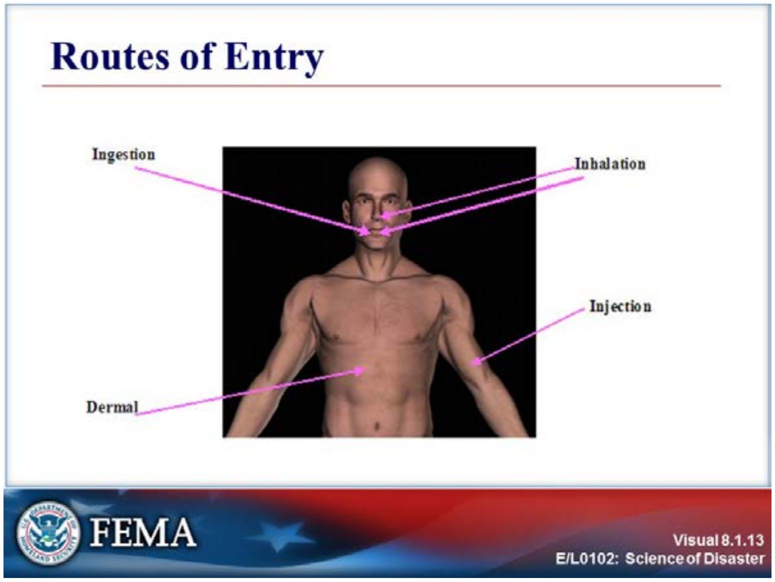


Key Points

The next section of this unit will discuss come common concepts and terms that will be used throughout the remainder of this module.

ROUTES OF ENTRY

Visual 8.1.13



Key Points

As we review the chemical classes, we will discuss the various hazards—including health hazards—associated with each. In many cases, the health impacts of exposure to a chemical depend on how an agent gets into the body (the route of entry).

There a several ways a chemical can enter the body:

a. **Ingestion:** Some chemicals may enter the body by ingestion of contaminated food or liquid, or the individual may contaminate themselves and then touch food or their mouth.

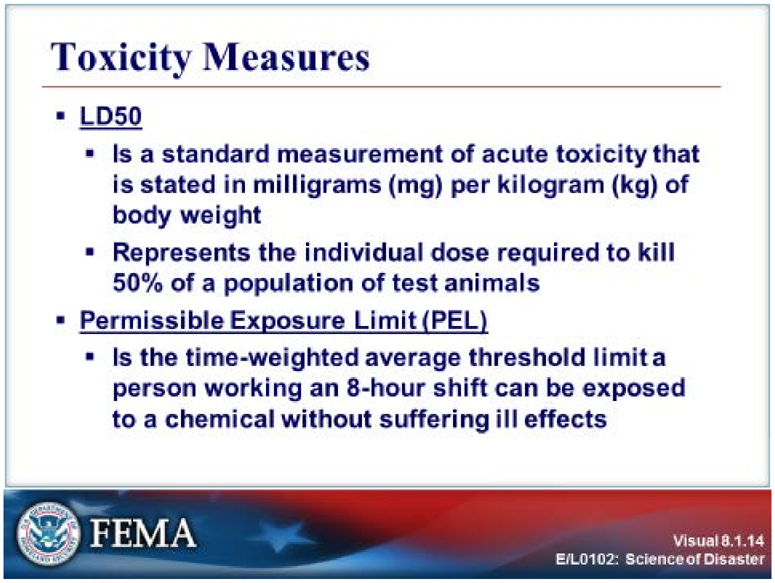
b. **Inhalation:** Chemicals that are in a gas phase, that form vapors, or that are dispersed in aerosol form can enter the body through the respiratory tract and enter the lungs.

c. **Injection:** Chemicals may enter the skin through puncture and penetration wounds.

d. **Absorption**: Liquid chemicals may enter via skin contact. Chemicals in gas or vapor form, if the concentration is high enough or the exposure long enough, can also penetrate the skin and cause the same effects as skin contact with liquid agent.

TOXICITY MEASURES

Visual 8.1.14



Alt Text for Visual 8.1.14
Toxicity Measures

- LD50
  - o Is a standard measurement of acute toxicity that is stated in milligrams (mg) per kilogram (kg) of body weight
  - o Represents the individual dose required to kill 50% of a population of test animals
- Permissible Exposure Limit (PEL)
  - o Is the time-weighted average threshold limit a person working an 8-hour shift can be exposed to a chemical without suffering ill effects

Key Points

Toxicity can be measured by its effects on the target (organism, organ, tissue, or cell). Because individuals typically have different levels of response to the same dose of a toxin, a population-level measure of toxicity is often used, which relates the probabilities of an outcome for a given individual in a population. One such measure is the LD50.

LD50 description: An LD50 is a standard measurement of acute toxicity that is stated in milligrams (mg) of product per kilogram (kg) of body weight. An LD50 represents the individual dose required to kill 50 percent of a population of test animals (e.g., rats, fish, mice, cockroaches)—i.e., a lethal dose.

Because LD50 values are standard measurements, it is possible to compare relative toxicities among chemicals. The lower the LD50 dose, the more toxic the substance. (For example, a substance with an LD50 value of 10 mg/kg is 10 times more toxic than a substance with an LD50 of 100 mg/kg).

TOXICITY MEASURES

Visual 8.1.14 (Continued)

Toxicity in relation to route of entry: The toxicity of a chemical is related to the route of entry of the chemical into an organism.

- **Oral toxicity** refers to:
  - A liquid with a lethal dose (LD50) for acute oral toxicity of not more than 500 mg/kg, or

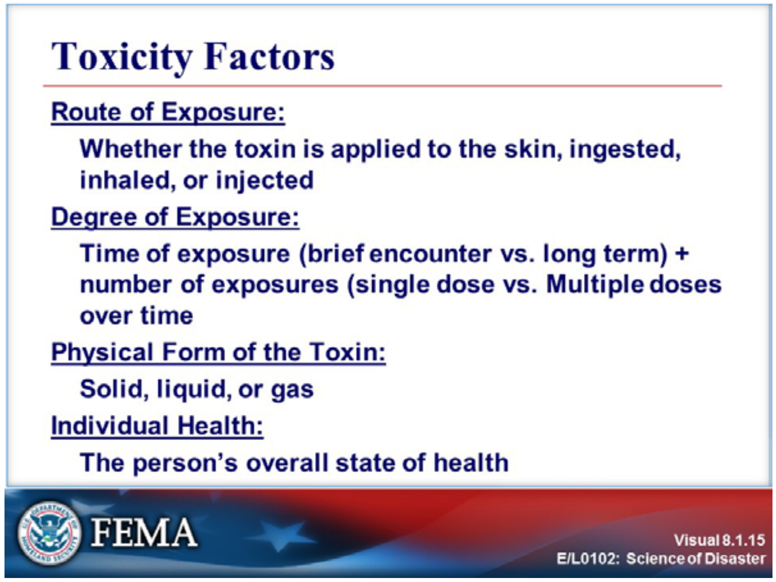
    A solid with an LD50 for acute oral toxicity of not more than 200 mg/kg, which, when administered by mouth, is likely to cause death within 14 days in half of the test animals.
- **Dermal toxicity** refers to:
  - A material with an LD50 for acute dermal toxicity of not more than 1,000 mg/kg which, when administered by continuous contact with bare skin, is likely to cause death within 14 days in half of the test animals.
- **Inhalation toxicity** applies to:
  - A dust or mist with a lethal concentration (LC50) for acute inhalation toxicity of not more than 10 mg/L
  - A saturated vapor concentration in air at 68 °F (20 °C) of more than one-fifth of the LC50 for acute toxicity on inhalation of vapors and with an LC50 for acute inhalation toxicity of vapors of not more than 5,000 ml/m3 which, when administered by continuous inhalation for 1 hour, is likely to cause death within 14 days in half of the test animals.
- **Irritating material** is any liquid or solid substance (such as tear gas) that gives off intense fumes and causes extreme, but reversible, localized irritant effects on the eyes, nose, and throat, temporarily impairing a person’s ability to function.

Often the inhalation LD50 is lower (more toxic) than the oral LD50, which is, in turn, lower (more toxic) than the dermal LD50.

Permissible exposure limits: OSHA sets enforceable permissible exposure limits (PELs) to protect workers against the health effects of exposure to hazardous substances. PELs are regulatory limits on the amount or concentration of a substance in the air. They may also contain a skin designation. OSHA PELs are based on an 8-hour, time-weighted, average (TWA) exposure.

TOXICITY FACTORS

Visual 8.1.15



Alt Text for Visual 8.1.15
Toxicity Factors
Route of Exposure: Whether the toxin is applied to the skin, ingested, inhaled, or injected
Degree of Exposure: Time of exposure (brief encounter vs. long term) + number of exposures (single dose vs. Multiple doses over time
Physical Form of the Toxin: Solid, liquid, or gas
Individual Health: The person's overall state of health

Key Points

The toxicity of a chemical can be affected by many different factors, such as:

- **Route of exposure**—whether the toxin is applied to the skin, ingested, inhaled, or injected
- **Degree of exposure**—including:
  - **Time of exposure**—a brief encounter vs. long term
  - **Number of exposures**—a single dose vs. multiple doses over time
  - **Concentration—**amount of toxic component in relation to total volume
- **Physical form of the toxin**—solid, liquid, or gas phase.
- **Individual health**—the genetic makeup of an individual, an individual's overall health, and other health factors.

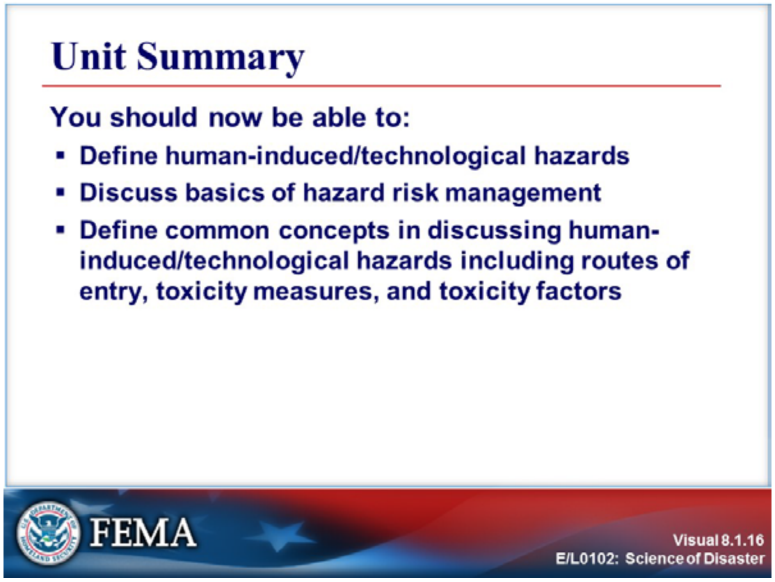
TOXICITY FACTORS

Visual 8.1.15 (Continued)

- It is more difficult to determine the toxicity of a chemical mixture than a pure chemical because each component displays its own toxicity, and components may interact to produce enhanced or diminished effects.
- Common mixtures include gasoline, cigarette smoke, and industrial waste. Even more complex are situations with more than one type of toxic entity, such as the discharge from a malfunctioning sewage treatment plant, with both chemical and biological agents.

UNIT SUMMARY

Visual 8.1.16



Alt Text for Visual 8.1.16
Unit Summary
You should now be able to:

- Define human-induced/technological hazards
- Discuss basics of hazard risk management
- Define common concepts in discussing human-induced/technological hazards including routes of entry, toxicity measures, and toxicity factors

Key Points

Do you have any questions about the material covered in this unit?

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UNIT 2. RADIATION

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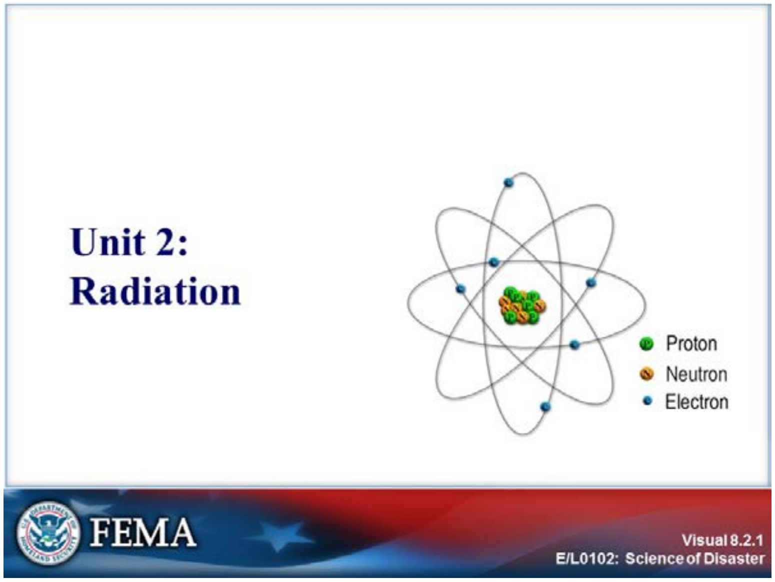
INTRODUCTION

Visual 8.2.1



Key Points

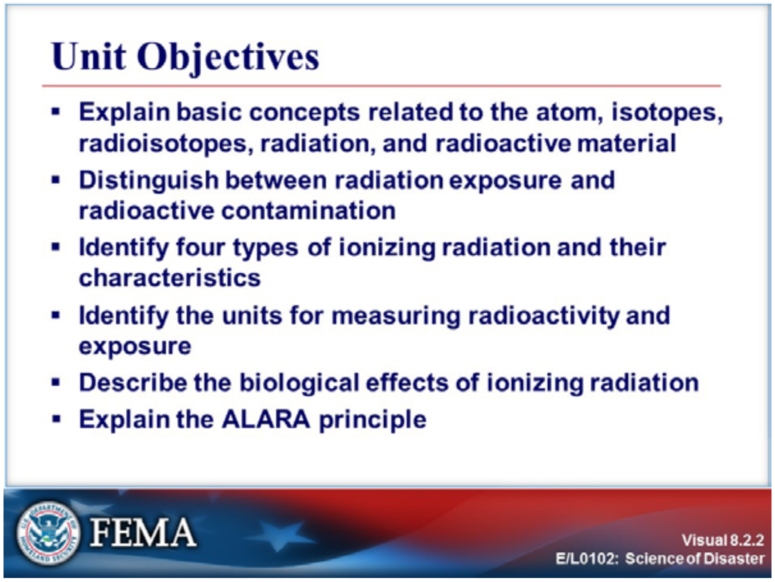
This unit will introduce fundamental concepts related to radiation.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction Radiation Basics	5 minutes
Radiation Basics	10 minutes
Exposure and Contamination	20 minutes
Optional Demo	5 minutes
Effects of Radiation	15 minutes
Activity 8.1 – Goiânia Contamination	30 minutes
Unit Summary	5 minutes
Activity 8.2 – Assessing Radiological Exposure Risk for Your Community	10 minutes
Total Time	**1 hour 40 minutes**

INTRODUCTION

Visual 8.2.2



Alt Text for Visual 8.2.2
Unit Objectives

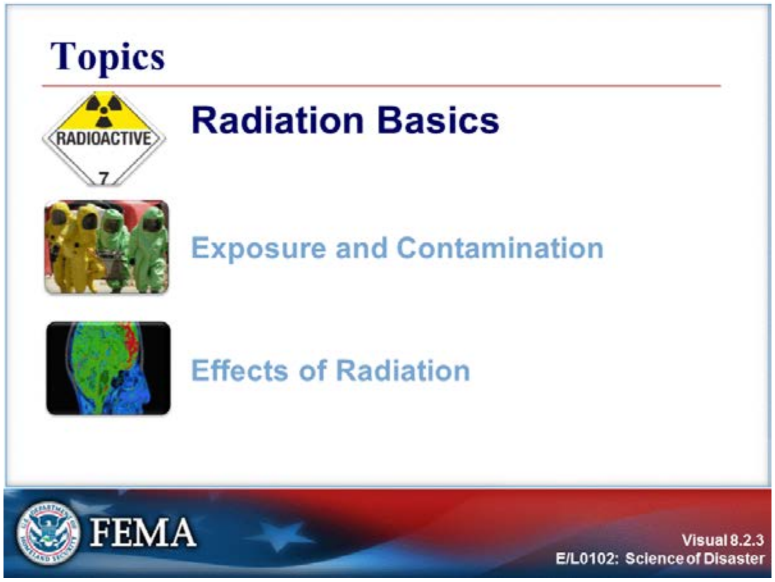
- Explain basic concepts related to the atom, isotopes, radioisotopes, radiation, and radioactive material
- Distinguish between radiation exposure and radioactive contamination
- Identify four types of ionizing radiation and their characteristics
- Identify the units for measuring radioactivity and exposure
- Describe the biological effects of ionizing radiation
- Explain the ALARA principle

Key Points

Review the unit objectives as shown on the visual.

RADIATION BASICS

Visual 8.2.3

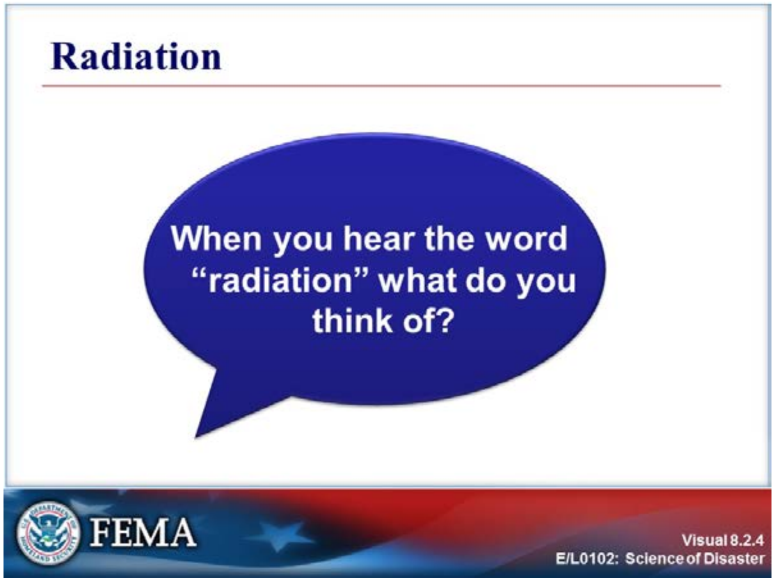


Key Points

Three main topics will be covered in this module: radiation basics, exposure and contamination, and effects of radiation. We will begin with radiation basics—the underlying concepts of radiation and radioactivity.

RADIATION BASICS

Visual 8.2.4

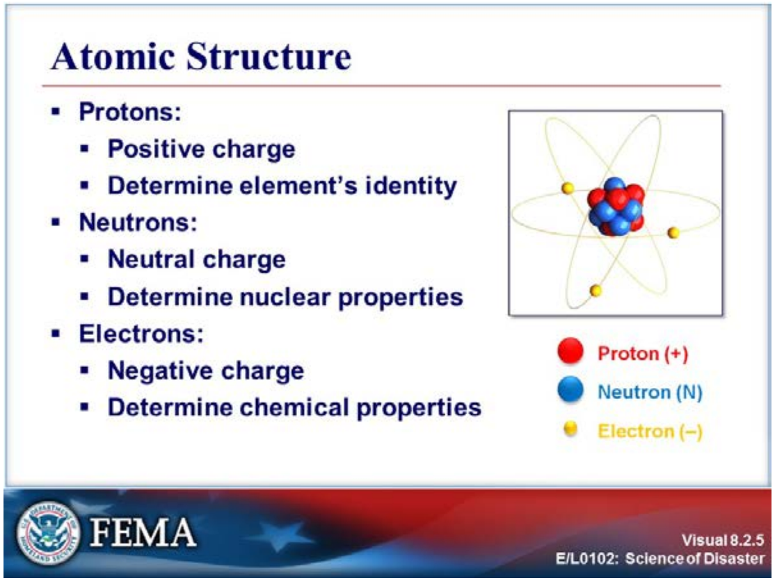


Key Points

<u>Discussion Question</u>: When you hear the word "radiation," what do you think of?

RADIATION BASICS

Visual 8.2.5



Alt Text for Visual 8.2.5
Atomic Structure

- Protons:
  - Positive charge
  - Determine element's identity
- Neutrons:
  - Neutral charge
  - Determine nuclear properties
- Electrons:
  - Negative charge
  - Determine chemical properties

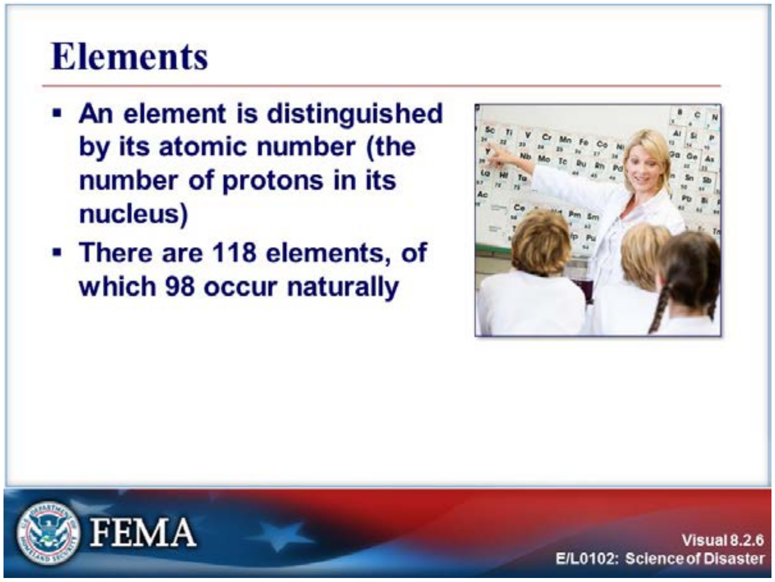
Key Points

The atom is made up of three fundamental parts: protons, neutrons, and electrons. Protons and neutrons are located in the center part or nucleus of the atom. Electrons revolve around the nucleus similar to the way the planets orbit the sun.

- **Protons** have a positive electrical charge and determine the element's identity.
- **Neutrons** have a neutral electrical charge and determine the nuclear properties of an atom.
- **Electrons** have a negative electrical charge and determine the chemical properties of an atom.

RADIATION BASICS

Visual 8.2.6



Key Points

A chemical element is a type of atom that is distinguished by its atomic number; that is, by the number of protons in its nucleus. The term is also used to refer to a pure chemical substance composed of atoms with the same number of protons.

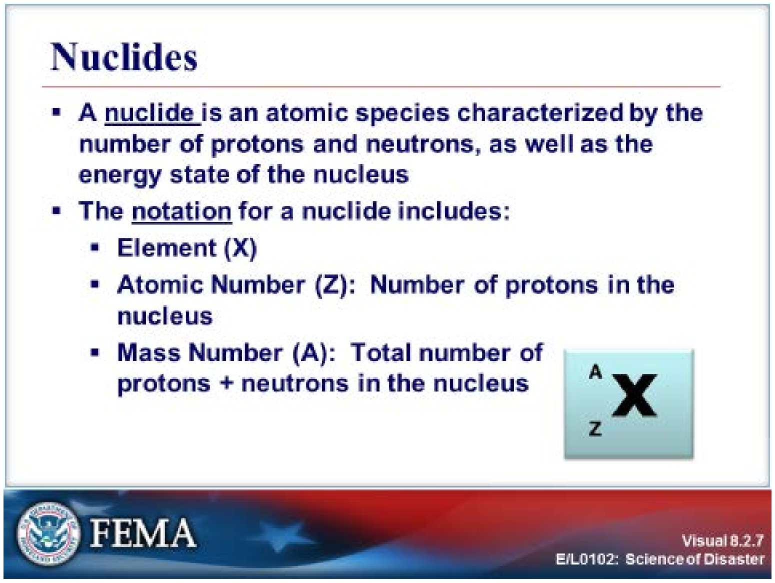
The following are common examples of elements:

- Iron
- Copper
- Silver
- Gold
- Hydrogen
- Carbon
- Nitrogen
- Oxygen

As of 2011, 118 elements had been observed, of which 98 occur naturally on Earth.

RADIATION BASICS

Visual 8.2.7



Alt Text for Visual 8.2.7

Nuclides

- A nuclide is an atomic species characterized by the number of protons and neutrons, as well as the energy state of the nucleus
- The notation for a nuclide includes:
  - Element (X)
  - Atomic Number (Z): Number of protons in the nucleus
  - Mass Number (A): Total number of protons + neutrons in the nucleus

A diagram illustrating a nuclide – with the letter x and to the right of the x is a capital A on the top and a capital Z on the bottom.

Key Points

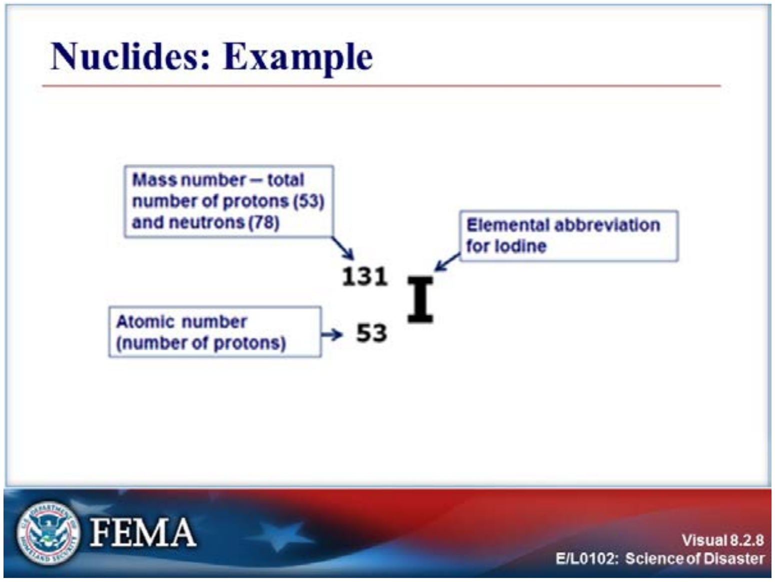
Nuclides: A nuclide is an atomic species characterized by the number of protons and neutrons, as well as the energy state of the nucleus.

Nuclide notation: A general notation for a nuclide is shown on the visual, with X representing the element.

- The **atomic mass number (A)** refers to the total number of protons and neutrons in the nucleus.
- The **atomic number (Z)** refers to the total number of protons in the nucleus.

RADIATION BASICS

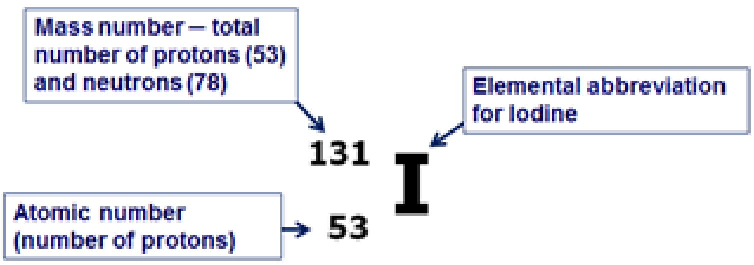
Visual 8.2.8



Key Points

On the right is an example of one nuclide of the element iodine, I-131. It contains 53 protons and 78 neutrons, which add up to 131, the atomic mass number.

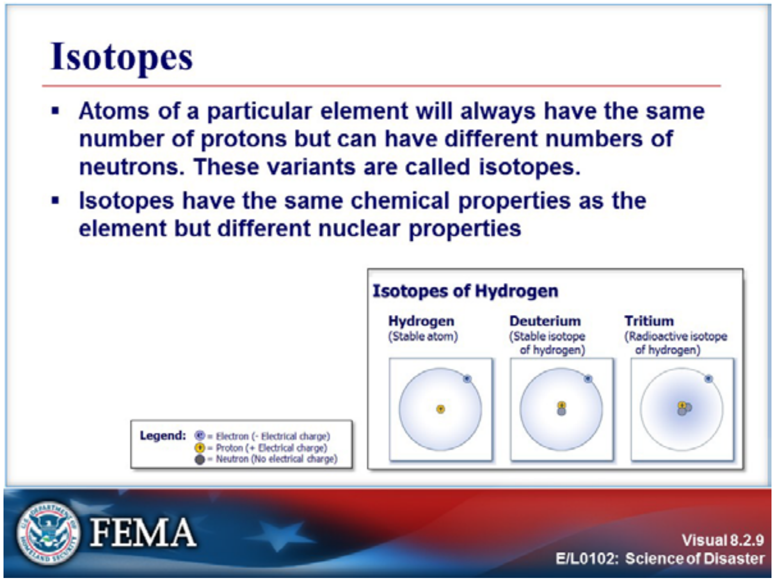
Because the number of protons in the nucleus is unique to each element, nuclides can also be represented by the element and its specific atomic mass number—for example: L



- Iodine-131,
- I-131, or
- ^{131}I

RADIATION BASICS

Visual 8.2.9



Alt Text for Visual 8.2.9
Isotopes

- Atoms of a particular element will always have the same number of protons but can have different numbers of neutrons. These variants are called isotopes.
- Isotopes have the same chemical properties as the element but different nuclear properties

A diagram illustrating the Isotopes of Hydrogen.
Hydrogen (stable atom)
Deuterium (Stable isotope of hydrogen)
Tritium (Radioactive isotope of hydrogen)

Key Points

Isotopes: Some nuclides are isotopes.

Atoms of a particular element will always have the same number of protons; however, atoms of a particular element can have **different numbers of neutrons** in the nucleus. For example, hydrogen (H-1), deuterium (H-2), and tritium (H-3) are different nuclides of the same element, hydrogen. These variants are called isotopes.

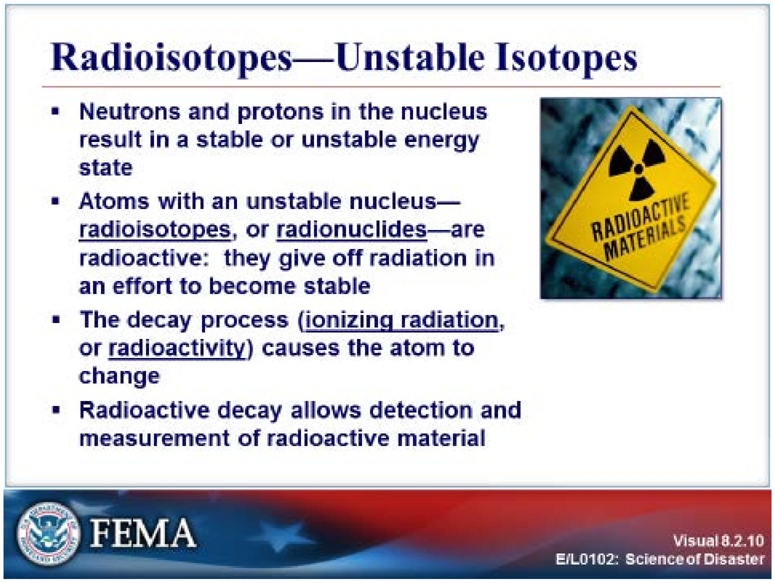
Properties of isotopes: Isotopes of the same element:

- Have the same chemical properties, regardless of the number of neutrons
- Can have different nuclear properties

For example, all three hydrogen isotopes have the same chemical properties. However, tritium has different nuclear properties; it is a radioactive isotope or **radioisotope**.

RADIATION BASICS

Visual 8.2.10



Alt Text for Visual 8.2.10

Radioisotopes—Unstable Isotopes

- Neutrons and protons in the nucleus result in a stable or unstable energy state
- Atoms with an unstable nucleus—radioisotopes, or radionuclides—are radioactive: they give off radiation in an effort to become stable
- The decay process (ionizing radiation, or radioactivity) causes the atom to change
- Radioactive decay allows detection and measurement of radioactive material

Key Points

Unstable isotopes: In combination, the neutrons and protons in the nucleus result in an energy state that is either stable or unstable. If there are too many or too few neutrons for a given number of protons, the resulting nucleus will have too much energy. This isotope will not be stable. Unstable isotopes are also called radioactive isotopes, radioisotopes, or radionuclides.

Radioactivity, or ionizing radiation: A radioactive isotope will give off this excess energy as radiation in an effort to become stable—a process referred to as radioactivity, or ionizing radiation. Radioactive material is any material that spontaneously emits ionizing radiation.

This radioactive decay process will cause an atom to change from one form to another. A radioactive atom may even change from one element to another element during the decay process. For example, through radioactive decay uranium will change to lead.

RADIATION BASICS

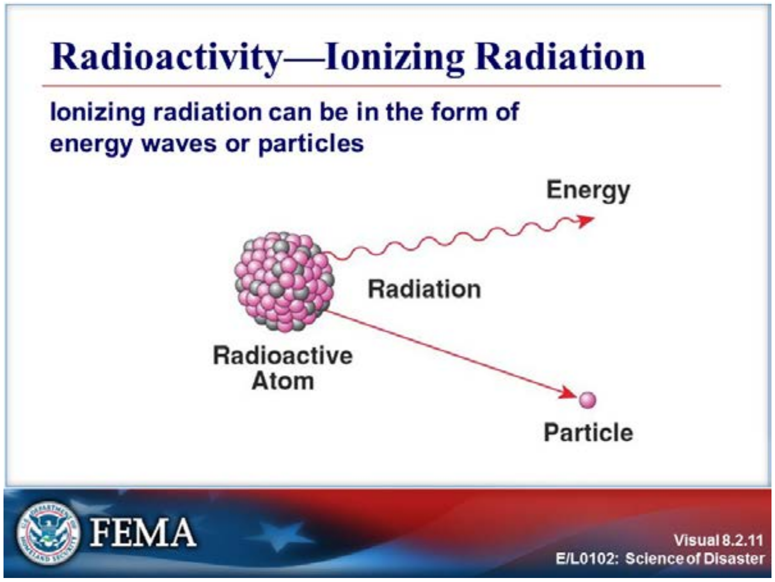
Visual 8.2.10 (Continued)

Note: Since the first detection of naturally occurring radioactive material in 1896, more than1,000 unstable nuclear species have been discovered and/or created. One approach to producing radionuclides is **particle acceleration**, in which stable atomic nuclei are bombarded with high-speed charged particles, neutrons, or in certain instances, photons, resulting in a reaction at the nuclear level and inducing a transmutation. Today there are numerous types of particle accelerators (once called “atom smashers”) that are used in physics research, medicine (particle therapy), and industry.

Another source of radionuclides is through the process of **nuclear fission**, in which a heavy nuclide splits into two smaller nuclides. Upwards of 600 possible fission products can be created through nuclear fission, which is the source of energy for nuclear reactors and some types of nuclear weapons.

RADIATION BASICS

Visual 8.2.11



Key Points

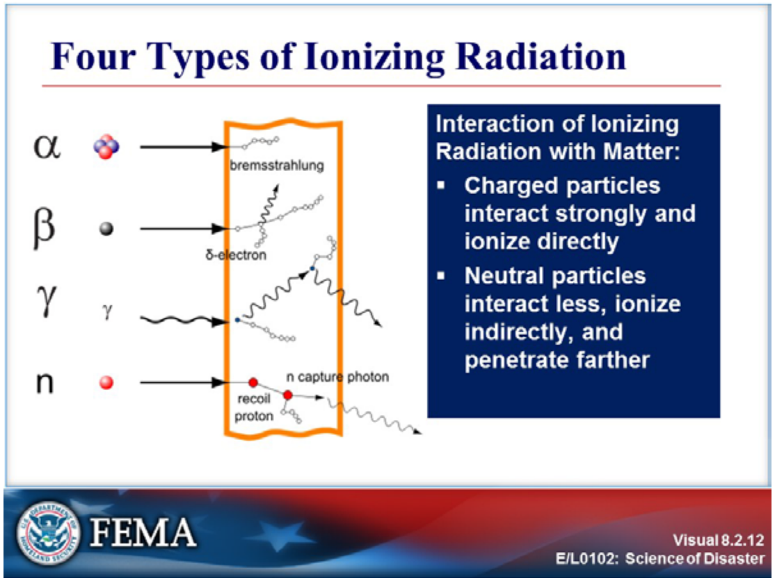
In this course, when we speak of radiation, we are referring to radioactive decay, which is more energetic than other types of radiation. It has enough energy to remove electrons from atoms as it passes through matter. (The process of removing electrons from atoms is called **ionization**.)

Ionizing radiation can be in the form of energy waves or particles.

The ability to remove electrons from atoms is what makes ionizing radiation potentially hazardous.

RADIATION BASICS

Visual 8.2.12



Alt Text for Visual 8.2.12
Four Types of Ionizing Radiation
Interaction of Ionizing Radiation with Matter:

- Charged particles interact strongly and ionize directly
- Neutral particles interact less, ionize indirectly, and penetrate farther

A graphic illustration the four types of ionizing radiation.

Key Points

The four basic types of ionizing radiation are:

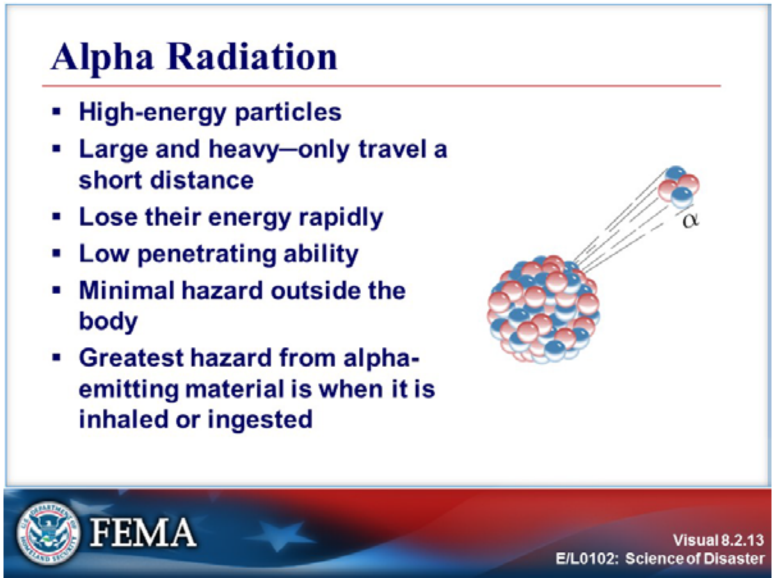
- Alpha radiation
- Beta radiation
- Gamma radiation
- Neutron radiation

These types differ in their penetrating power and the manner in which they affect human tissue.

Next, we will take a closer look at each type of ionizing radiation and its penetrating ability.

RADIATION BASICS

Visual 8.2.13



Alt Text for Visual 8.2.13
Alpha Radiation

- High-energy particles
- Large and heavy—only travel a short distance
- Lose their energy rapidly
- Low penetrating ability
- Minimal hazard outside the body
- Greatest hazard from alpha-emitting material is when it is inhaled or ingested

A graphic illustrating alpha radiation. The graphic shows how two protons and two neutrons (but no electrons) are ejected from the nucleus of a radioactive atom.

Key Points

Alpha radiation: Alpha radiation consists of particles with two protons and two neutrons (but no electrons) that are ejected from the nucleus of a radioactive atom. Alpha particles:

- Are high-energy particles that are relatively large, heavy, and only travel a short distance (a few inches in air)
- Lose their energy very rapidly
- Have a low penetrating ability

Hazard: Alpha particles pose a minimal biological hazard outside the body. The greatest hazard occurs when the material is inhaled or ingested. Once inside the body, the alpha radiation can cause harm to individual cells or organs.

RADIATION BASICS

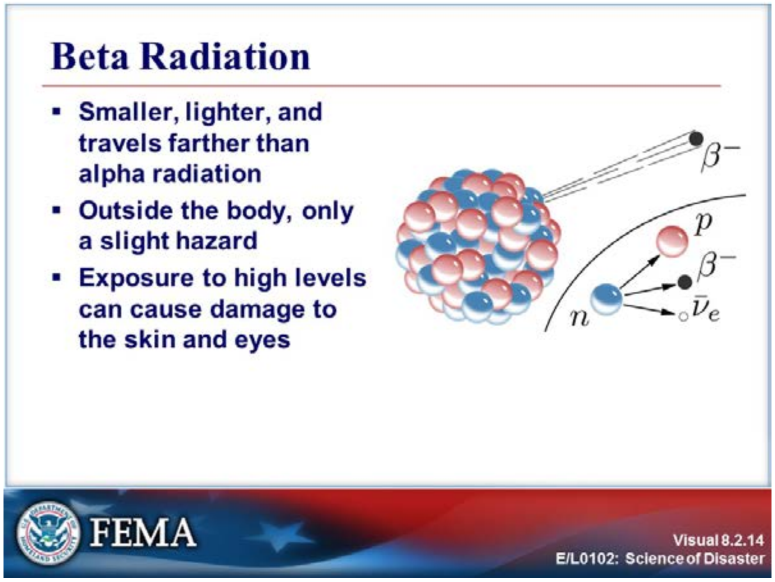
Visual 8.2.13 (Continued)

Note that the alpha "particle" is not what poses the internal hazard; it is the material that is emitting the alpha particles that poses the internal hazard. Once an alpha particle is emitted from the nucleus of an atom, it travels a few inches and stops. When the particle stops, it picks up two free electrons and becomes a harmless helium atom. Therefore, it is not really possible to inhale or ingest alpha particles but, rather, the material that is emitting the alpha particles.

Shielding: The characteristics of alpha radiation make it easy to shield, and something as thin as a sheet of paper can block the passage of alpha radiation.

RADIATION BASICS

Visual 8.2.14



Alt Text for Visual 8.2.14
Beta Radiation

- Smaller, lighter, and travels farther than alpha radiation
- Outside the body, only a slight hazard
- Exposure to high levels can cause damage to the skin and eyes

A graphic illustrating beta radiation. It shows electrons ejected from the nucleus of a radioactive atom.

Key Points

Beta radiation: Beta radiation consists of particles—electrons ejected from the nucleus of a radioactive atom. Beta particles:

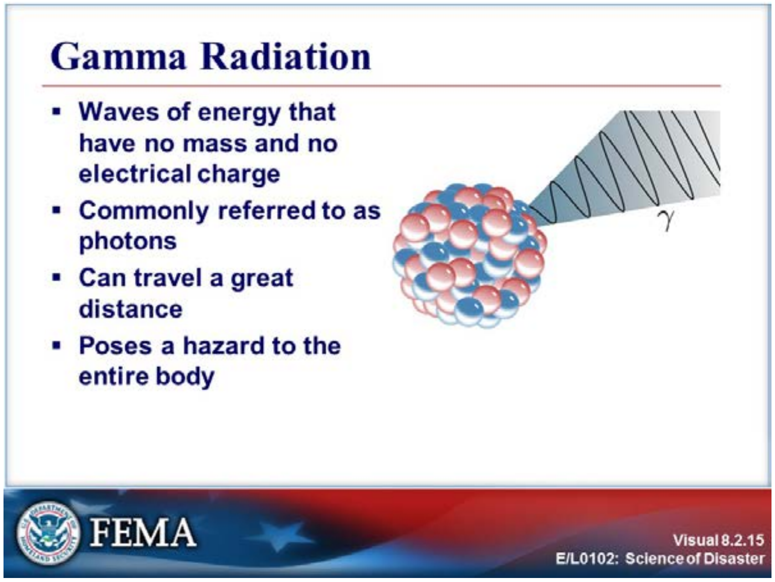
- Are smaller and lighter than alpha particles
- Travel farther than alpha particles. In air, beta radiation can travel several feet.

Hazard: Beta radiation is more penetrating than alpha radiation, but outside of the body is only a slight hazard. The range of penetration in human tissue is less than ¼ inch.

Shielding: The characteristics of beta radiation make it easy to shield with moderately dense materials like aluminum.

RADIATION BASICS

Visual 8.2.15



Alt Text for Visual 8.2.15
Gamma Radiation

- Waves of energy that have no mass and no electrical charge
- Commonly referred to as photons
- Can travel a great distance
- Poses a hazard to the entire body

A graphic illustrating gamma radiation. Gamma radiation is an electromagnetic wave of energy (not particles) ejected from the nucleus of a radioactive atom.

Key Points

Gamma radiation: Gamma radiation is an electromagnetic wave of energy (not particles) ejected from the nucleus of a radioactive atom. Gamma waves:

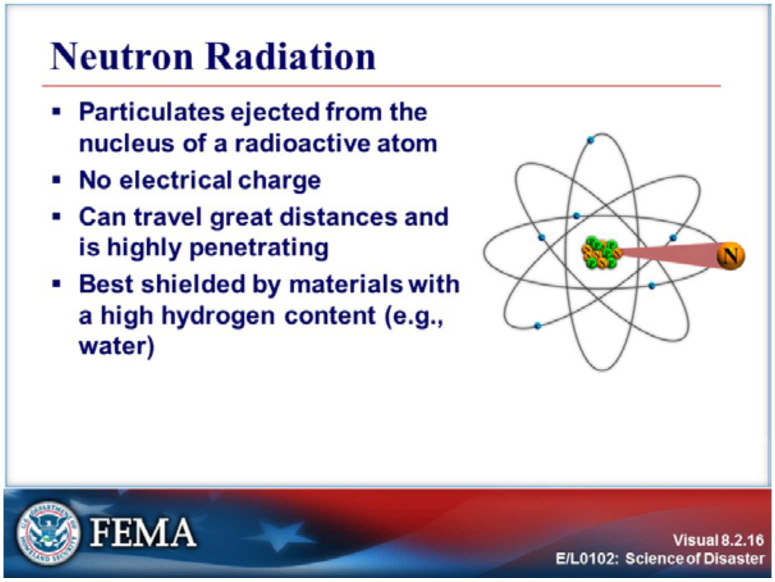
- Have no mass and no electrical charge
- Are commonly referred to as “photons”
- Can travel great distances because they have no mass and no electrical charge

Hazard: Gamma radiation poses a hazard to the entire body because it can easily penetrate human tissue.

Shielding: The characteristics of gamma radiation make it very difficult to shield because of its high penetrating ability. Very dense materials, such as concrete, are required to shield gamma radiation.

RADIATION BASICS

Visual 8.2.16



Alt Text for Visual 8.2.16
Neutron Radiation

- Particulates ejected from the nucleus of a radioactive atom
- No electrical charge
- Can travel great distances and is highly penetrating
- Best shielded by materials with a high hydrogen content (e.g., water)

A graphic illustrating neutron radiation. Neutron radiation consists of particles ejected from the nucleus of a radioactive atom.

Key Points

Neutron radiation: Neutron radiation, such as alpha and beta radiation, consists of particles ejected from the nucleus of a radioactive atom. Neutrons:

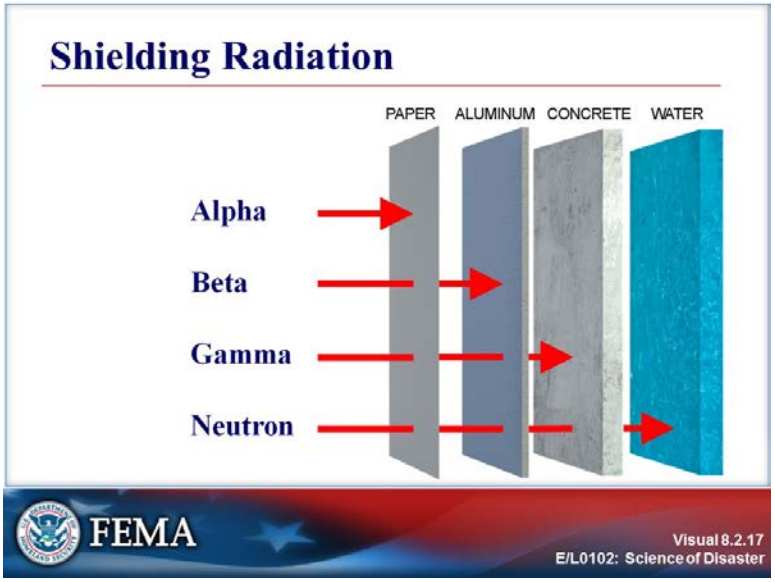
- Do not interact readily with other atoms because they do not have a charge
- Can travel great distances as a result

Hazard: Neutron radiation, like gamma radiation, is highly penetrating.

Shielding: The characteristics of neutron radiation make it difficult to shield. Typically, materials with a high hydrogen content (e.g., water) are required to shield neutron radiation. In transportation situations, neutron radiation is not commonly encountered.

RADIATION BASICS

Visual 8.2.17



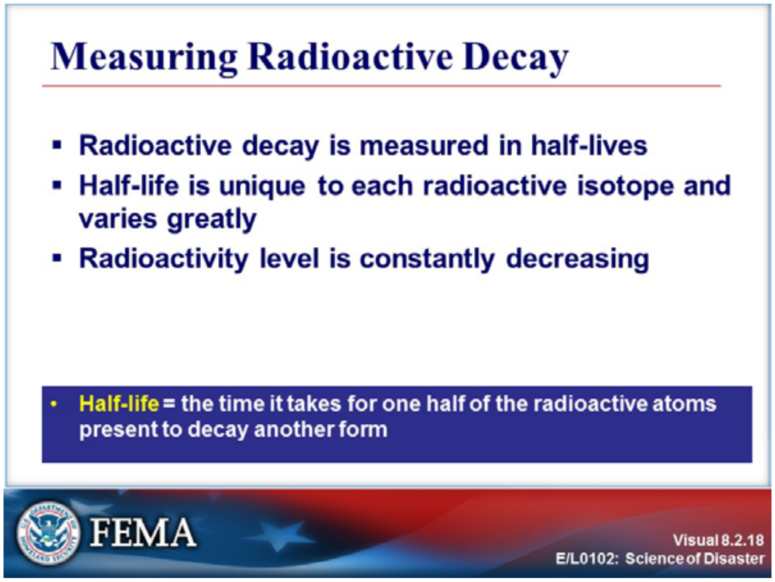
Key Points

Compare the shielding required for the four types of ionizing radiation discussed:

- **Alpha radiation:** Something as thin as a sheet of paper can block the passage of alpha radiation
- **Beta radiation:** Beta radiation can be shielded with moderately dense materials like aluminum.
- **Gamma radiation:** Because of its high penetrating ability, very dense materials such as concrete are required to shield gamma radiation
- **Neutron radiation:** The characteristics of neutron radiation make it difficult to shield. Typically, materials with a high hydrogen content (e.g., water) are required to shield neutron radiation. The cooling pools in a nuclear reactor are a good example.

RADIATION BASICS

Visual 8.2.18



Alt Text for Visual 8.2.18
Measuring Radioactive Decay

- Radioactive decay is measured in half-lives
- Half-life is unique to each radioactive isotope and varies greatly
- Radioactivity level is constantly decreasing

Half-life = the time it takes for one half of the radioactive atoms present to decay another form

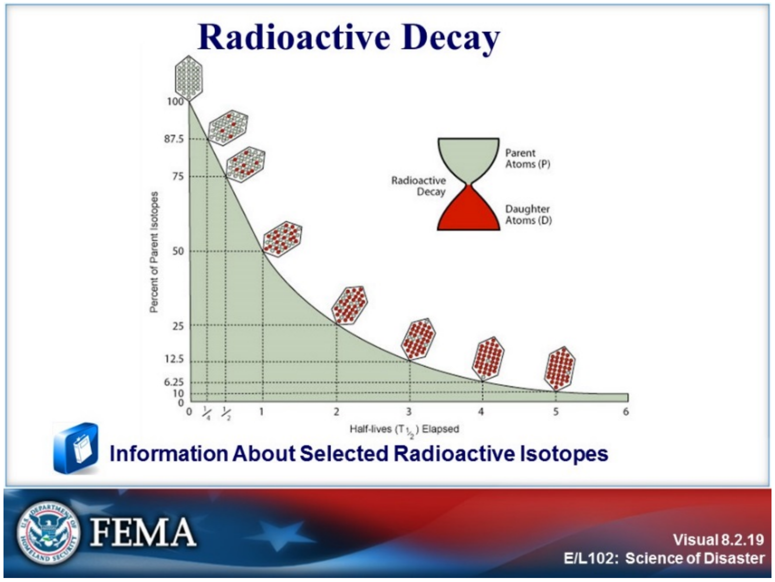
Key Points

Radioactive decay is measured in half-lives.

- Following a transformation, the nucleus is usually more stable than it was, but it may not be completely stable. In such cases, another transformation takes place in which the nucleus again emits radiation.
- Each step in the series of transformations results in a distinct reduction in the total mass-energy of the nucleus. As the energy of the nucleus is reduced, the nucleus is said to disintegrate or decay. **Half-life is the time it takes for one-half of the radioactive atoms present to decay to another form.**
- Half-life is unique to each radioactive isotope and can vary greatly from one radioactive material to another. Radioactive pharmaceutical products (called radiopharmaceuticals) typically have half-lives of a few hours or days.
- Regardless of the half-life, the radioactivity level of any given amount of radioactive material is **constantly decreasing** by half during every "half-life."

RADIATION BASICS

Visual 8.2.19



Key Points

Due to the constant decrease in radioactivity, **after seven half-lives, the activity of the material will be at less than 1 percent of its original activity.**

The curve shown in the graphic represents the same shape common to the radioactive decay of all isotopes through the first several half-lives.

The table below shows several common radioactive materials and their respective half-lives. More information about each of these materials and their uses is provided in the chart that follows.

Radioactive Isotope	Half-Life
Nitrogen-16	**7 seconds**
Technetium-99m	**6 hours**
Thallium-201	**73 hours**
Cobalt-60	**5 years**
Cesium-137	**30 years**
Americium-241	**432 years**
Uranium-238	**4.5 billion years**

RADIATION BASICS

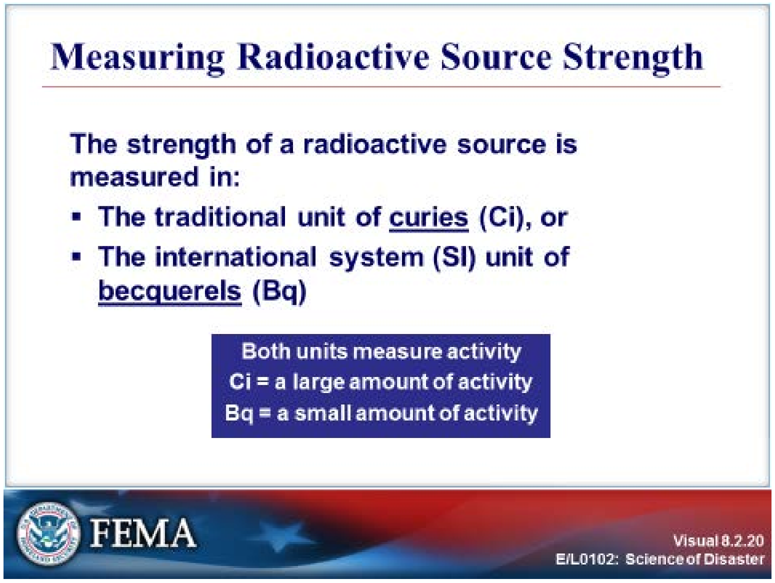
Visual 8.2.19 (Continued)

Information About Selected Radioactive Isotopes

Isotope	Description
Nitrogen-16	A radionuclide associated with nuclear power plant operations Produced in a process called activation when oxygen in reactor coolant is exposed to neutron radiation Formed when Oxygen-16 captures a neutron and emits a proton to form Nitrogen-16
Technetium-99m	The most widely used radiopharmaceutical for diagnosing diseased organs. (A small amount of the radioactive isotope is placed in the patient's body, usually injected into the bloodstream, for the purpose of imaging some part of the body.) One of the things that make technetium-99m so popular for this purpose is its short half-life, which leads to very fast clearing from the body after an imaging process.
Thallium-201	Widely used in as a radiopharmaceutical for diagnosis of coronary artery disease, other heart conditions such as heart muscle death, and for location of low-grade lymphomas
Cobalt-60	Produced in a process called activation, when materials (such as steel) are exposed to neutron radiation in reactors. Can also be produced in a particle accelerator In medicine, used for cancer radiotherapy Industrial uses include testing of welds and castings, and various measurement and test instruments (e.g., leveling devices and thickness gauges) Commonly used to sterilize instruments and to irradiate food to kill microbes and prevent spoilage
Cesium-137	A common radionuclide produced when nuclear fission of uranium and plutonium occurs in a reactor or atomic bomb Commonly used in hospitals for diagnosis and treatment, as a calibration source, and to sterilize medical equipment In industry, used to irradiate food and in industrial instruments
Americium-241	A human-made radioactive metal that exists as a solid under normal conditions and is produced when plutonium absorbs neutrons in nuclear reactors and nuclear weapons tests Blended with beryllium, is used in various types of test gauges Used as a radiation source in medical diagnostic devices and in research Commonly used in minute amounts in smoke detectors as an ionization source
Uranium	A naturally occurring radioactive metal present in low amounts in rocks, soil, water, plants, and animals that contributes to low levels of natural background radiation in the environment Occurs in three forms or isotopes: uranium-234, uranium-235, and uranium-238. About 99 percent of uranium in rock is uranium-238, which decays to form other radioisotopes, including radium-226 and radon-222 Significant concentrations of uranium occur naturally in some substances such as phosphate deposits and uranium-enriched ores

RADIATION BASICS

Visual 8.2.20



Alt Text for Visual 8.2.20
Measuring Radioactive Source Strength
The strength of a radioactive source is measured in:
- The traditional unit of curies (Ci), or
- The international system (SI) unit of becquerels (Bq)

Both units measure activity
Ci = a large amount of activity
Bq = a small amount of activity

Key Points

Radioactive material is not typically measured by its mass, weight, or volume. Rather, radioactivity is measured in the number of nuclear decays or disintegrations that occur in a sample during a specific time. This is known as the **activity** of the sample.

> The curie (Ci) is defined as 3.7 x 1010 or 37 billion (37,000,000,000) disintegrations per second (dps).
> The becquerel (Bq) is defined as 1 dps.

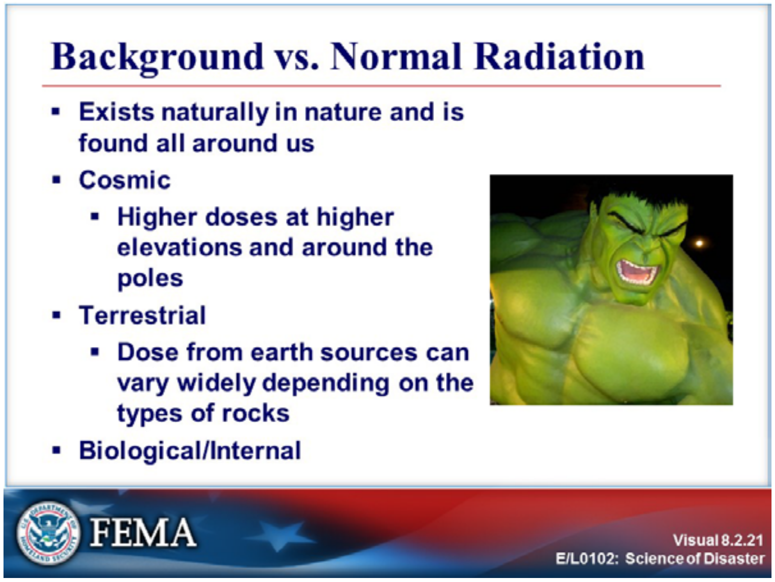
- The traditional unit of activity is the **curie (Ci)**, named after Marie and Pierre Curie, physicists who were pioneers in the study of radioactivity.
- The international system (SI) unit of activity is the **becquerel (Bq)**, after Henri Becquerel, who shared a Nobel Prize for Physics with the Curies in 1903.

Both the curie and becquerel measure the same thing: activity. One curie is considered to be a large amount of activity, whereas one becquerel is a very small amount of activity.

Because the base unit for measuring activity may be either very large (Ci) or very small (Bq), prefixes (e.g., nano, micro, milli, kilo, mega, giga) are often used to change the size of the unit.

BACKGROUND VS. NORMAL RADIATION

Visual 8.2.21



Alt Text for Visual 8.2.21

Background vs. Normal Radiation

- Exists naturally in nature
- Cosmic
    - Higher doses at higher elevations and around poles
- Terrestrial
    - Dose from earth sources can vary depending on the types of rocks
- Biological/Internal.

Image of the Hulk

Key Points

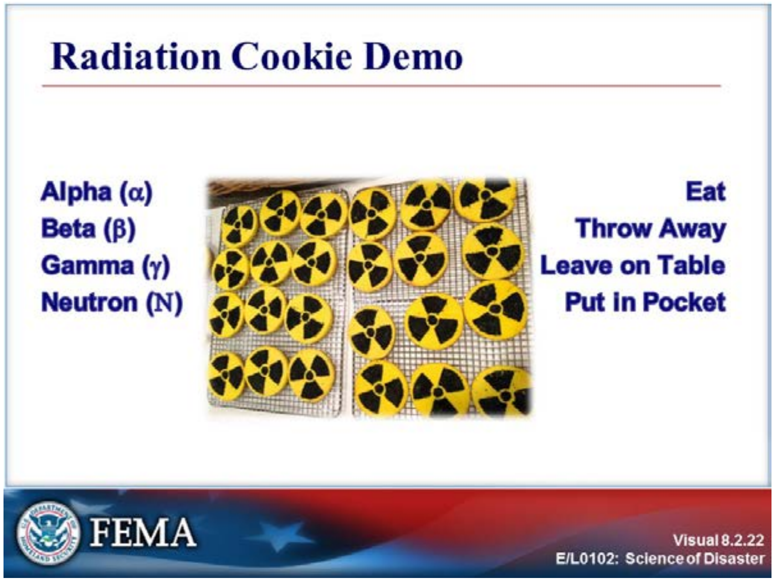
Background radiation encompasses all natural radiation that is present in the environment. This includes cosmic radiation from the sun and stars, terrestrial radiation from the soil/earth, and internal radiation that exists in all living things. On average, a United States resident is exposed to about 0.3 rem per year.

When taking radiation readings, HAZMAT technicians and scientists must account for background radiation by taking sample/control readings without the materials to be tested:

- Source Radiation = Radiation Sampled by Meter – Background Radiation

RADIATION COOKIE DEMONSTRATION

Visual 8.2.22



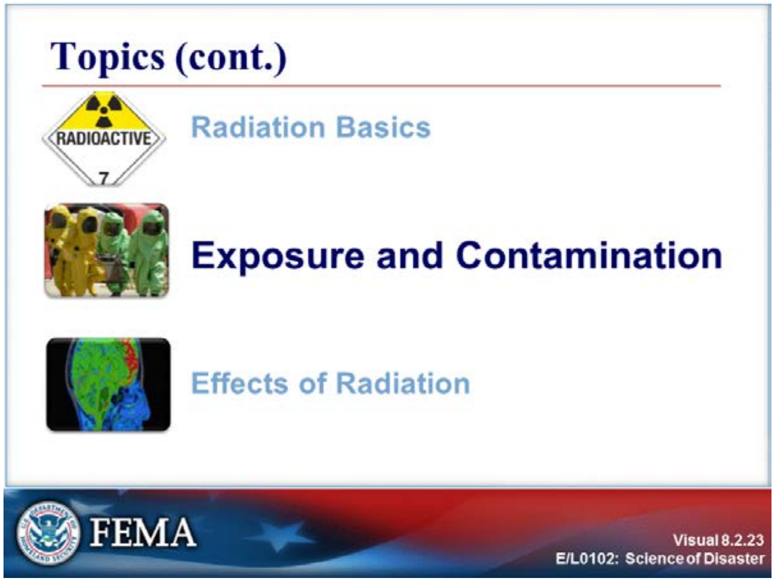
Key Points

You have an Alpha Cookie, a Beta Cookie, a Gamma Cookie, and a Neutron Cookie. You can:

- Eat one
- Throw one away
- Leave one on the table
- Put one in your pocket

EXPOSURE AND CONTAMINATION

Visual 8.2.23

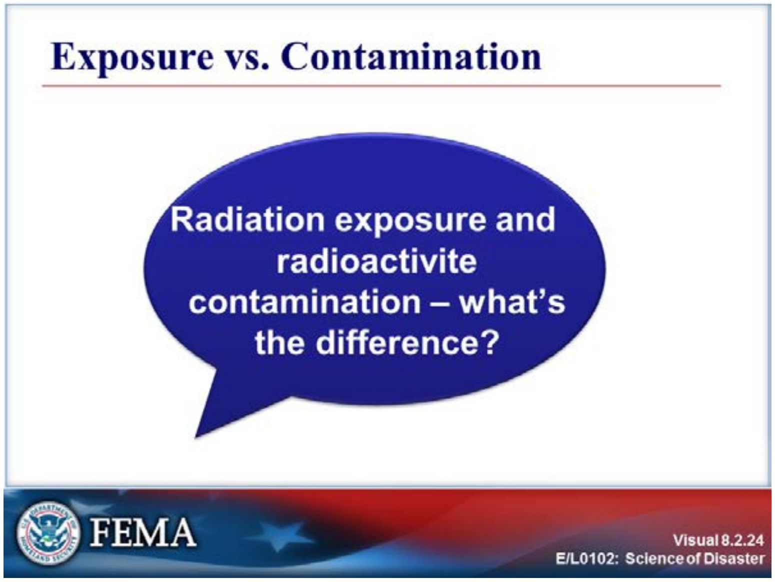


Key Points

Next, we will look at exposure and contamination—what they mean and how they can occur.

EXPOSURE AND CONTAMINATION

Visual 8.2.24

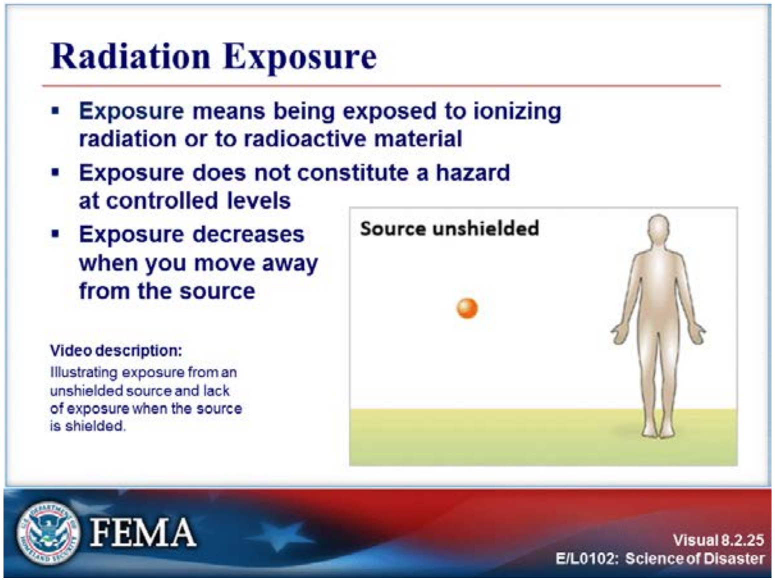


Key Points

<u>Discussion Question</u>: Radiation and radioactive contamination—what's the difference?

EXPOSURE AND CONTAMINATION

Visual 8.2.25



Key Points

Radiation exposure and radioactive contamination are not the same thing.

Radiation exposure means being exposed to ionizing radiation or to radioactive material. A person who has been exposed to radiation has had radioactive waves or particles penetrate the body, like having an x-ray.

We are exposed to low levels of radiation in the natural environment every day. Exposure does not, in and of itself, constitute a hazard at controlled levels. For example, there are many applications in medicine for radiation exposure.

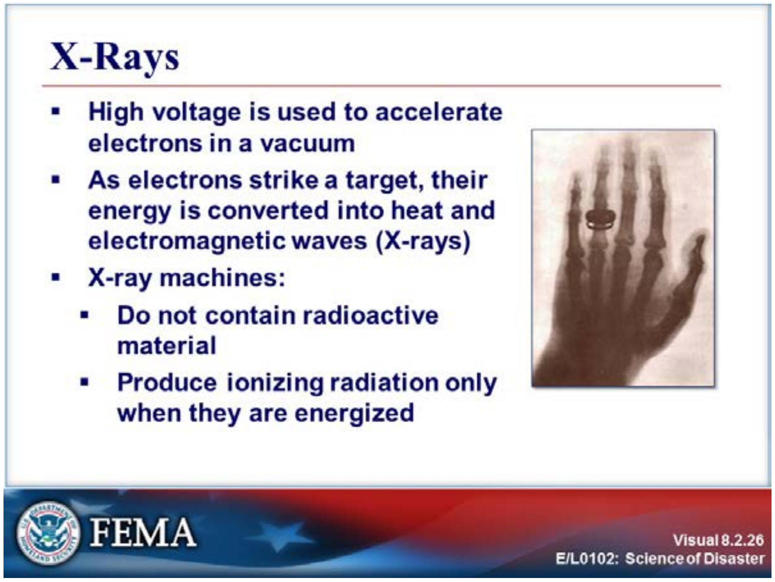
Exposure decreases as soon as the person is moved away from the radiation source. The animation on this visual illustrates the difference between what happens when the source is unshielded and what happens when it is shielded.

Video description:

Illustrating exposure from an unshielded source and lack of exposure when the source is shielded.

EXPOSURE AND CONTAMINATION

Visual 8.2.26



Alt Text for Visual 8.2.26

- X-Rays
- High voltage is used to accelerate electrons in a vacuum
- As electrons strike a target, their energy is converted into heat and electromagnetic waves (X-rays)
- X-ray machines:
  - Do not contain radioactive material
  - Produce ionizing radiation only when they are energized

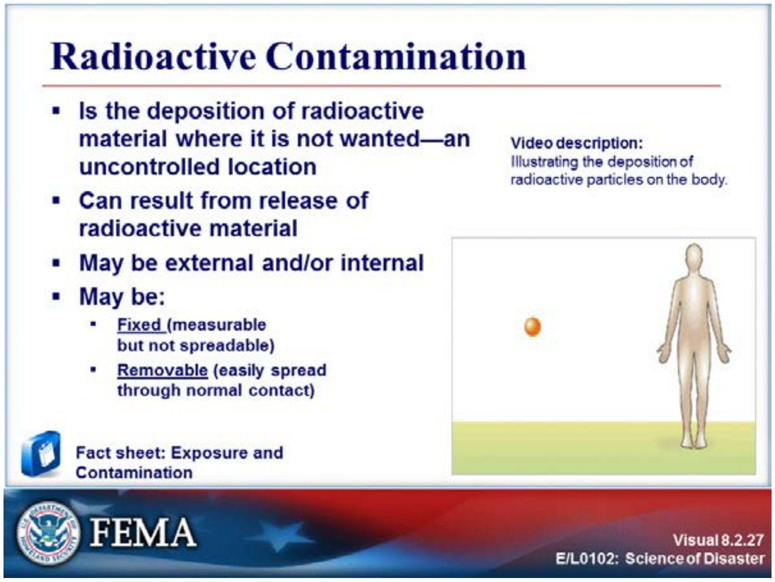
Key Points

X-rays provide a good example of exposure without contamination.

- X-rays are created by using high voltage to accelerate electrons in a vacuum and stopping them in a target. Electrons have mass and, when they are accelerated, they gain kinetic energy—energy from being “in motion.”
- When an electron strikes the target it gives up its kinetic energy. Most of that energy ends up generating heat in the target, but some of that energy will generate x-rays. The higher the voltage, the higher the kinetic energy of the electron and the higher the energy of the x-ray generated.
- X-ray machines do not contain a radioactive source. You cannot become contaminated by exposure to x-rays.
- Without high voltage, the x-rays cannot be created. Removing the energy source removes the hazard.

EXPOSURE AND CONTAMINATION

Visual 8.2.27



Alt Text for Visual 8.2.27
Radioactive Contamination

- Is the deposition of radioactive material where it is not wanted—an uncontrolled location
- Can result from release of radioactive material
- May be external and/or internal
- May be:
  - Fixed (measurable but not spreadable)
  - Removable (easily spread through normal contact)

Fact sheet: Exposure and Contamination
A graphic illustrating the deposition of radioactive particles on the body.

Key Points

Radioactive contamination, in short, means the deposition of radioactive material where you don't want it, such as on surfaces, on people, or ingested by living things.

For a person to be contaminated, radioactive material must be on or inside of his or her body. A contaminated person is exposed to radiation released by the radioactive material.

An uncontaminated person can be exposed by being too close to radioactive material or to a contaminated person, place, or thing.

Video description:

Illustrating the deposition of radioactive particles on the body.

EXPOSURE AND CONTAMINATION

Visual 8.2.27 (Continued)

Radioactive contamination can be categorized as either fixed or removable.

- **Fixed contamination** is radioactive material that is not easily transferred to other people or equipment through normal contact. Fixed contamination poses an exposure hazard only to what it is affixed to, whether it be people, places, or things.
- **Removable contamination** is radioactive material that is easily transferred to other people or equipment through normal contact. Removable contamination poses a hazard to everything, and more importantly, everyone.

When contamination is discovered at an incident scene or on a person, it will likely be a combination of both fixed and removable.

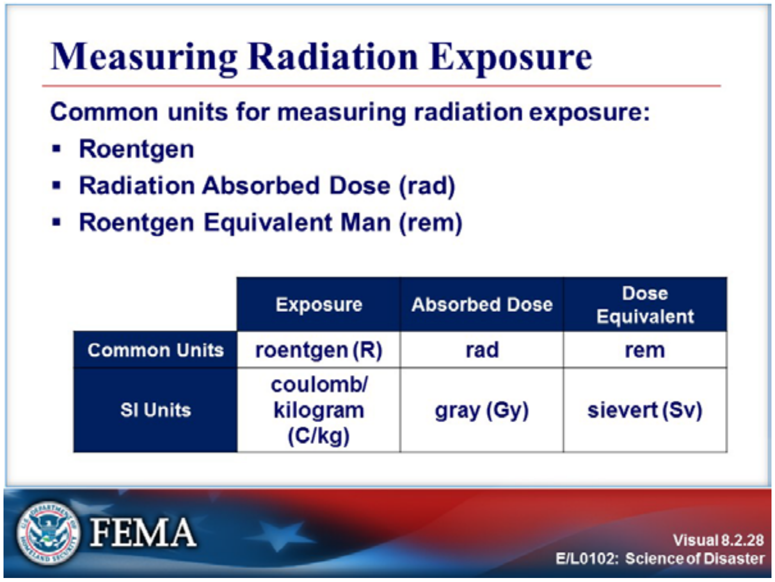
EXPOSURE AND CONTAMINATION

Visual 8.2.27 (Continued)

Fact Sheet: Exposure and Contamination	
Exposure vs. Contamination	• Radiation exposure does not equal contamination. • Radiation is a type of energy that can pass through people and objects. We are exposed to low levels of radiation every day from common sources, such as cosmic rays, x-rays, and even the bricks used to make buildings. • Exposure to radiation at controlled levels does not constitute a hazard. • Exposure stops when one moves away from the radiation source. • Radioactive contamination, on the other hand, continues to emit radiation.
Contamination	• Radioactive contamination is, simply stated, radioactive material in a place where it is not wanted—an uncontrolled location. Radioactive material on the ground, in water, or on you, is referred to as contamination. • Should radioactive material be released during an incident, it is possible for anyone or anything present to become contaminated if they come in contact with the material. The possibility of contamination is increased when the material is in the form of a liquid or powder. • Radioactive contamination can be external, internal, or a combination of the two.
External Contamination	External contamination is radioactive material that is *on* something where it is not wanted. • While a short exposure to radioactive material may be safe, prolonged or very close exposure may not be. • As long as the material is on you or your clothing, you are still being exposed to radiation from the material. • People who are contaminated may contaminate others, either directly or by secondary contamination. Secondary contamination occurs when a contaminated person or object touches or is touched by another person.
Internal Contamination	Internal contamination is radioactive material that is *in* something where it is not wanted. • Internal contamination occurs when people swallow or breathe in radioactive material, usually a liquid or powder, or when radioactive material is absorbed through the skin. • Once inside the body, radioactive material may be difficult to remove. • Radioactive material that might not be very dangerous outside the body may be dangerous if allowed to enter the body.
Avoiding Contamination	In the presence of radioactive material, it is important not to eat, drink, smoke, or chew to prevent the possibility of internal contamination. It is also important to use personal protective equipment (PPE) to prevent external contamination.

EXPOSURE AND CONTAMINATION

Visual 8.2.28



Alt Text for Visual 8.2.28
Measuring Radiation Exposure
Common units for measuring radiation exposure:

- Roentgen
- Radiation Absorbed Dose (rad)
- Roentgen Equivalent Man (rem)

Units	Exposure	Absorbed Dose	Dose Equivalent
Common Units	roentgen (R)	rad	rem
SI Units	coulomb/ kilogram (C/kg)	gray (Gy)	sievert (Sv)

Key Points

Common units for measuring radiation exposure include the roentgen (R), radiation absorbed dose (rad), and roentgen equivalent man (rem). Each common unit has a corresponding international (SI) unit, as shown on the visual.

Roentgen

- **Definition:** The roentgen (R), one of the common units used to measure radiation exposure, is defined as the sum of charge per unit mass of air. 1 R = 2.58 x 10^{-4} coulombs/kg of air. The SI equivalent is C/kg.
- **What it measures:** It is a measure of the ability of photons (X and gamma) to produce ionizations in air. In the United States, instrumentation (both new and old) will typically be displayed in roentgen. The roentgen does not relate the biological damage done from the radiation.

EXPOSURE AND CONTAMINATION

Visual 8.2.28 (Continued)

Radiation Absorbed Dose (Rad)

- **Definition:** The rad, is defined as the deposition by any radiation of 100 ergs of energy in one gram of any material. (An erg is a unit of energy.) The SI unit for absorbed dose is the gray (Gy): 1 rad = .01 Gy.
- **What it measures:** The rad is the customary unit for measuring absorbed dose and can be applied to all types of radiation. The rad only measures absorbed dose and does not relate biological damage done from the radiation.

Roentgen Equivalent Man (rem)

- **Definition:** The rem is the customary unit of dose equivalence. The rem is the quantity of ionizing radiation whose biological effect (in man) is equal to that produced by 1 roentgen of X or gamma radiation. The SI unit is the sievert (Sv):
  - 1 rem = .01 Sv
  - 1 Sv = 100 rem = 100,000 mrem
- **What it measures:** Because the same amount of absorbed dose of different kinds of radiation causes different degrees of damage, and neither the roentgen nor the rad conveys those differences, we need a way to account for biological damage.

  Each type of radiation is assigned a quality factor (QF) that relates the relative risk from the type of radiation absorbed to the risk from the same dose of X or gamma radiation. The quality factor converts the absorbed dose to a unit of dose equivalence, a common scale that can be added with and compared to damage caused by any kind of ionizing radiation. The rem is calculated as rad x QF.
- Example: Alpha radiation is assigned a quality factor of 20. This means that 1 rad of alpha radiation is equal to 20 rem (1 rad x 20 QF = 20 rem).

EXPOSURE AND CONTAMINATION

Visual 8.2.29

Alt Text for Visual 8.2.29
Potential for Exposure/Contamination (1 of 2)
Widespread use of radioactive materials in:
- Consumer products (small amounts)
- Research – Academic, medical, pharmaceutical
- Medicine – Diagnosis and treatment
- Industry – Construction, manufacturing, food processing
- Nuclear reactors – Research,
  energy production

Uses/Sources of Radioactive Material

Key Points

Radioactive material is a natural part of our environment and is widely used for industrial and commercial applications. It has specialized uses in consumer products, building materials, research, medicine, industry, nuclear reactors, irradiators, and transportation.

Because of regulations governing the use of radioactive material and the enhanced safety precautions utilized, it presents a low exposure risk to the general public.

Common uses of radioactive materials are summarized in the following table.

EXPOSURE AND CONTAMINATION

Visual 8.2.29 (Continued)

Uses/Sources of Radioactive Material

Area of Use	Description
Consumer Products	The following are examples of consumer products that may contain radioactive materials: • Antique items including: ceramic-glaze products in orange, red, or yellow (e.g., antique cups and plates, decorative floor tiles, jewelry, pottery) and "Vaseline" glass (emerald green glass used in some antique tableware) • Older camera lenses and gas lantern mantels (thorium-232) • Radio-luminescent products (using radium paint) including older watches, clocks, and instrument gauges • Low-sodium salt substitutes (potassium-40) • Propane tanker trucks (from radioactive deposits on the tanker's interior walls) • Smoke detectors (Am-241) • Thoriated aluminum (an alloy containing Th-233) • Thoriated tungsten arc-welding electrodes (often labeled thoriated welding rods) • Uranium ore samples • Other materials that contain naturally occurring radioactive material, such as: marble, monazite sand, sandstone, slate and concrete, feldspar, fertilizers, and granite
Research	Radioactive material is commonly used for research by academic and medical institutions, pharmaceutical companies, and small research and development companies. Radioactive isotopes can be chemically incorporated into the molecules that make up DNA. When processed appropriately, the materials can create an image showing where the radioactively labeled genetic material has concentrated. This technique is used in forensic analyses of biological specimens to provide physical evidence in legal proceedings. Research facilities may use a wide variety of isotopes. The activity levels used may be very high or low.

EXPOSURE AND CONTAMINATION

Visual 8.2.29 (Continued)

Area of Use	Description
Medicine	Radioactive materials are used for diagnosing and treating cancer and other illnesses. • **Diagnostic imaging** with radiopharmaceuticals involves binding a radioactive isotope to a chemical or drug that is injected, ingested, or inhaled by a patient. The type of isotope and the chemical form vary, depending on the type and purpose of the medical procedure being performed. • **Therapeutic treatments,** such as brachytherapy and teletherapy, use radioactive material to treat cancer and other illnesses. In brachytherapy, radioactive sources are placed in close proximity to a tumor to kill cancer cells. The radioactive material is sealed in specially formed capsules (“seeds”) that are implanted into the body. In teletherapy, intense and focused beams of radiation are used to treat cancerous tumor growths. One approach is to use linear accelerators that generate electron beams. Another is to use gamma emitting isotopes like cobalt-60 and cesium-137. These sources may contain thousands of curies of radioactive material.

EXPOSURE AND CONTAMINATION

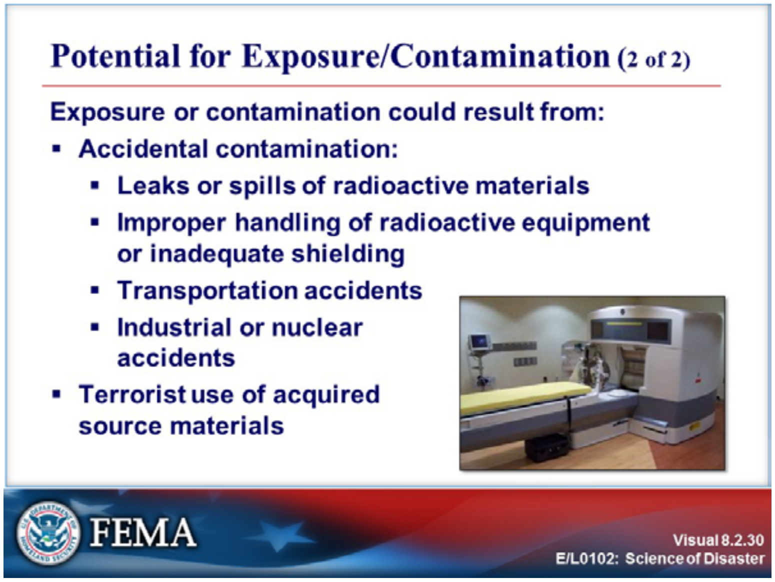
Visual 8.2.29 (Continued)

Uses/Sources of Radioactive Material (Continued)

Area of Use	Description
Industry	Radioactive material is used in a variety of industrial applications, including: • **Density gauges** for measuring thickness, compaction, density, or moisture content. • **Industrial radiography equipment** used for nondestructive testing and internal inspection of an object, such as checking welds and metal for flaws. • **Irradiators** used to calibrate instrumentation, sterilize blood, and treat food products to kill harmful bacteria. Sources commonly used in industry that may be of concern if misused include: • Americium (Am-241) • Cobalt (Co-60) • Barium (Ba-133) • Iridium (Ir-192) • Cesium (Cs-137) • Radium (Ra-226) • Cobalt (Co-57) • Thorium (Th-232)
Reactors	As of October 2012, there were 104 commercial nuclear power plants across the United States and an additional 31 licensed research and test reactors operated by universities and national laboratories. Isotopes of major concern for accidental or terrorism-related contamination include: • Plutonium (Pu-239). • Enriched Uranium (U-235). • Uranium (U-233). • Neptunium (Np-237).
Transportation	Approximately 3 million packages of radioactive materials are shipped each year in the United States by highway, rail, air, and water, opening the possibility of transportation accidents. However, as with other hazardous materials, the transportation of radioactive material is strictly regulated. Many governmental agencies have jurisdiction over the transfer and shipment of radioactive material from nuclear facilities. The regulatory requirements become more restrictive as the quantity, concentration, and potential hazard of the radioactive material increases. Most of the regulatory restrictions apply to the packaging and the methods of shipment used to transport the package.

EXPOSURE AND CONTAMINATION

Visual 8.2.30



Alt Text for Visual 8.2.30
Potential for Exposure/Contamination (2 of 2)

- Exposure or contamination could result from:
- Accidental contamination:
  - Leaks or spills of radioactive materials
  - Improper handling of radioactive equipment or inadequate shielding
  - Transportation accidents
  - Industrial or nuclear accidents
- Terrorist use of acquired source materials

Key Points

With the wide range of radioactive materials in use today, radiation exposure or contamination could result from accidental contamination or from malicious use of acquired source materials.

Accidental contamination can result from leaks or spills of radioactive materials, improper handling of radioactive equipment, inadequate shielding, transportation accidents, or industrial or nuclear accidents. The risks vary with the type of radioactive material, the quantities involved, and whether the material is sealed or unsealed.

- **Unsealed radioactive material** is a potential internal radiation hazard because it can be inhaled, ingested, or absorbed through the skin, leading to dangerous exposure to internal organs. Some isotopes (e.g., P-32, Cs-137) also pose an external radiation hazard, so shielding is required to protect against exposure to the radiation field. Isotopes, such as C-14 and H-3, emit such low energy beta radiation that they can be safely handled without concern to external radiation exposure.

EXPOSURE AND CONTAMINATION

Visual 8.2.30 (Continued)

- **Sealed source** means radioactive material that is permanently bonded or fixed in a capsule or matrix designed to prevent release and dispersal of the radioactive material under the most severe conditions. An example is the Gamma Knife® unit (pictured on the visual) which uses cobalt-60. A small, pea-sized source is sealed in a small welded capsule, and the capsule is encased in a shield, usually lead, with a small shuttered opening that controls the gamma beam.

In medical facilities, radioactive material may be sealed or unsealed. Research facilities may use a wide variety of isotopes, typically in an unsealed or dispersible form, which increases the potential for radiological contamination. The activity levels used may be very high or low. Incidents that occur at such facilities therefore may require a hazardous materials response.

EXPOSURE AND CONTAMINATION

Visual 8.2.31

Alt Text for Visual 8.2.31

Radiological Terrorism

- Attack on a nuclear facility:
  - Power plants
  - Cooling pools for spent fuel rods
  - Research reactors
  - Reprocessing facilities
  - Calibration laboratories
  - Waste sites
- Attack on nuclear shipments
- Malicious use of a radiological device

Key Points

Background: Not long after their development, nuclear weapons became a symbol of both military and national power, and nuclear testing became a useful tool for sending political messages. Many nations have evaluated the use of nuclear or radiological weapons, but in the aftermath of atomic attacks on Hiroshima and Nagasaki, they have so far concluded that the consequences of using such weapons would outweigh any military gains they might make. These consequences include high civilian casualties, destroyed land and property, and a fierce international backlash, which could include retaliation with nuclear weapons.

EXPOSURE AND CONTAMINATION

Visual 8.2.31 (Continued)

Methods: There are two primary ways to implement radiological terror, and the motives for either action would be the same: to cause injury and ruin property, escalate public fears of radiation, damage the economy, and prompt political changes.

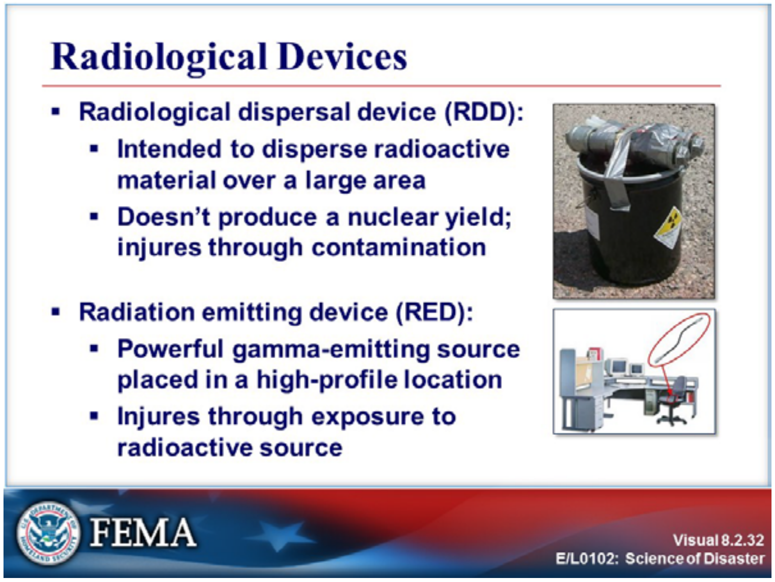
- **Attacks on nuclear facilities and transport:** Attacks on nuclear facilities could be in populated or rural areas. Potential facility targets include nuclear power plants, cooling pools for spent nuclear fuel rods, nuclear reactors used for research or other non-electricity purposes, nuclear reprocessing facilities, calibration laboratories, and nuclear waste sites. Trucks or railcars carrying nuclear weapons, spent nuclear fuel, and high-level radioactive waste are also potential terrorist targets.

  Because of the **robust safeguards** in place for nuclear facilities and nuclear shipments in the United States, the likelihood of a successful attack on a nuclear installation or nuclear shipment is considered remote.

- **Malicious use of a radiological device:** While terrorists would face significant obstacles in the development and deployment of a radiological device, an attack is possible. Consequently, responders need to plan and train for a response to a radiological terrorism incident. Radiological devices would most likely be used in large cities.

EXPOSURE AND CONTAMINATION

Visual 8.2.32



Alt Text for Visual 8.2.32
Radiological Devices

- Radiological dispersal device (RDD):
  - Intended to disperse radioactive material over a large area
  - Doesn't produce a nuclear yield; injures through contamination
- Radiation emitting device (RED):
  - Powerful gamma-emitting source placed in a high-profile location
  - Injures through exposure to radioactive source

Key Points

There are two main types of radiological devices: those that disperse radioactive material and those that emit radiation.

Radiological Dispersal Device (RDD):

- **Definition:** An RDD (often popularly referred to as a "dirty bomb") is defined by the Department of Defense as:

  > "any device, including weapon or equipment, other than a nuclear explosive device, specifically designed to employ radioactive material by disseminating it to cause destruction, damage, or injury by means of the radiation produced by the decay of such material."

  Stated more simply, an RDD is a device intended to disperse radioactive material over a large area for malicious reasons, but it is not capable of producing a nuclear yield and is not an atomic bomb. The intent of an RDD is to create fear and panic by exposing people to radioactive material or to contaminate areas and buildings, making them unusable for long periods of time.

EXPOSURE AND CONTAMINATION

Visual 8.2.32 (Continued)

- **Method:** An RDD typically uses the force of conventional explosives to scatter radioactive material. The devastation caused by the explosion could be much worse than the impact or effects of the distributed radioactive material. A detonation of a large-scale explosive device near a target that contains a large amount of radioactive material could cause a dispersion of that material. Depending on wind speed and direction, the radioactive material could be spread over a large area.
- **Use:** The primary use of an RDD is generally thought to be for terror, political, and area denial purposes, rather than mass killings. Most experts have predicted that to maximize the effect, terrorists would conduct an RDD attack in a densely populated city, such as New York City, Washington, D, C,, or Los Angeles. If the terrorists' primary goal is public fear and economic disruption rather than injury and death, an RDD could be a very effective tool.
- **Effects:** The contamination spread by an RDD could ruin property, crops, and cause large areas to become unusable for a period of time. The economic impacts from an RDD could be enormous, not only because of the potential health impacts to human life and animals, but because populations could be denied access to large areas for years while clean-up and recovery efforts were underway.

Radiation-Emitting Device (RED):

- **Description:** An RED is a powerful gamma-emitting radioactive source that can be placed in a high-profile location, such as a high-traffic urban area or government facility, which could expose a large number of people to the intense radioactive source.

  REDs can also be (and have been in the past) used to target specific individuals and/or harm a limited number of people over a long period of time.

  More detailed information on the use and potential impacts is provided in the RDD Fact Sheet that follows.

EXPOSURE AND CONTAMINATION

Visual 8.2.32 (Continued)

Radiological Dispersal Device (RDD) Fact Sheet

Background

A radiological dispersal device (RDD) (sometimes referred to as a “dirty bomb”) is a device that combines conventional explosives, such as dynamite, with radioactive material. Most RDDs would not release enough radiation to kill people or cause severe illness—the conventional explosive itself would be more harmful to individuals than the radioactive material. However, depending on the situation, an RDD explosion could create fear and panic, contaminate property, and require potentially costly cleanup. Making prompt, accurate information available to the public may prevent the panic sought by terrorists.

An RDD is in no way similar to a nuclear weapon or nuclear bomb. A nuclear bomb creates an explosion that is millions of times more powerful than that of an RDD. The cloud of radiation from a nuclear bomb could spread tens to hundreds of square miles, whereas an RDD’s radiation could be dispersed within a few blocks or miles of the explosion. An RDD is not a “Weapon of Mass Destruction” but a “Weapon of Mass *Disruption*,” where contamination and anxiety are the terrorists’ major objectives.

Impact

The extent of local contamination would depend on a number of factors, including the size of the explosive, the amount and type of radioactive material used, the means of dispersal, and weather conditions. Those closest to the RDD would be the most likely to sustain injuries due to the explosion.

As radioactive material spreads, it becomes less concentrated and less harmful. Prompt detection of the type of radioactive material used will greatly assist local authorities in advising the community on protective measures, such as sheltering in place, or quickly leaving the immediate area. Radiation can be readily detected with equipment already carried by many emergency responders. Subsequent decontamination of the affected area may involve considerable time and expense.

Immediate health effects from exposure to the low radiation levels expected from an RDD would likely be minimal. The effects of radiation exposure would be determined by:

- The amount of radiation absorbed by the body
- The type of radiation (gamma, beta, or alpha)
- The distance from the radiation to an individual
- The means of exposure—external or internal (absorbed by the skin, inhaled, or ingested— and the length of time exposed

The health effects of radiation tend to be directly proportional to radiation dose. In other words, the higher the radiation dose, the higher the risk of injury.

EXPOSURE AND CONTAMINATION

Visual 8.2.32 (Continued)

Radiological Dispersal Device (RDD) Fact Sheet (Continued)

Sources of Radioactive Material
Radioactive materials are routinely used at hospitals, research facilities, industrial activities, and construction sites. These radioactive materials are used for such purposes as diagnosing and treating illnesses, sterilizing equipment, and inspecting welding seams. The Nuclear Regulatory Commission (NRC) together with 37 “Agreement” States, which also regulate radioactive material, administers more than 20,000 licenses of such materials. The vast majority of these materials are not useful as an RDD.
Control of Radioactive Material
NRC and state regulations require owners licensed to use or store radioactive material to secure it from theft and unauthorized access. These measures have been greatly strengthened since the attacks of September 11, 2001. Licensees must promptly report lost or stolen risk-significant radioactive material. “Risk-significant” refers to radioactive sources that may pose a significant risk to individuals, society, and the environment if not properly used, protected, or secured. Local authorities also assist in making a determined effort to find and retrieve such sources. Most reports of lost or stolen material involve small or short-lived radioactive sources that are not useful for an RDD. Past experience suggests there has not been a pattern of collecting such sources for the purpose of assembling an RDD.

EXPOSURE AND CONTAMINATION

Visual 8.2.33

Alt Text for Visual 8.2.33
Weapons of Mass Destruction

- Improvised Nuclear Device (IND): produces nuclear-yield reaction
- Detonation of the smallest nuclear weapon would cause:
  - Mass casualties
  - Extensive damage.
  - Potentially lethal radiation levels from widespread contamination

Key Points

Definition: Nuclear weapons are defined as:

> "a weapon in which enormous energy is released by nuclear fission (splitting the nuclei of a heavy element like uranium 235 or plutonium 239)."

They are the world's most powerful and destructive weapons. In a nuclear weapon there is enough fissile material for the formation of several critical masses, but prior to detonation it is kept in a "sub-critical" state (that is, the fissile material is arranged so that spontaneous neutrons cannot start chain reactions, or only very short ones, which quickly die out).

Method: Unlike an RDD that disperses radioactive material using conventional explosives, a nuclear attack is the use of a device that produces a nuclear explosion. The effect of detonating even the smallest of nuclear weapons in any city would be devastating. Responders would encounter mass casualties, extensive damage, and potentially lethal radiation levels from widespread contamination.

EXPOSURE AND CONTAMINATION

Visual 8.2.33 (Continued)

Existing Weapons: According to the Federation of American Scientists, there are more than 17,000 nuclear warheads, with the largest stockpiles in the United States and Russia. Many safeguards are in place to protect nuclear weapons controlled by the United States. While many nuclear weapons in Russia are adequately protected from theft, it is believed that others are not. Many Soviet-era tactical nuclear devices are vulnerable and, given the smaller size of such weapons, would be particularly useful to terrorist groups. Some reports have estimated that several hundred weapons are vulnerable to theft by terrorists or criminals who might sell them to terrorist organizations. While it may be unlikely, it is at least conceivable that a terrorist group could purchase and smuggle a nuclear weapon into the United States or explode one off its coasts, either by construction of a weapon on its own, or by obtaining a weapon from a rogue nation.

Improvised Weapons: There is little doubt among experts that technically competent terrorists could make a device given sufficient quantities of the right radioactive material. Such a device would be called an Improvised Nuclear Device (IND),sometimes called "dirty nukes". According to the Department of Defense (DOD), an IND is a:

> "device incorporating radioactive materials designed to result in the dispersal of radioactive material or in the formation of nuclear-yield reaction. Such devices may be fabricated in a completely improvised manner or may be an improvised modification to a U.S. or foreign nuclear weapon."

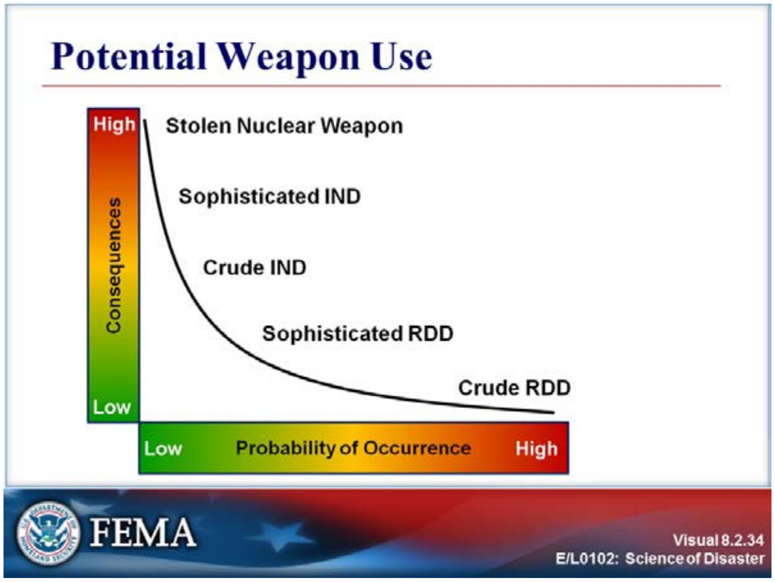
Purpose: Like RDDs, one of the primary intents of INDs is to scatter radiological contamination. A key difference between an IND and an RDD, however, is that an IND results in a nuclear yield that can cause widespread destruction whereas an RDD does not.

Impact of a Nuclear Explosion:

- A fireball, roughly spherical in shape, is created from the energy of the initial explosion. It can reach tens of millions of degrees.
- A shockwave races away from the explosion and can cause great damage to structures and injuries to humans.
- The ionization of the atmosphere around the blast can result in an electromagnetic radiation pulse (EMP) that, for ground detonations, can drive an electric current through underground wires causing local damage. For high-altitude nuclear detonations, EMP can cause widespread disruption to electronic equipment and networks.
- A mushroom cloud typically forms as everything inside of the fireball vaporizes and is carried upwards. Radioactive material from the nuclear device mixes with the vaporized material in the mushroom cloud.
- Fallout results when the vaporized radioactive material in the mushroom cloud cools, condenses to form solid particles, and falls back to Earth. Fallout can be carried long distances on wind currents as a plume and contaminate surfaces miles from the explosion, including food and water supplies.

EXPOSURE AND CONTAMINATION

Visual 8.2.34

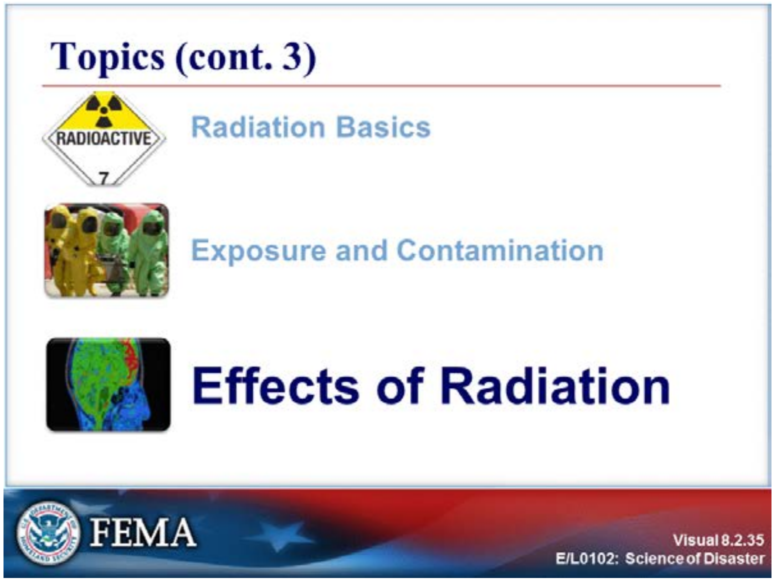


Key Points

The chart on the visual illustrates that radiological weapons with the greatest consequences are the least likely to be used, while weapons with lower consequences have a higher probability of occurrence.

EFFECTS OF RADIATION

Visual 8.2.35

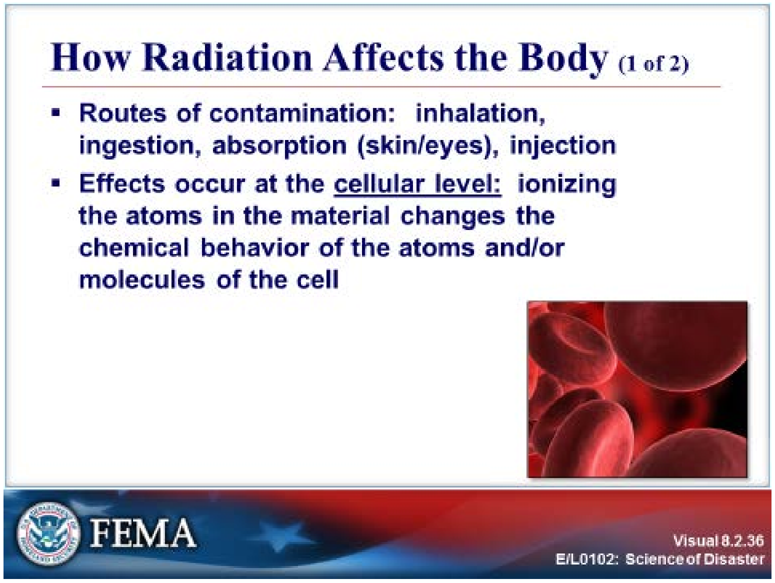


Key Points

The final section of this unit will focus on the effects of radiation on the human body.

EFFECTS OF RADIATION

Visual 8.2.36



Alt Text for Visual 8.2.36
How Radiation Affects the Body (1 of 2)

- Routes of contamination: inhalation, ingestion, absorption (skin/eyes), injection
- Effects occur at the cellular level: ionizing the atoms in the material changes the chemical behavior of the atoms and/or molecules of the cell

Key Points

Routes of exposure: Radiation exposure can occur through the same primary routes as we have discussed for other hazards: inhalation, ingestion, absorption (through the skin or eyes), and injection.

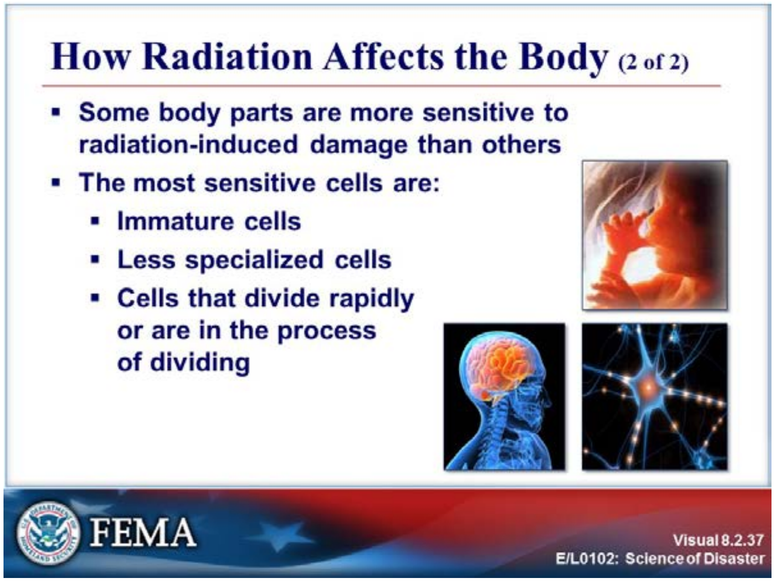
- Gamma radiation can penetrate into your body, delivering a deep dose. The radiation affects the blood and internal organs. Gamma radiation is a significant external and internal health hazard.
- All types of radiation cause health effects through internal contamination, when people swallow or breathe in radioactive materials, or when radioactive materials enter the body through an open wound or are absorbed through the skin. Some types of radioactive materials stay in the body and are deposited in different body organs. Other types are eliminated from the body in blood, sweat, urine, and feces.

Cellular damage: Scientists have determined that the effects of ionizing radiation occur at the cellular level. Each organ of the body is made up of specialized cells, and ionizing radiation can affect the normal operation of these cells.

How damage occurs: Radiation causes damage to any material by ionizing the atoms in that material—changing its atomic structure. When atoms are ionized, the chemical properties of those atoms are altered. If a person receives a sufficiently high dose of radiation and many cells are damaged, there may be observable health effects.

EFFECTS OF RADIATION

Visual 8.2.37



Alt Text for Visual 8.2.37

How Radiation Affects the Body (2 of 2)

- Some body parts are more sensitive to radiation-induced damage than others
- The most sensitive cells are:
  - Immature cells
  - Less specialized cells
  - Cells that divide rapidly or are in the process of dividing

Key Points

Sensitivity: Some parts of the body are more sensitive to radiation-induced damage than others. Radiation damage to the cells of the body depends on how sensitive the cells are to ionizing radiation.

Most sensitive cells: Generally speaking, the most sensitive cells are those that are immature and less specialized, those that divide rapidly, or those that are in the process of dividing. These cells are most vulnerable because it is **difficult or impossible for them to repair damage that occurs during cell division.** Examples of rapidly dividing, immature cells include:

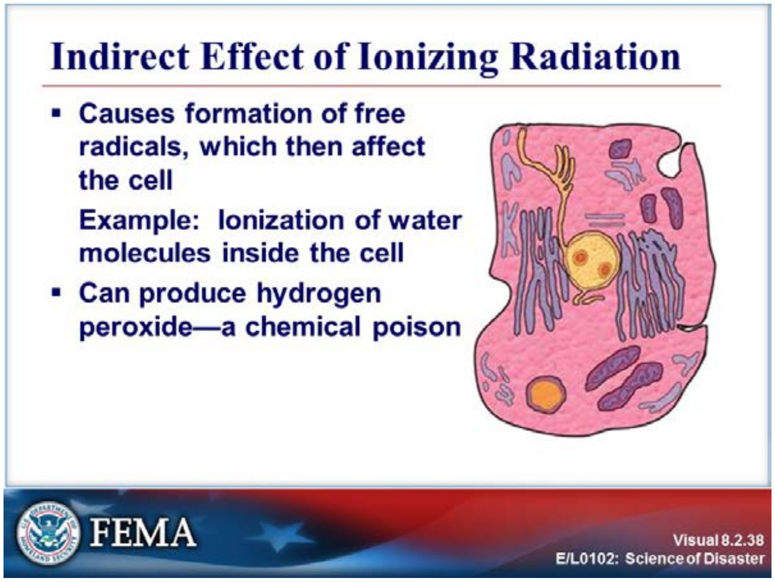
- Blood-forming cells (bone marrow). The more primitive stem cells are more sensitive than the more mature ones.
- Cells lining the intestinal tract. Again, the more primitive crypt cells are more sensitive than the more mature epithelial cells lining the gut.
- Cells in an embryo or fetus.

Cells that divide more slowly and cells that are more specialized are not as easily damaged by ionizing radiation. Examples include:

- Nerve cells
- Brain cells
- Muscle cells

EFFECTS OF RADIATION

Visual 8.2.38



Alt Text for Visual 8.2.38
Indirect Effect of Ionizing Radiation

- Causes formation of free radicals, which then affect the cell
  Example: Ionization of water molecules inside the cell
- Can produce hydrogen peroxide—a chemical poison

Key Points

Formation of free radicals: In an indirect effect, the radiation does not directly affect the cell but rather causes the formation of free radicals, which then go on to affect the cell.

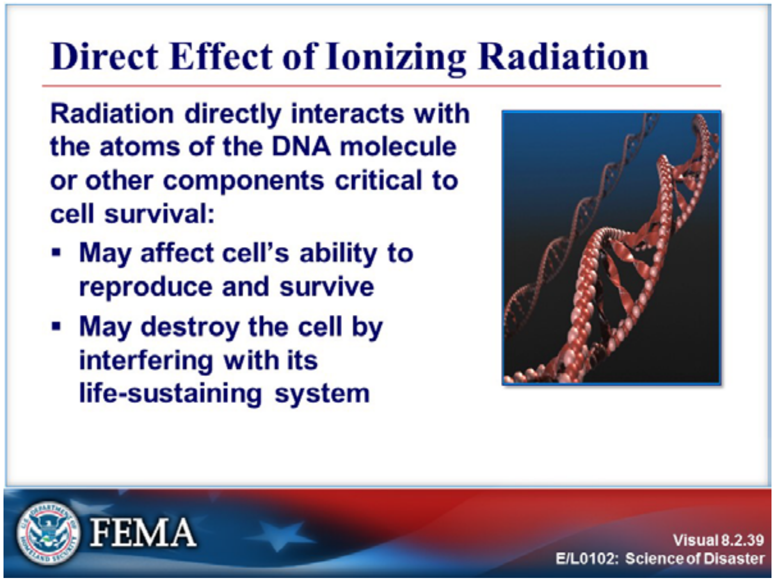
Interaction with water: Each cell, just as is the case for the human body, is mostly water. Therefore, there is a much higher probability of radiation interacting with the water that makes up most of the cell's volume than other parts, such as the DNA molecule.

When radiation interacts with water, it may break the bonds that hold the water molecule together, producing fragments such as hydrogen (H) and hydroxyls (OH) radicals (free radicals).

Result: The free radicals are very reactive chemically, and when two hydroxyl radicals combine, hydrogen peroxide is formed. Hydrogen peroxide is a chemical poison. It is the most harmful free-radical product and can contribute to the destruction of the cell.

EFFECTS OF RADIATION

Visual 8.2.39



Alt Text for Visual 8.2.39
Direct Effect of Ionizing Radiation
Radiation directly interacts with the atoms of the DNA molecule or other components critical to cell survival:
- May affect cell's ability to reproduce and survive
- May destroy the cell by interfering with its life-sustaining system

Key Points

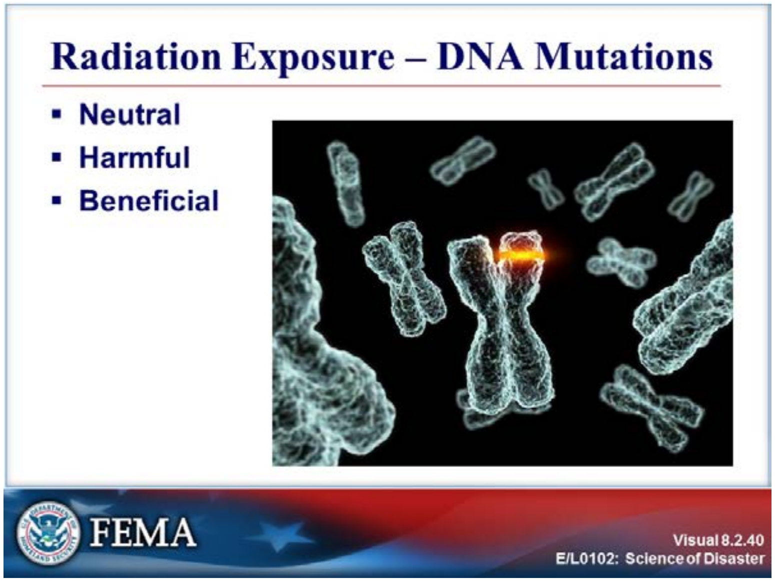
As the name would imply, a direct effect is one where the radiation directly interacts with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell.

Although the probability of radiation directly interacting with the DNA molecule is very small because these critical components make up such a small part of the cell, it can occur.

Impact on cell reproduction: Such an interaction may affect the ability of the cell to reproduce and, thus, survive. If enough atoms are affected such that the chromosomes do not replicate properly, or if there is significant alteration in the information carried by the DNA molecule, then the cell may be destroyed by "direct" interference with its life-sustaining system.

EFFECTS OF RADIATION

Visual 8.2.40



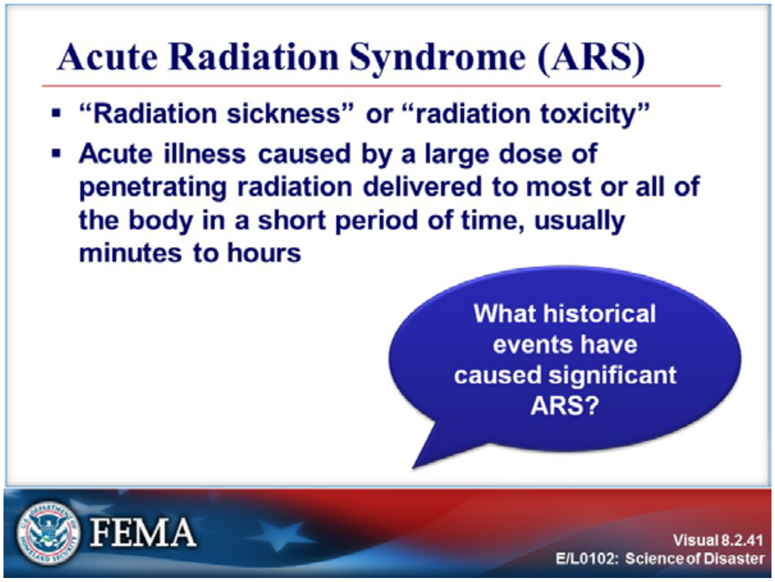
Key Points

Mutations are permanent changes in the DNA. Most mutations are neutral; they either make no change in the expression of any gene, or the changes made do not affect the function of any gene product. Of those mutations which do make a difference, most have a negative effect.

- **Neutral** – Most mutations to DNA are neutral and have no negative or beneficial impact to the host organism.
  - This is ppartly because most DNA has little-to-no known function and is not incorporated in a gene.
  - Not all portions of the DNA are equally important.
- **Harmful**
  - Can modify DNA to a point where protein structures are rendered ineffective, dead, or cancerous
- **Beneficial**
  - While extremely rare, it is possible for DNA mutations to lead to overall positive impacts.

EFFECTS OF RADIATION

Visual 8.2.41



Alt Text for Visual 8.2.41
Acute Radiation Syndrome (ARS)
- "Radiation sickness" or "radiation toxicity"
- Acute illness caused by a large dose of penetrating radiation delivered to most or all of the body in a short period of time, usually minutes to hours

What historical events have caused significant ARS?

Key Points

An extreme example of the effects of ionizing radiation is Acute Radiation Syndrome (ARS).

What is ARS? It is an acute illness caused by a large dose of penetrating radiation delivered to most or all of the body in a short period of time—usually within a matter of minutes to hours. The major cause of this syndrome is depletion of immature stem cells in specific tissues.

Necessary conditions: The following are required conditions for ARS:

- **Large:** The radiation dose must be large (i.e., greater than 70 rem).
- **External:** The dose is usually external (i.e., the source of radiation is outside of the person's body).
- **Penetrating:** The radiation must be penetrating (i.e., able to reach the major organs).
- **Entire body:** The entire body (or a significant portion of it) must have received the dose. Most radiation injuries are local, frequently involving just the hands, and these local injuries seldom cause classical signs of ARS.
- **Short timeframe:** The dose must have been delivered in a short time (usually a matter of minutes). Fractionated doses are often used in radiation therapy. These large total doses are delivered in small daily amounts over a period of time. Fractionated doses are less likely to induce ARS than a single dose of the same magnitude.

EFFECTS OF RADIATION

Visual 8.2.41 (Continued)

Acute Effects: Symptoms of acute radiation sickness include:

- Changes in blood cells and blood vessels
- Skin irritation (similar to sunburn but lasting 3 weeks)
- Gastrointestinal system effects
- Nausea and vomiting
- Diarrhea
- High fever
- Hair loss
- Dermal burns
- Severe injury to internal organs
- Long-term physiological effects

Symptoms may appear shortly after exposure, then disappear for a few days, and reappear in a much more serious form a week or so later. Later symptoms may include:

- Malaise, fatigue, and drowsiness
- Weight loss
- Fever
- Abdominal pain
- Insomnia and restlessness
- Blisters

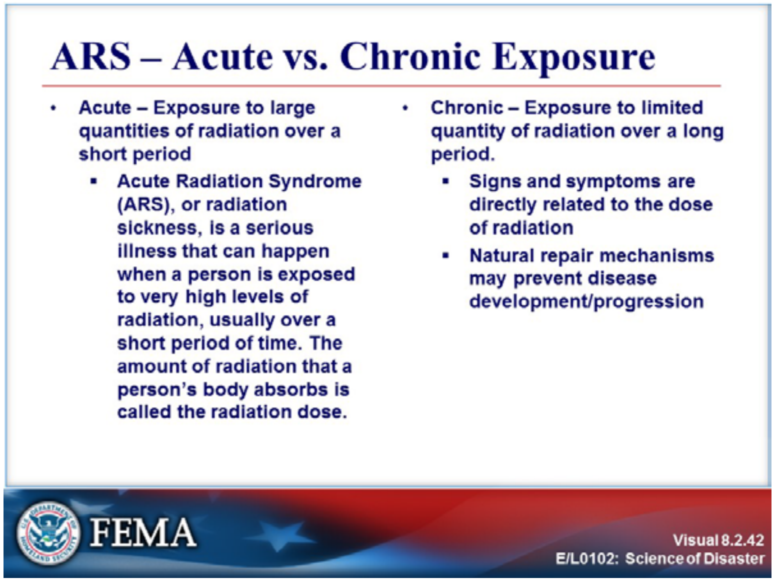
Long-Term Effects: The probability of experiencing long-term effects increases as the level of exposure increases. Long-term effects may include various forms of cancer (leukemia, bone cancer, thyroid cancer, lung cancer), cataracts, and shortened life span.

The severity and course of acute radiation sickness depends on how much total dose is received, how much of the body is exposed, and the radio sensitivity of the individual.

Discussion Question: What historical events have caused significant ARS?

EFFECTS OF RADIATION

Visual 8.2.42



Alt Text for Visual 8.2.42

- ARS – Acute vs. Chronic Exposure
- Acute – Exposure to large quantities of radiation over a short period
  - Acute Radiation Syndrome (ARS), or radiation sickness, is a serious illness that can happen when a person is exposed to very high levels of radiation, usually over a short period of time. The amount of radiation that a person's body absorbs is called the radiation dose.
- Chronic – Exposure to limited quantity of radiation over a long period.
  - Signs and symptoms are directly related to the dose of radiation
  - Natural repair mechanisms may prevent disease development/progression

Key Points

Acute Radiation Syndrome occurs when one is exposed to large quantities of radiation over a short period.

Symptoms of ARS may include nausea, vomiting, headache, and diarrhea. These symptoms start within minutes to days after the exposure, can last for minutes up to several days, and may come and go. If you have these symptoms after a radiation emergency, seek medical attention as soon as emergency officials determine it is safe to do so.

Chronic exposure to radiation occurs when one is exposed to a limited quantity of radiation over a long period of time. Chronic radiation syndrome is a range of symptoms occurring over a period of time. These symptoms can happen immediately or months or years after exposure to radiation:

- Radiation syndrome includes fatigue, weight loss, nausea, vomiting, diarrhea, sweating, fever, headache with bleeding and complications affecting the digestive system, nervous system, heart, and lungs.
- Central nervous system diseases
- Kidney, liver, or gastrointestinal problems

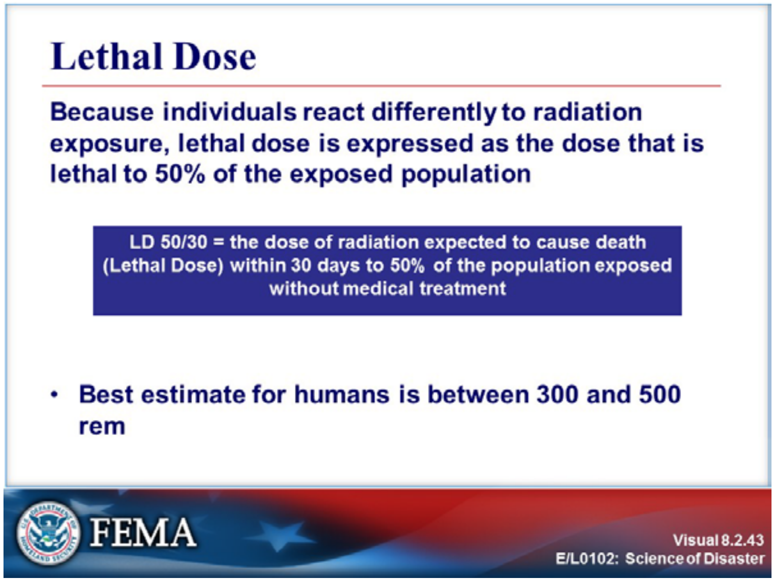
EFFECTS OF RADIATION

Visual 8.2.42 (Continued)

- Poor growth in children
- Skin conditions
- Pericarditis (inflammation of the sac around the heart)
- Lung infections or conditions, respiratory failure
- Vision problems, including cataracts
- Problems with the reproductive organs
- Heart disease

EFFECTS OF RADIATION

Visual 8.2.43



Alt Text for Visual 8.2.43
Lethal Dose
Because individuals react differently to radiation exposure, lethal dose is expressed as the dose that is lethal to 50% of the exposed population
LD 50/30 = the dose of radiation expected to cause death (Lethal Dose) within 30 days to 50% of the population exposed without medical treatment
Best estimate for humans is between 300 and 500 rem

Key Points

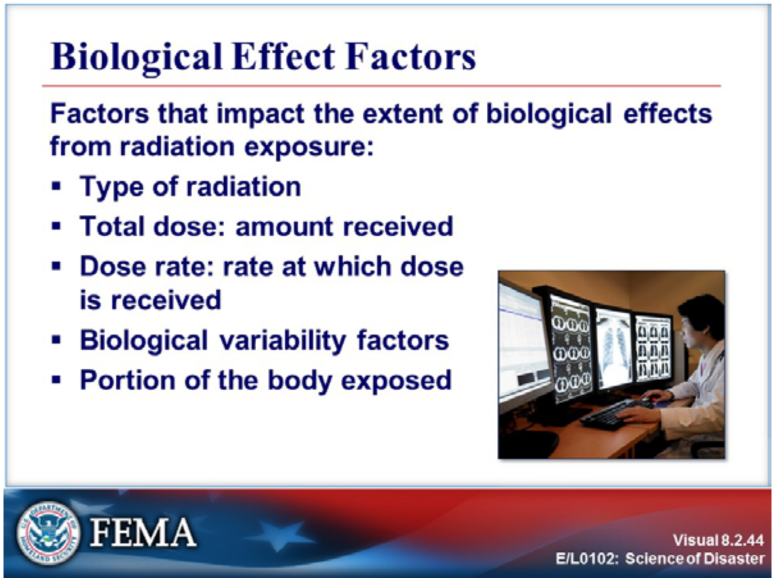
How much of a radiation dose is too much?

Organisms vary in their sensitivity to radiation. In fact, individuals of the same species will also react differently. Because there is biological variability, we often use the dose that is lethal to 50 percent of the exposed population. This is called the LD 50/30.

Definition: LD 50/30 is defined as the dose of radiation expected to cause death (Lethal Dose) within 30 days to 50 percent of the population exposed, without medical treatment. The best estimate for the LD 50/30 for humans is between 300 and 500 rem.

EFFECTS OF RADIATION

Visual 8.2.44



Alt Text for Visual 8.2.44
Biological Effect Factors
Factors that impact the extent of biological effects from radiation exposure:

- Type of radiation
- Total dose: amount received
- Dose rate: rate at which dose is received
- Biological variability factors
- Portion of the body exposed

Key Points

Background: Within a year after the discovery of x-rays, it was learned that exposure to ionizing radiation could lead to biological damage. In fact, in 1904 the first United States radiation fatality (Clarence Dally) was reported.

Scientists continued to conduct research in attempts to interpret the reactions that take place from the moment that radiation enters a living cell. From beginning to end, these initial reactions are probably completed in a millionth of a second, making them very difficult to study.

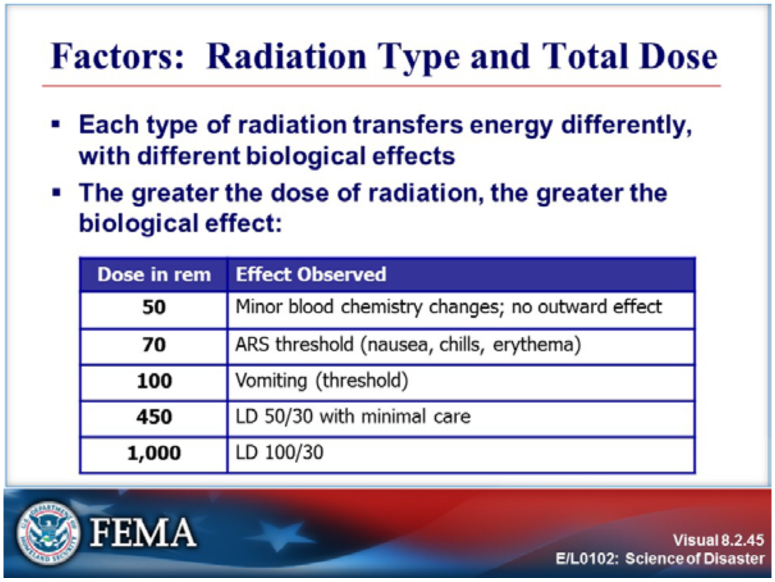
However, scientists have had the opportunity to study groups of individuals—such as early radiation workers, atomic bomb survivors, cancer patients, and radiation accident victims—who have received acute doses of radiation throughout history. The ability to study these individuals has allowed scientists to understand more about the biological effects of ionizing radiation than we do about many other hazards.

Factors: Five factors—which we will look at next—have an impact on the degree of biological effects from radiation exposure:

- Type of radiation
- Total dose
- Dose rate
- Biological variability factors
- Portion of the body exposed

EFFECTS OF RADIATION

Visual 8.2.45



Alt Text for Visual 8.2.45
Factors: Radiation Type and Total Dose

- Each type of radiation transfers energy differently, with different biological effects
- The greater the dose of radiation, the greater the biological effect:

Dose in rem	Effect Observed
50	Minor blood chemistry changes; no outward effect
70	ARS threshold (nausea, chills, erythema)
100	Vomiting (threshold)
450	LD 50/30 with minimal care
1,000	LD 100/30

Key Points

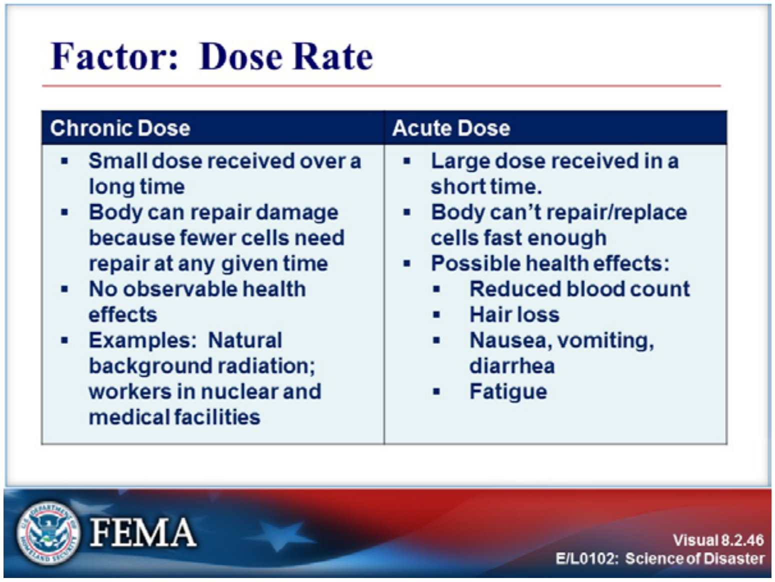
Type of radiation: Each type of radiation transfers energy to a biological system differently. Transfer of energy is measured in linear energy transfer (LET). In general, alpha particles, which are relatively slow moving, have a much higher LET than beta particles or gamma rays.

A radiation with a high LET transfers a great deal of energy in a short distance and produces greater biological effects because it can deposit most of its energy within the volume of one cell of the body and the chance of damage to the cell DNA is therefore larger.

Total dose: Another key factor is the total dose or amount of exposure received. In general, the greater the dose of radiation, the greater the biological effect.

EFFECTS OF RADIATION

Visual 8.2.46



Alt Text for Visual 8.2.46
Factor: Dose Rate

Chronic Dose	Acute Dose
Small dose received over a long time Body can repair damage because fewer cells need repair at any given time No observable health effects Examples: Natural background radiation; workers in nuclear and medical facilities	Large dose received in a short time. Body can't repair/replace cells fast enough Possible health effects: Reduced blood count Hair loss Nausea, vomiting, diarrhea Fatigue

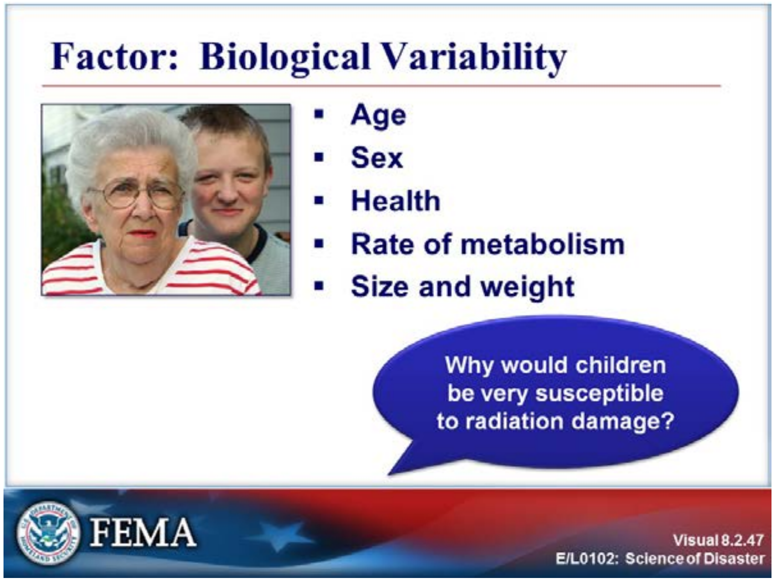
Key Points

Often, the biological effects of ionizing radiation depend not only on how much radiation is received but also on dose rate, or **how fast a radiation dose is received.** There are two categories of radiation doses: chronic radiation doses and acute radiation doses.

- **Chronic Dose: A small amount of radiation received over a long period of time.** Examples of chronic radiation doses include the everyday doses we receive from natural background radiation and the doses received by workers in nuclear and medical facilities. The body can repair the damage from chronic doses because fewer cells will need repair at any given time, and it has enough time to replace dead or nonfunctioning cells with healthy ones. Chronic doses do not result in detectable health effects.
- **Acute Dose: A large dose of radiation received in a short period of time.** The body cannot repair or replace cells fast enough after a large acute dose of radiation, so physical effects may be seen. It takes a large acute dose of radiation before people experience any observable physical effects. The physical reaction to an acute dose of radiation is the result of extensive cell damage over a short period of time.

EFFECTS OF RADIATION

Visual 8.2.47



Key Points

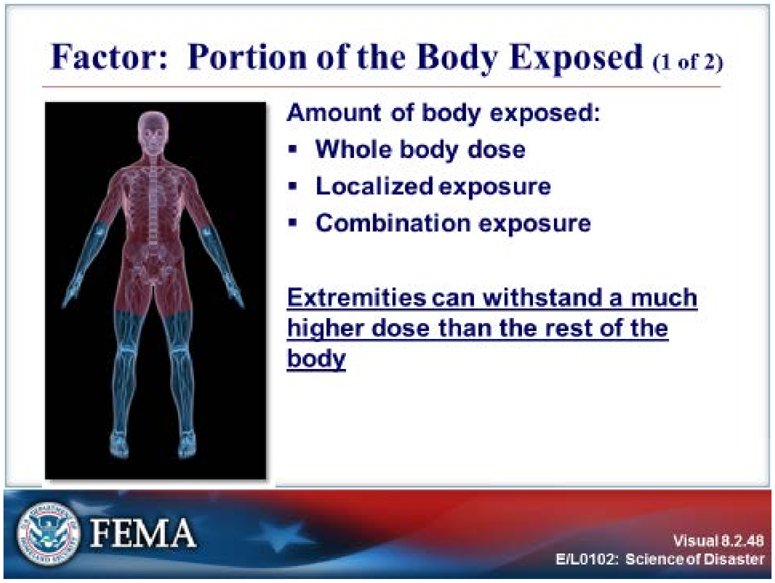
Individuals also have biological variability factors that impact how they are affected by radiation.

These factors include the exposed person's age, sex, health, rate of metabolism, size, and weight. Children are very susceptible to the damage caused by ionizing radiation.

Discussion Question: Why would children be very susceptible to radiation damage?

EFFECTS OF RADIATION

Visual 8.2.48



Alt Text for Visual 8.2.48
Factor: Portion of the Body Exposed (1 of 2)
Amount of body exposed:

- Whole body dose
- Localized exposure
- Combination exposure

Extremities can withstand a much higher dose than the rest of the body
A skeleton showing that the extremities of the body can withstand a much higher dose of radiation than the whole body (head, trunk, arms above the elbow, or legs above the knee).

Key Points

The extremities of the body can withstand a much higher dose of radiation than the whole body (head, trunk, arms above the elbow, or legs above the knee). This is because the major blood-forming organs are located in the whole body area.

Whole body dose: When a whole body dose occurs, the radiation dose is delivered to the whole body homogeneously. For example, a person may enter a radiation field (e.g., a sterilizer that uses a radioactive source, or an industrial radiography area) where the entire body is exposed to radiation.

Localized exposure: In the case of localized radiation exposure, the dose is only delivered to a portion of the body, as would occur if a person placed a hand into the path of a radiation beam or picked up a radioactive rod.

Combination exposure: In some cases, the dose may occur as a combination of whole body and localized exposure. For example, in one case a janitor placed an industrial radiography source in his back pocket and sustained severe local injury to his buttock; he also received a whole-body dose sufficient to cause ARS.

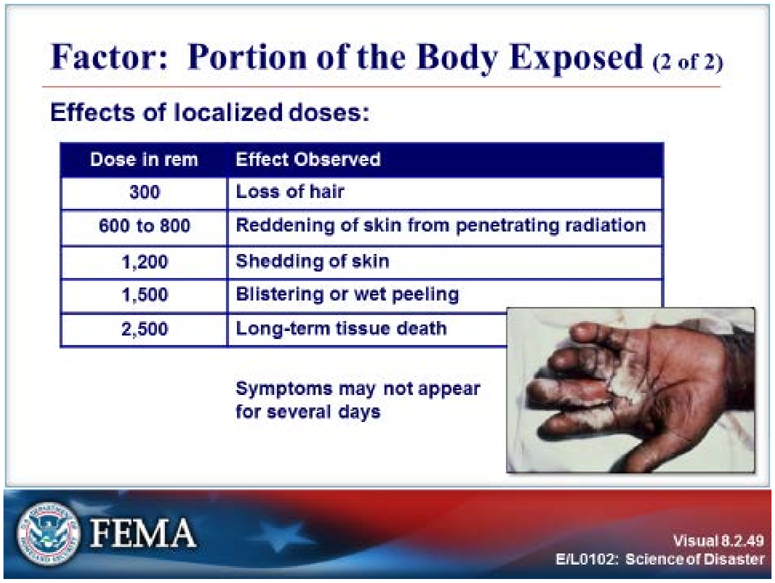
EFFECTS OF RADIATION

Visual 8.2.48 (Continued)

Amount of body exposed: The amount of the body exposed to radiation is a factor in determining the biological effect. While many cancer patients receive large doses of radiation to destroy tumors, this radiation is concentrated on a specific portion of the body. Exposing the whole body poses a greater risk because the radiation-induced damage affects a larger area.

EFFECTS OF RADIATION

Visual 8.2.49



Alt Text for Visual 8.2.49
Factor: Portion of the Body Exposed (2 of 2)

Effects of localized doses:

Dose in rem	Effect Observed
300	Loss of hair
600 to 800	Reddening of skin from penetrating radiation
1,200	Shedding of skin
1,500	Blistering or wet peeling
2,500	Long-term tissue death

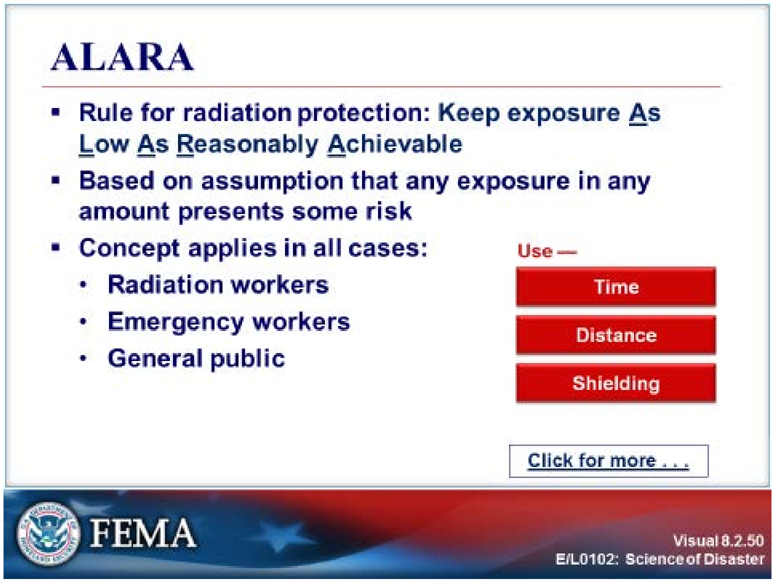
Symptoms may not appear for several days

Key Points

With localized radiation injury, symptoms may not appear for several days and may include redness, itching, and tingling in the exposed area.

EFFECTS OF RADIATION

Visual 8.2.50



Alt Text for Visual 8.2.50
ALARA

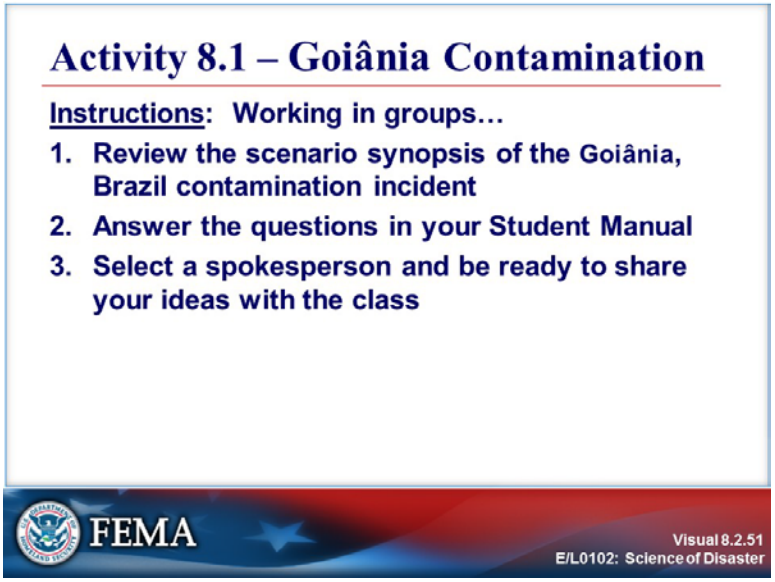
- Rule for radiation protection: Keep exposure As Low As Reasonably Achievable
- Based on assumption that any exposure in any amount presents some risk
- Concept applies in all cases:
  - Radiation workers
  - Emergency workers
  - General public

Key Points

The rule for radiation protection is to keep exposure "As Low as Reasonably Achievable" (ALARA), based on the assumption that any radiation exposure in any amount presents some risk. The ALARA concept applies in all cases—to radiation workers, emergency workers, and the general public.

ACTIVITY 8.1 – GOIÂNIA CONTAMINATION

Visual 8.2.51



Key Points

<u>Instructions</u>: Working in groups…

1. Review the scenario synopsis of the Goiânia, Brazil contamination incident.
2. Answer the questions in your Student Manual.
3. Select a spokesperson and be ready to share your ideas with the class.

ACTIVITY 8.1 – GOIÂNIA CONTAMINATION

Visual 8.2.51 (Continued)

Activity 8.1 – Goiânia Contamination Synopsis

The **Goiânia accident** was a radioactive contamination (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Radioactive_contamination) accident that occurred on September 13, 1987, at Goiânia (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Goi%C3%A2nia), in the Brazilian state of Goiás (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Goi%C3%A1s), after an old radiotherapy (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Radiation_therapy) source was stolen from an abandoned hospital site in the city. It was subsequently handled by many people, resulting in four deaths. About 112,000 people were examined for radioactive contamination, and 249 were found to have significant levels of radioactive material in or on their bodies.[1] (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Goi%C3%A2nia_accident#cite_note-MTCDPub-1) [2] (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Goi%C3%A2nia_accident#cite_note-NYT-2)

Health outcomes: News of the radiation incident was broadcast on local, national, and international media. Within days, nearly 130,000 people swarmed local hospitals concerned that they might have been exposed. Of those, 250 were indeed found to be contaminated— some with radioactive residue still on their skin— through the use of Geiger counters (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Geiger_counter). Eventually, 20 people showed signs of radiation sickness (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Acute_radiation_syndrome) and required treatment.

Fatalities: (Ages in years are given, with dosages listed in grays (Gy) (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Gray_(unit).)

- **Leide das Neves Ferreira**, age 6 (6.0 Gy), was the daughter of Ivo Ferreira. When an international team arrived to treat her, she was discovered confined to an isolated room in the hospital because the hospital staff were afraid to go near her.
- She was buried in a common cemetery in Goiânia, in a special fiberglass coffin lined with lead to prevent the spread of radiation. Despite these measures, news of her impending burial caused a riot of more than 2,000 people in the cemetery on the day of her burial, all fearing that her corpse would poison the surrounding land. Rioters tried to prevent her burial by using stones and bricks to block the cemetery roadway.

Other affected people: Afterwards, about 112,000 people were examined for radioactive contamination; 249 were found to have significant levels of radioactive material in or on their body. Of this group, 129 people had internal contamination. The majority of the internally contaminated people only suffered small doses (< 50 mSv (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Sievert), less than a 1 in 400 risk of getting cancer as a result).

Cleanup: Topsoil (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Topsoil) had to be removed from several sites, and several houses were demolished. All the objects from within those houses were removed and examined. Those that were found to be free of radioactivity were wrapped in plastic bags, while those that were contaminated were either decontaminated or disposed of as waste. In industry, the choice between decontaminating or disposing objects is based on only the economic value (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Value_(economics)) of the object and the ease of decontamination (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Decontamination). In this case, the IAEA recognized that to reduce the psychological impact (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Psychological_trauma) of the event, greater effort should have been taken to clean up items of personal value, such as jewellry (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Jewellery) and photographs (This link can also be accessed at the following URL: https://en.wikipedia.org/wiki/Photograph). It is not clear from the IAEA report to what degree this was practiced.

ACTIVITY 8.1 – GOIÂNIA CONTAMINATION

Visual 8.2.51 (Continued)

Activity 8.1 – Goiânia Contamination Worksheet

- **What would you do if this occurred in your community? (Response)**
- **What resources/partners would be available to help your community? (Preparedness-Planning)**
- **What are the long-term impacts of an incident such as this? (Recovery)**

GOIANIA VIDEO

Visual 8.2.52

Key Points

Introduction: The 1987 Goiânia radiological incident changed worldwide regulations for radiological waste. More than 200 people were exposed to cesium-137 with four deaths. More than 100,000 people were monitored and screened for radiation exposure.

Transcript:

Speaker: Thank you for staying with CNN. It is a symbol that can save lives. A red triangle with radiation waves and a man running. It was just adopted last year, but there was no such sticker to convey danger when scavengers went routing through debris at a deserted clinic in Brazil over 20 years ago. UN TV has details.

Voiceover speaker: Two families live at this scrapyard at the Brazilian city of Goiania. It is also home to the world's worst accident involving a radiative source. Its lessons still shape actions on nuclear safety and security decades later.

It started in September 1987 when scrap dealers pillaged and then sold a metal canister from an abandoned medical clinic. They had no clue it contained a powerful radioactive source used to treat cancer: Cesium Chloride, a glittering powder that glows blue in the dark.

Dr Nelson Jose L. Valverde: They took the equipment to his dining room and called the neighbors, relatives, friends to show them that glittering object, and small fragments of the source were taken, were robbed on the scene, were given to other people as souvenirs, and that's the way contamination came to spread.

GOIANIA VIDEO

Visual 8.2.52 (Continued)

Voiceover: The powdery cesium spread undetected for over 2 weeks. Almost 250 people were contaminated or died in the first month, including a little girl who lived here. The legacy of a handful of cesium is three thousand cubic meters of contaminated waste. It's buried here. Goiania's plight brought global change. The international atomic energy agency introduced rigorous safety standards for sources. Brazil now requires that each and every source is licensed for lifetime tracking to final disposal.

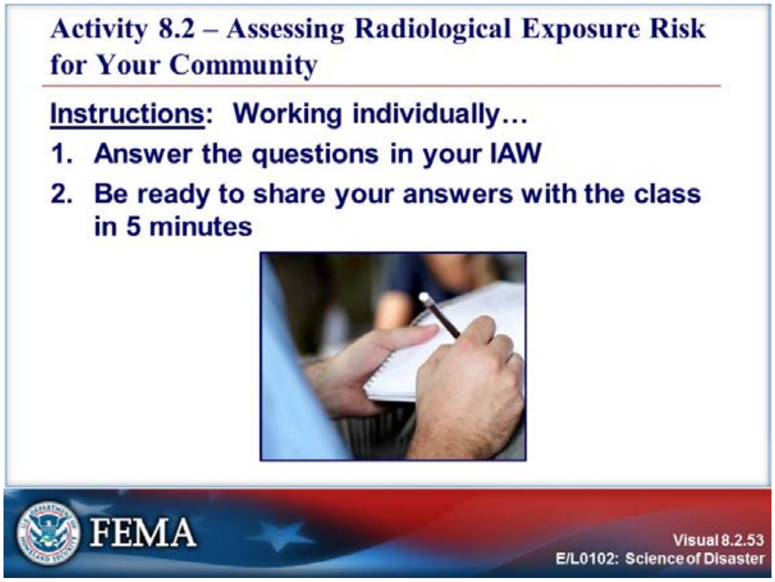
Didier Louvat: Certainly the public and the environment are better protected now than thirty years ago.

Voiceover: Lessons were learned in Goiania, but worldwide radioactive sources are still dumped and lost. Efforts are underway to assist countries to search and secure abandoned sources, train body guards to detect them, as part of a cradle to grave approach needed to keep radioactive materials secure so that what happened in Goiania is never repeated.

From UN Television, this is Kirsty Hansen, with *CNN World Report.*

ACTIVITY 8.2 – ASSESSING RADIOLOGICAL EXPOSURE RISK FOR YOUR COMMUNITY

Visual 8.2.53



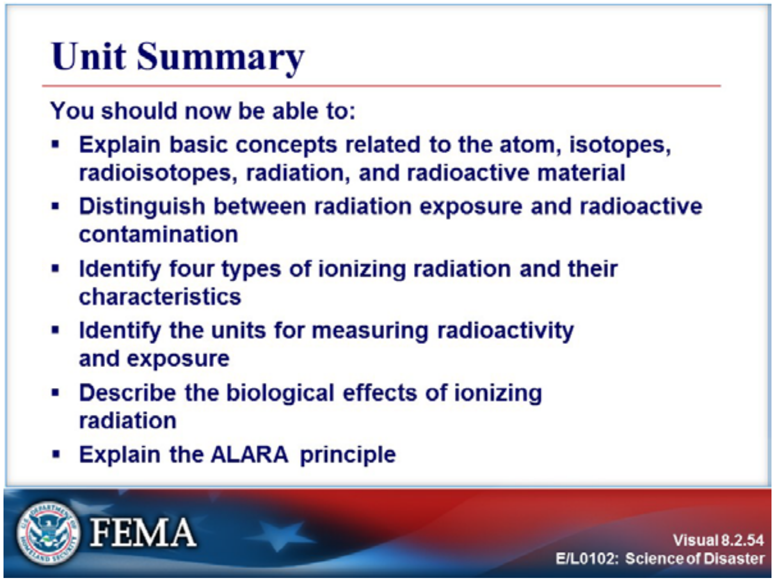
Key Points

Instructions: Working individually…

1. Answer the questions in your IAW.
2. Be ready to share your answers with the class in 5 minutes.

MODULE SUMMARY

Visual 8.2.54



Key Points

You should now be able to:

- Explain basic concepts related to the atom, isotopes, radioisotopes, radiation, and radioactive material
- Distinguish between radiation exposure and radioactive contamination
- Identify four types of ionizing radiation and their characteristics
- Identify the units for measuring radioactivity and exposure
- Describe the biological effects of ionizing radiation
- Explain the ALARA principle

Do you have any questions about the material covered in this module?

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UNIT 3. BIOLOGICAL BASICS

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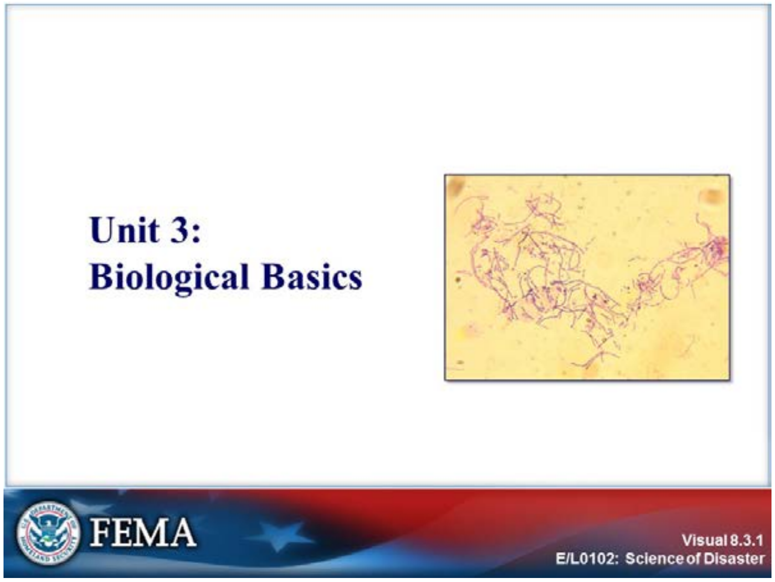
INTRODUCTION

Visual 8.3.1



Key Points

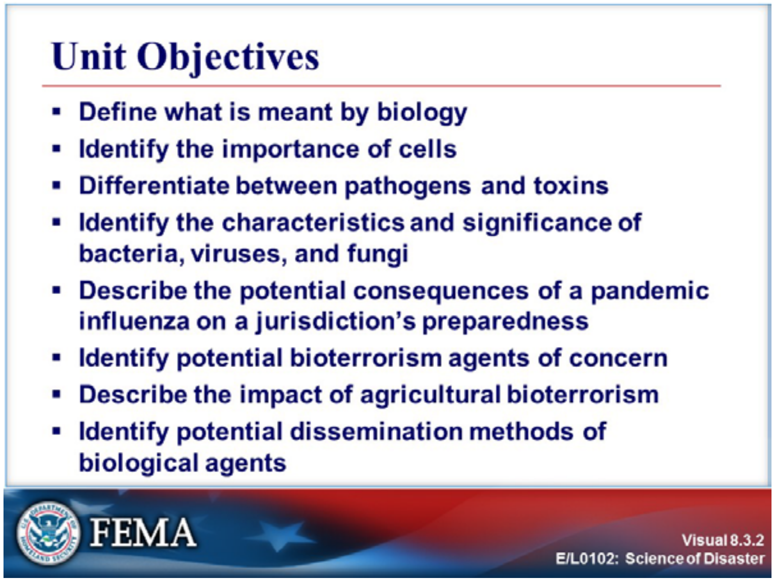
This unit will explore the scientific basis for biological hazards and threats.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Cell Basics	10 minutes
Biological Hazards	10 minutes
Toxins and Pathogens	20 minutes
Activity 8.3 – Hurricane Sandy	30 minutes
Bioterrorism	40 minutes
Activity 8.4 – Bioterrorism Tabletop	30 minutes
Unit Summary	5 minutes
Total Time	**2 hours, 30 minutes**

INTRODUCTION

Visual 8.3.2



Alt Text for Visual 8.3.2
Unit Objectives

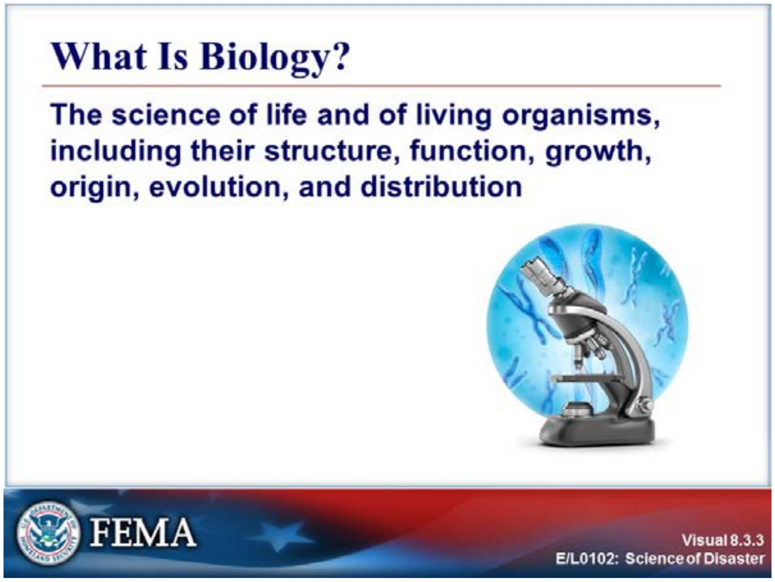
- Define what is meant by biology
- Identify the importance of cells
- Differentiate between pathogens and toxins
- Identify the characteristics and significance of bacteria, viruses, and fungi
- Describe the potential consequences of a pandemic influenza on a jurisdiction's preparedness
- Identify potential bioterrorism agents of concern
- Describe the impact of agricultural bioterrorism
- Identify potential dissemination methods of biological agents

Key Points

Review the unit objectives as shown on the visual.

INTRODUCTION

Visual 8.3.3



Key Points

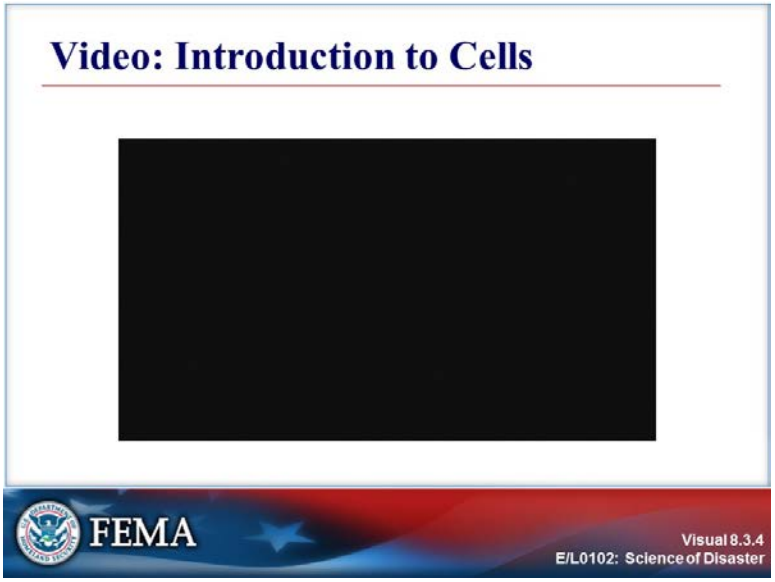
Biology is defined as “the science of life and of living organisms, including their structure, function, growth, origin, evolution, and distribution.”

There are numerous sub disciplines of biology. For example:

- Cellular biology examines the basic building block of all life—the cell.
- Biochemistry examines the rudimentary chemistry of life.
- Molecular biology studies the complex interactions of systems of biological molecules.

CELL BASICS

Visual 8.3.4



Key Points

Introduction: This video introduces the characteristics of cells.

Transcript:

Have you ever wondered what we are all made of? All life is made of CELLS. They come in thousands of shapes and sizes! The human body has over 100 trillion of them carrying out the dance of life! They are so tiny that 10,000 could fit on the head of a pin. The cells in our body undergo over 500 quadrillion chemical reactions every second. Their amazing biochemistry has nurtured life on Earth for billions of years and protected us from harm! They ask only that we take care of ourselves! Our science has barely begun to understand them.

Cell theory—the widely accepted theory that all living organisms are composed of cells—states that the cell:

- Is the basic unit of all living things
- Makes up all organs
- Is produced from other cells

CELL BASICS

Visual 8.3.4 (Continued)

Cells also:

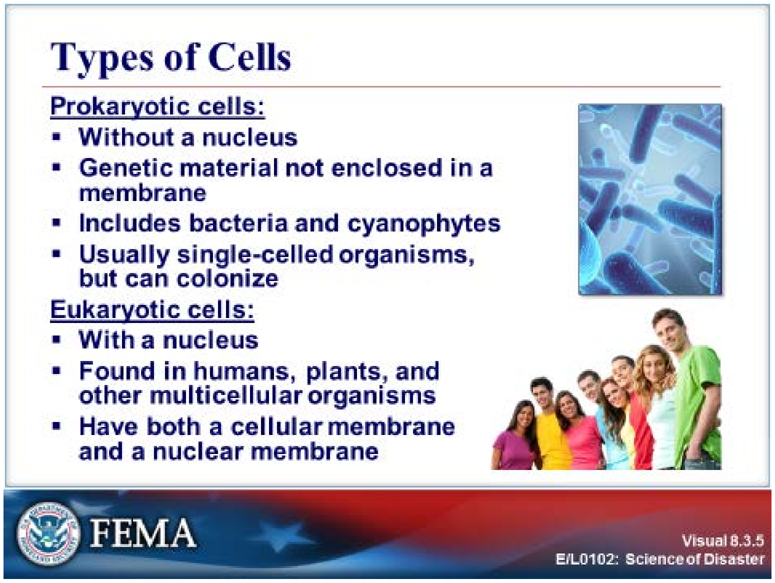
- Are living things themselves, and carry out the functions of respiration, reproduction (meiosis), and growth (mitosis).
- Have a membrane, DNA, cytoplasm, and ribosomes in common, but also vary greatly in terms of their:
  - Shape (spheres, cubes, flat, etc.)
  - Length (long and narrow, short and wide, etc.)
  - Structure (rigid cell well, flexible cell membrane, no membrane at all, etc.)

Below are additional theories and definitions related to cells:

- **Gene theory:** Traits are inherited through gene transmission. Genes are located on chromosomes and consist of DNA.
- **Evolution:** Any genetic change in a population that is inherited over several generations. These changes may be small or large, noticeable or not so noticeable.
- **Homeostasis:** Ability to maintain a constant internal environment in response to environmental changes
- **Thermodynamics:** Energy is constant and energy transformation is not completely efficient.

CELL BASICS

Visual 8.3.5



Alt Text for Visual 8.3.5
Types of Cells
<u>Prokaryotic cells:</u>
- Without a nucleus
- Genetic material not enclosed in a membrane
- Includes bacteria and cyanophytes
- Usually single-celled organisms, but can colonize

<u>Eukaryotic cells:</u>
- With a nucleus
- Found in humans, plants, and other multicellular organisms
- Have both a cellular membrane and a nuclear membrane

Key Points

In understanding biological hazards and threats, it is useful to distinguish between cell types. There are two types of cells: prokaryotes and eukaryotes. The following table highlights their differences.

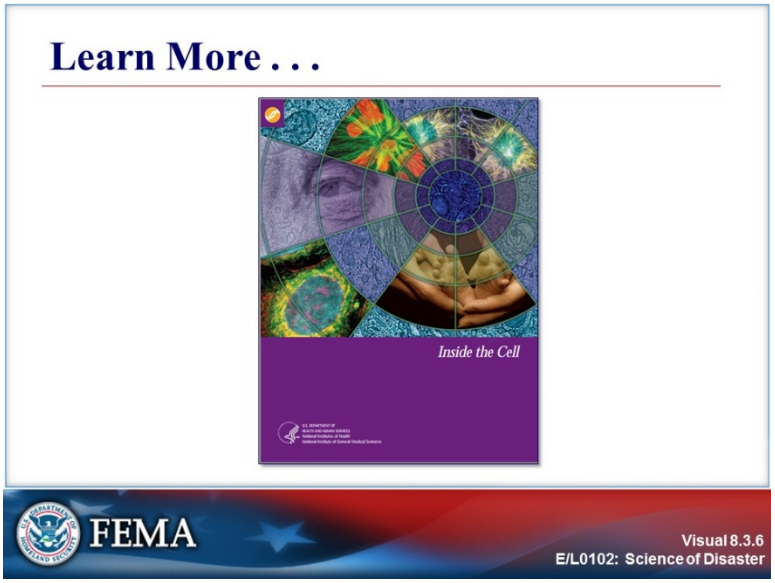
CELL BASICS

Visual 8.3.5 (Continued)

Prokaryotic Cells	Eukaryotic Cells
Are cells without a nucleus	Are cells with a nucleus
Have genetic material but are not enclosed in a membrane.	Have both a cellular membrane and nuclear membrane.
Include bacteria and cyanophytes	Are found in humans, plants, and other multicellular organisms
Genetic material is a single DNA strand contained in the cytoplasm, because there is no nucleus. This DNA works in just the same way as it does in other organisms, but it is not gathered together into chromosomes visible through a microscope.	Genetic material forms multiple chromosomes.

CELL BASICS

Visual 8.3.6



Key Points

You can learn more about cells in the science education booklet, *Inside the Cell*, which explores the interior design of cells and vividly describes the processes that take place within.

Inside the Cell is available online (This link can also be accessed at the following URL: https://publications.nigms.nih.gov/insidethecell/pdf/inside_the_cell.pdf) and is published by the U.S. Department of Health and Human Services, NIH Publication No. 07-2778, National Institutes of Health.

BIOLOGICAL HAZARDS

Visual 8.3.7

Key Points

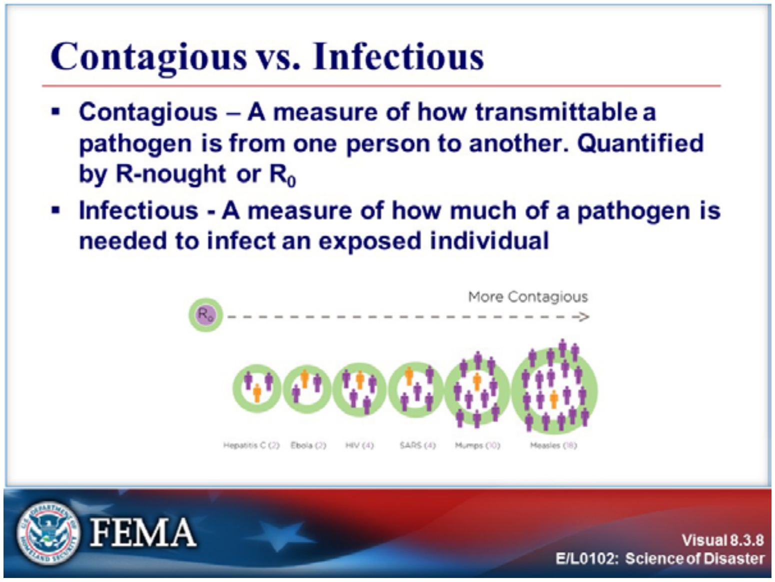
The basic cell concepts just discussed provide a basis for understanding biological hazards and threats that can attack the cells.

What do we know about biological hazards? There are various types of biological hazards, and they vary widely from one to the next in their characteristics. However, there are a few general facts that are important to keep in mind:

- **Contagion:** Not all hazards are contagious. Some are, but others cannot be transmitted from one person to another.
- **Exposure:** Biological hazards may have multiple routes of exposure. The routes of entry for pathogens and toxins are the same as chemicals—ingestion, eyes, inhalation, and absorption. Common means for spread pathogens and toxins include:
  - Airborne: Coughing and/or sneezing
  - Contact: Touching another person or object
  - Ingestion: Eating food touched by someone with dirty hands
  - Bloodborne: Coming in contact with body fluids, such as blood, saliva, etc.
- **Incubation:** A hazard may not be evident for days or weeks.
- **Symptoms:** Different hazards may present a variety of symptoms.
- **Treatment:** Many hazards are treatable.

CONTAGIOUS VS. INFECTIOUS

Visual 8.3.8



Alt Text for Visual 8.3.8
Contagious vs. Infectious

- Contagious – A measure of how transmittable a pathogen is from one person to another. Quantified by R-nought or R_0
- Infectious - A measure of how much of a pathogen is needed to infect an exposed individual

Image of a scale of infection and contagion showing Hep C, Ebola, HIV, SARS, Mumps, and Measles

Key Points

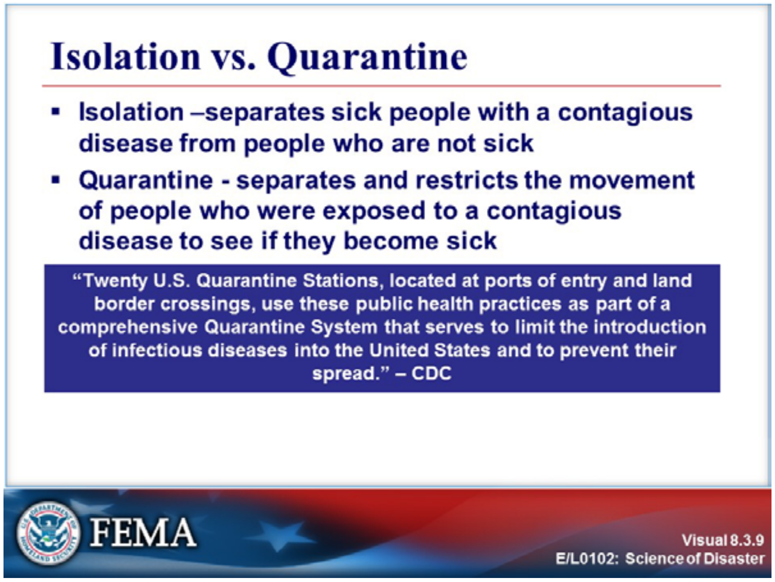
The media often confuses the terms infectious and contagious. It is important to understand the distinction between the two.

Infectious refers to how many bacteria, virions or other pathogen particles are needed to infect an exposed individual.

Contagious means the bacteria or virus can be transmitted from person to person (a communicable disease), and is quantified by R-nought.

ISOLATION VS. QUARANTINE

Visual 8.3.9



Alt Text for Visual 8.3.9
Isolation vs. Quarantine

- Isolation –separates sick people with a contagious disease from people who are not sick
- Quarantine - separates and restricts the movement of people who were exposed to a contagious disease to see if they become sick

"Twenty U.S. Quarantine Stations, located at ports of entry and land border crossings, use these public health practices as part of a comprehensive Quarantine System that serves to limit the introduction of infectious diseases into the United States and to prevent their spread." – CDC

Key Points

The media also often confuses the terms isolation and quarantine. Especially given recent events regarding Ebola, as well as challenges to the powers of public health officials, it is important to understand what each term means.

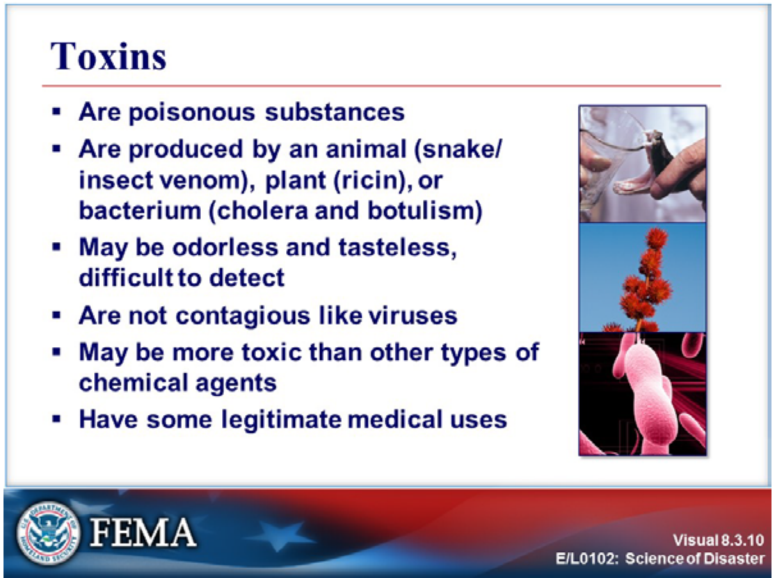
"Under section 361 of the Public Health Service Act (42 U.S. Code § 264), the U.S. Secretary of Health and Human Services is authorized to take measures to prevent the entry and spread of communicable diseases from foreign countries into the United States and between states."

"States have police power functions to protect the health, safety, and welfare of persons within their borders. To control the spread of disease within their borders, states have laws to enforce the use of isolation and quarantine. These laws can vary from state to state and can be specific or broad. In some states, local health authorities implement state law. In most states, breaking a quarantine order is a criminal misdemeanor. Tribes also have police power authority to take actions that promote the health, safety, and welfare of their own tribal members. Tribal health authorities may enforce their own isolation and quarantine laws within tribal lands, if such laws exist."

Source: Centers for Disease Control and Prevention (This link can also be accessed at the following URL: https://www.cdc.gov/quarantine/)

TOXINS

Visual 8.3.10



Alt Text for Visual 8.3.10

Toxins

- Are poisonous substances
- Are produced by an animal (snake/ insect venom), plant (ricin), or bacterium (cholera and botulism)
- May be odorless and tasteless, difficult to detect
- Are not contagious like viruses
- May be more toxic than other types of chemical agents
- Have some legitimate medical uses

Key Points

Description: Toxins are substances produced within living organisms that are poisonous to humans. (Notice that their origin differentiates toxins from chemical, or manmade “toxics” or “toxicants.”)

Production: Toxins are produced by:

- Animals—e.g., snake or insect venom
- Plants—e.g., ricin from castor beans
- Bacteria—e.g., cholera and botulism

The majority of toxins that are problems for human beings are released by bacteria. In fact, the bacterial toxin *Clostridium botulinum* is the most poisonous substance known to scientists. It causes severe food poising (botulism) that can lead to death by suffocation in just a few days. (We will look at botulism in greater detail later in this unit.)

TOXINS

Visual 8.3.10

Many toxins are produced by marine organisms. One such example is saxitoxin, which is synthesized by a type of blue-green algae (cyanobacteria). These algae provide food for different shellfish—for example, mussels. The mussels themselves are not influenced by the poison, but human beings who later eat the mussels may become seriously ill.

Characteristics: Toxins:

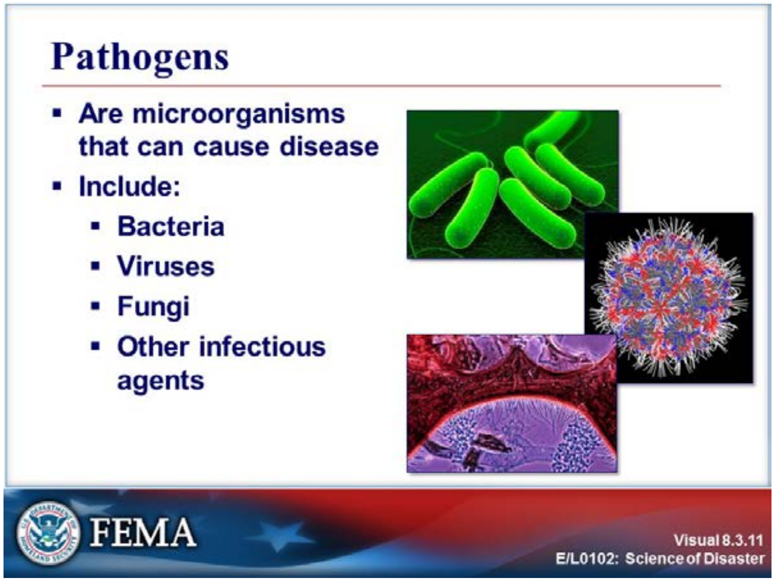
- May be odorless and tasteless, and therefore difficult to detect
- Are made unstable by heat or other environmental factors
- Are not contagious like viruses are
- May be more toxic than other types of chemical agents

Legitimate uses: Although toxins are extremely dangerous (and often fatal), many toxins have legitimate medical use in smaller doses.

For example, *botulinum* toxin is used to treat muscular disorders, and forms of ricin (the plant-generated toxin) are studied in order to treat leukemia and liver cancer.

PATHOGENS

Visual 8.3.11



Key Points

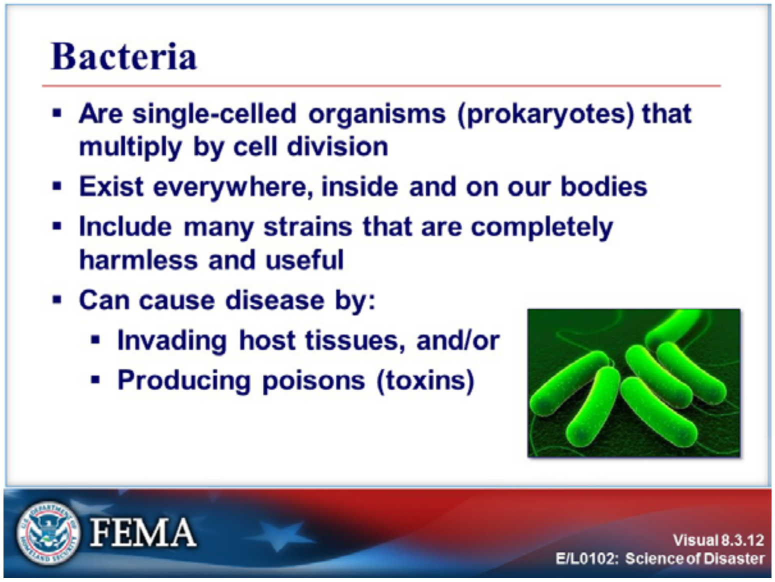
Pathogens are microorganisms that can cause disease in a host (another living thing). There are human pathogens and animal pathogens. Pathogens include:

- Bacteria
- Viruses
- Fungi
- Other infectious agents, such as parasites and prions.

In this section we'll take a closer look at bacteria, viruses, and fungi.

PATHOGENS: BACTERIA

Visual 8.3.12



Alt Text for Visual 8.3.12
Bacteria

- Are single-celled organisms (prokaryotes) that multiply by cell division
- Exist everywhere, inside and on our bodies
- Include many strains that are completely harmless and useful
- Can cause disease by:
  - Invading host tissues, and/or
  - Producing poisons (toxins)

Key Points

Description: Bacteria:

- Are one-celled organisms (recall the difference between prokaryotes and eukaryotes) that multiply by cell division
- Are visible only with a microscope. Bacteria are so small that if you lined up a thousand of them end to end, they could fit across the end of a pencil eraser.
- Are shaped like short rods, spheres, or spirals
- Exist everywhere, including inside and on our bodies

Useful bacteria: Not all bacteria are harmful. In fact, less than 1 percent cause disease, and some bacteria that live in your body are useful. For instance, *Lactobacillus acidophilus*—a harmless bacterium that resides in the intestines—helps digest food, destroys some disease-causing organisms, and provides nutrients to your body.

PATHOGENS: BACTERIA

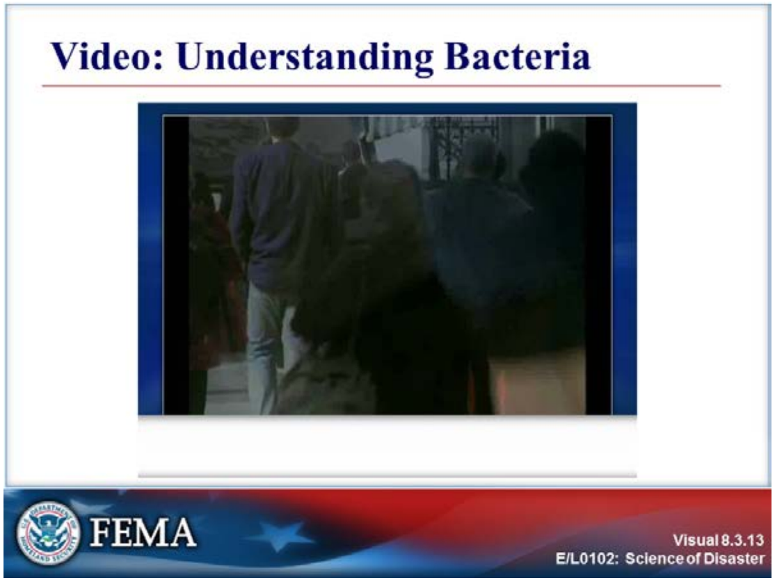
Visual 8.3.12 (Continued)

Disease: Some bacteria cause disease, either by invading host tissues (infection) or by producing toxins—powerful chemicals that damage cells and make you ill. Bacteria cause diseases such as:

- Strep throat.
- Tuberculosis.
- Urinary tract infections.

PATHOGENS: BACTERIA

VISUAL 8.3.13



Key Points

Introduction: This video examines the pervasiveness and resilience of bacteria, and their potential to do both great good and great harm to the human body.

Video Transcript:

Narrator: Pneumonia, Salmonella, meningitis—all caused by bacteria and passed among us every day. Infectious disease is the greatest cause of illness and death in human history. It is now the highest cause of death in the United States. Bacteria can make us deathly sick and often kill us; and just when we develop medicines to kill the germs, they do what they do best: mutate to resist our medicines.

Stanley Falkow, Ph.D., President American Society for Microbiology: We are destined to always live with microorganisms, and the concept that we will eradicate microorganisms—you can wash to your heart's content but you won't rid your skin of microorganisms. And you can scrub to your heart's content but you won't rid your mouth of bacteria. And there are other things that we know about—that bacteria are constantly present, our intestinal track is one great fermentation tube, and it's constantly gurgling and grinding and converting things. We absolutely depend on these things, and there's no way out of it.

Narrator: Actually, less than one percent of all bacteria cause disease. The others perform countless useful functions in everyday lives. Bacteria are behind many of our favorite foods, and when those foods spill down the front of us, bacterial enzymes help get the stains out.

PATHOGENS: BACTERIA

Visual 8.3.13 (Continued)

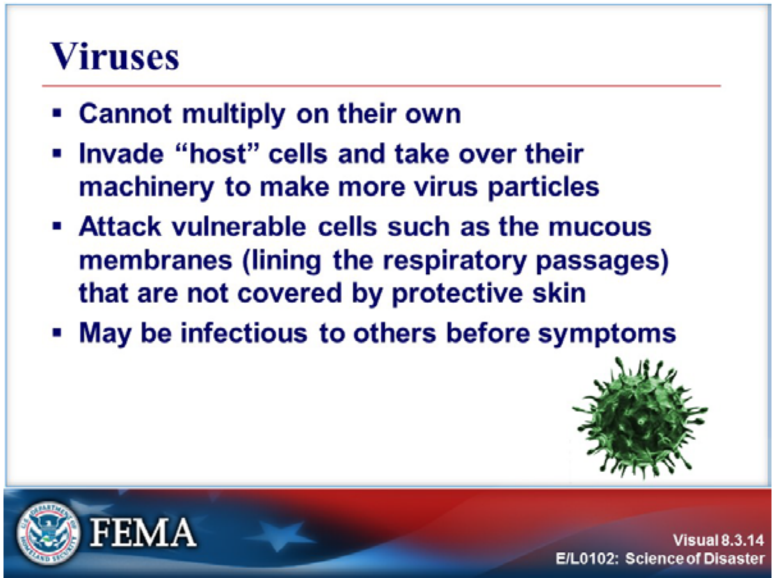
Even artificial snow relies on bacteria: protein from freeze-dried bacteria helps flakes to form out of water mist. Bacteria are the oldest life form on earth. They survive, even thrive, in some of the harshest environments—in the hot springs of Yellowstone, in pools of acid, in caves, in crevices in the Earth without light or air, next to ocean vents where the water temperature is 480 degrees Fahrenheit. This is what a bacterium is: a single-cell organism with its own branch on the tree of life. (Daisies, squirrels, and people are on the other side because their bodies are made up of many cells.) It's the smallest of free living organisms. About a million would fit on the head of a pin. Viruses are a hundred times smaller but they have to move into a host cell to survive. Bacteria come in a variety of shapes and sizes, and to reproduce they simply divide. In many species cell division occurs every 20 minutes.

Abigail Salyers, Ph.D., Professor of Microbiology, University of Illinois: Bacteria have studied us more closely and more lovingly than any other creature. Even your dog can't give you the devotion that your bacteria do. They've explored and understood and taken advantage of every nook and cranny of the body to which they can gain access.

Narrator: We are born bacteria free, but within hours we begin to be colonized with about 400 species of microbes—on our skin, in our intestines, in our mouths, noses, and throats. There are more bacteria in our mouths than living people on the planet; more bacteria in our bodies than human cells. Billions are helping to digest our last meal. Those bacteria—*E. coli*—turn our food into sugars and processed vitamins. They also keep us healthy by occupying spaces that otherwise might be occupied by disease-causing bacteria. But even good bacteria like *E. coli* can develop deadly strains. Bacteria are good or bad and sometimes they are both.

PATHOGENS: VIRUSES

Visual 8.3.14



Alt Text for Visual 8.3.14

Viruses

- Cannot multiply on their own
- Invade "host" cells and take over their machinery to make more virus particles
- Attack vulnerable cells such as the mucous membranes (lining the respiratory passages) that are not covered by protective skin
- May be infectious to others before symptoms

Key Points

Viruses are another type of pathogen.

Description: Viruses are basically just capsules—a protein coat and a core of genetic material, either RNA or DNA. They are much smaller than cells and may be shaped like rods, spheres, or tiny tadpoles.

Survival and reproduction: Unlike bacteria, viruses can't survive without a host. They can only reproduce by attaching themselves to cells and hijacking the cells' cellular machinery. In most cases, they reprogram the cells to make new viruses until the cells burst and die. In other cases, they turn normal cells into malignant or cancerous cells.

Disease: Also unlike bacteria, most viruses **do** cause disease, and they're quite specific about the cells they attack. For example, certain viruses are programmed to attacks cells in the liver, respiratory system, or blood. In some cases, viruses called bacteriophages target bacteria.

PATHOGENS: VIRUSES

Visual 8.3.14 (Continued)

Viruses are responsible for causing a wide range of diseases, including:

- AIDS
- Common cold
- Ebola hemorrhagic fever
- Herpes (chickenpox and later shingles)
- Influenza
- Measles
- Smallpox

Incubation and transmission: Viruses may be transmitted infectiously before any symptoms appear, as is the case with chickenpox; this is because they have an incubation period (the time between infection and symptoms) after access into your body, during which the virus multiplies "silently."

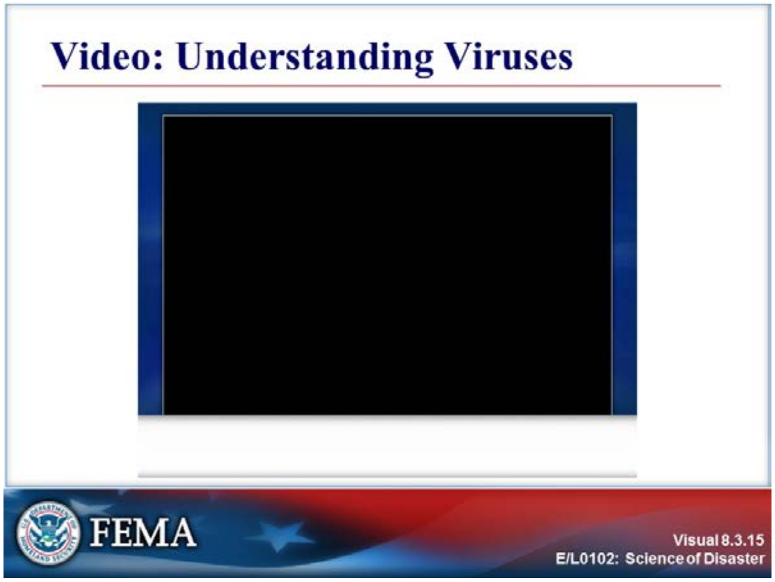
Below are examples of the incubation periods for some common viral infections:

Infection	Incubation Period
Chickenpox	10 to 21 days
Diphtheria	2 to 5 days
Influenza	Up to 7 days, most likely to be 2 to 3 days
Measles	About 10 days, with a further 2 to 4 days before the rash appears
Mumps	Around 17 days, with a range of 12 to 25 days
Rubella (German measles)	14 to 21 days, and the time you can infect someone else is from 1 week until 4 days before the rash appears
Slapped cheek syndrome (also known as parvovirus B19 or fifth disease)	Usually 13 to 18 days, but can be as long as 20 days
Tetanus	Between 4 and 21 days, most commonly about 10 days
Whooping cough (pertussis)	Between 7 and 10 days

Treatment: Antibiotics have no effect on viruses.

PATHOGENS: VIRUSES

Visual 8.3.15



Key Points

(Video used with permission of Zirus, Inc., the Anti-Virus Company, and XVIVO Scientific Animation.)

Introduction: This video examines how viruses infect cells and replicate themselves.

Video Transcript:

(Man sneezing)

Robert Krulwich (RK): So, let's say that this guy has the flu, could be any flu, and here's a droplet from his sneeze containing—if we move in and take a really close look, you see each one of those little purple things is a virus, and there are a lot of viruses floating through the air, some of which go inevitably up this unfortunate man's nose.

RK: How did that guy feel when you ripped off half of his face?

David Bolinsky (DB): It was interesting because we did it while he was sleeping. (Laughing)

RK: Okay, I am talking with medical illustrator David Bolinsky who designed this video for Zirus, a research company. So here comes the virus, and it's going to land on one of this guy's throat cells. So notice it's covered with little yellow knobby things—you call these keys, right?

PATHOGENS: VIRUSES

Visual 8.3.15 (Continued)

DB: Those are the keys… this is a key; this is a key; this is a key.

RK: Okay, if the keys on this virus happen to fit the locks, which are those little purple-y stick-up-y things on the surface of the cell. If there is a match, the cell—watch this—welcomes the virus in and what's this?

DB: This is the welcoming committee. They all interlock with each other and they pull this membrane down into the cell.

RK: And down it goes, deeper and deeper, and that welcoming structure disperses and the virus capsule bursts and out comes the secret recipe for how to make more viruses, those little noodle-y things. So this unsuspecting cell has been tricked into guiding these virus recipes right into its own command center, the nucleus. So in they go…

DB: And they are immediately recognized by this big pink molecule, which is a mini-factory.

RK: Yeah, what is it doing?

DB: It threads the nuclear material; the instruction code of the virus, through one hole—and out another hole comes a brand new instruction set.

RK: So it's a copying machine, making copy after copy after copy of virus recipes which then go out of the nucleus to the little chefs—those blue peanut-y things. They cook up proteins that go back into the nucleus where they are reassembled into baby viruses and then out they go. They get covered up and head to the surface, where they get new keys and then boom, here they come. This is an eruption of virus after virus after virus after only one virus entered the cell, but how many came out? Well, millions, millions. So if one virus can produce a million babies and do it again and again and again how come this guy doesn't just drop dead, I don't know, in like 10 minutes?

DB: Well, because you have about a hundred trillion cells.

RK: I see, so a million viruses is just a drop in the bucket when you have a hundred trillion cells. And anyway, remember you do have your own immune system, which when it sees a virus usually kills it. So, while the virus does multiply fast, with any luck your immune system will work just a little faster. So, yes, viruses, all viruses want to spread, that's what they do. But most of the time we do keep them in check…most of the time.

PATHOGENS: VIRUSES

Visual 8.3.16

Key Points

Influenza, or flu, is an example of a virus most of us are familiar with. Every year in the United States, the flu:

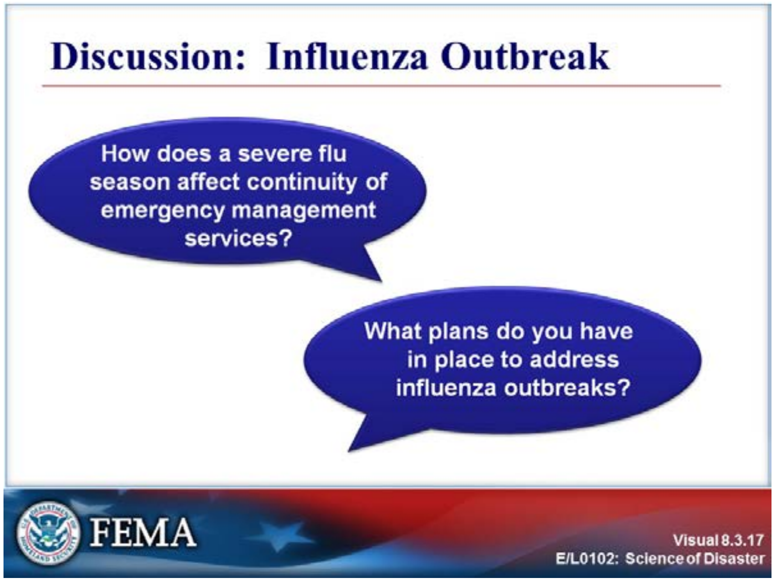
- Infects 5 percent to 20 percent of the population
- Hospitalizes more than 200,000 people with flu-related complications
- Kills approximately 36,000 people

People with a high risk for serious complications as a result of the flu include:

- The elderly
- Young children
- People with certain health conditions

PATHOGENS: VIRUSES

Visual 8.3.17



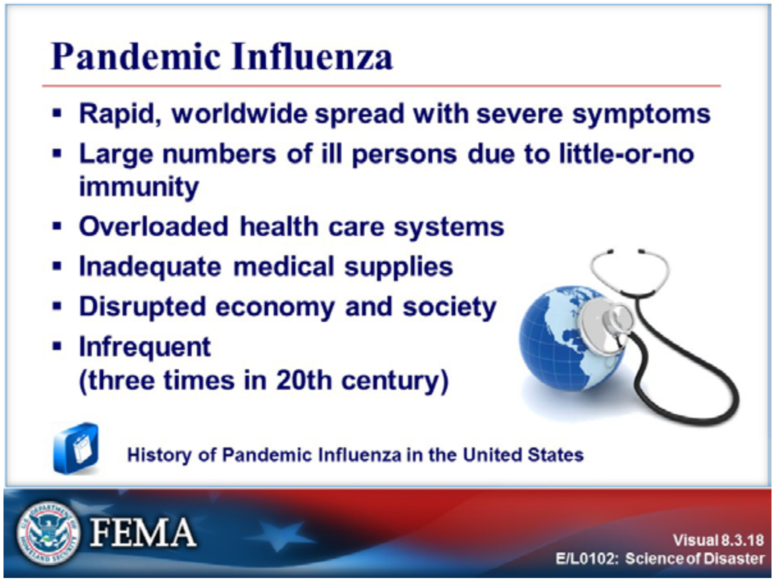
Key Points

<u>Discussion Questions</u>:

- **How does a severe flu season affect continuity of emergency management services?**
- **What plans do you have in place to address influenza outbreaks?**

PATHOGENS: VIRUSES

Visual 8.3.18



Alt Text for Visual 8.3.18
Pandemic Influenza

- Rapid, worldwide spread with severe symptoms
- Large numbers of ill persons due to little-or-no immunity
- Overloaded health care systems
- Inadequate medical supplies
- Disrupted economy and society
- Infrequent (three times in 20th century)

History of Pandemic Influenza in the United States

Key Points

Description: A pandemic is a global disease outbreak. It is determined by how the disease spreads, not how many deaths it causes.

When a new influenza A virus emerges, a flu pandemic can occur. Because the virus is new, the human population has little to no immunity against it. The virus spreads quickly from person to person worldwide.

Characteristics: According to the Centers for Disease Control and Prevention (CDC), the characteristics of a flu pandemic include:

- **Rapid worldwide spread.** A flu pandemic will spread quickly around the world, from country to country, even if governments attempt to close their borders, restrict travel, or otherwise protect their populations.
- **Overloaded health care systems.** As infection and illness rates soar, large populations require medical care, and death rates increase, medical staff and resources will become overloaded and overwhelmed. There may be a shortage of beds and treatment locations, in which case alternative sites like schools may be used as facilities.

PATHOGENS: VIRUSES

Visual 8.3.18

- **Inadequate medical supplies.** Just as medical staff will be overwhelmed by a pandemic, the need for vaccines will outrun the supply. High-risk patients will more than likely receive the vaccine (or antiviral medication) first.
- **Disrupted economy and society.** Communities and citizens will be greatly impacted by disruptions to the economy and society, including the banning of travel, cancellation of events, and the closing of schools and businesses. The economy will be affected as employees remain absent to care for sick family members.

PATHOGENS: VIRUSES

Visual 8.3.18 (Continued)

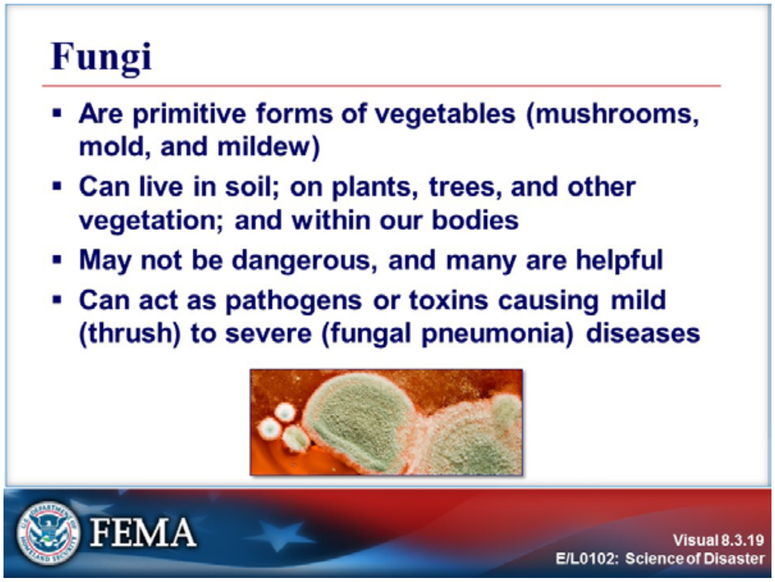
Although flu pandemics have happened throughout history, they are infrequent and occurred just three times in the 20th century. The table below presents the basic facts of the four flu pandemics that have occurred since 1918.

History of Pandemic Influenza in the United States

Pandemic	Description
1918 – 1919 Pandemic	• Called “The Spanish Flu” • Often resulted in deaths from secondary effects such as pneumonia • Made 20 percent to 40 percent of the worldwide population ill • Resulted in about 50 million fatalities, 675,000 of which were in the United States • Noted for high mortality rates among healthy adults rather than the elderly or children. In fact, the highest rates were seen among adults 20 to 50 years old.
1957 – 1958 Pandemic	• Started in February of 1957 with the identification of a new virus in the Far East. Officials predicted a pandemic, monitored outbreaks, and produced a limited supply of vaccine. • Came to the United States through small outbreaks and the spread of the disease in classrooms. October 1957 was the peak of infection rates for the “first wave.” • Resurged in “second wave” in January and February 1958 • Resulted in about 69,800 fatalities in the United States, with the highest rates of death occurring among the elderly
1968 – 1969 Pandemic	• Started in early 1968 with the identification of a new virus in Hong Kong • Became widespread in the United States in September 1968 and peaked that winter • Resulted in 33,800 deaths between September 1968 and March 1969—the mildest pandemic of the 20th century • Was similar to 1957 virus, leading researchers to conclude that U.S. citizens had built some immunity. The virus also hit during school vacation (December), which may have slowed the spread among children. • Was treated with improved medical care and antibiotics for secondary infections from bacteria
2009 – 2010 Pandemic	• Started in the spring of 2009 with the rapid spread of new virus (H1N1 – “swine flu”) across the United States and the world. CDC worked to develop a vaccine, and in April, the United States Government declared a public health emergency. • Affected 74 countries, with 18,000 cases reported in the United States by June. By November, 48 states had reported cases. Patients with the highest risk of complications related to the flu received the vaccine first. • Minimized by the vaccination of 80 million people against the virus • Resulted in 43 to 89 million infections between April 2009 and April 2010 (CDC estimate) and 8,870 to 18,300 H1N1-related deaths

PATHOGENS: FUNGI

Visual 8.3.19



Alt Text for Visual 8.3.19
Fungi

- Are primitive forms of vegetables (mushrooms, mold, and mildew)
- Can live in soil; on plants, trees, and other vegetation; and within our bodies
- May not be dangerous, and many are helpful
- Can act as pathogens or toxins causing mild (thrush) to severe (fungal pneumonia) diseases

Key Points

Description: A fungus is actually a primitive vegetable. Mushrooms, mold, and mildew are examples. Fungi can be found in soil; on plants, trees, and other vegetation; and on our skin, mucous membranes, and intestinal tracts.

Reproduction: Some fungi reproduce through tiny spores in the air. Spores can be inhaled, or they can land on the body. As a result, fungal infections often start in the lungs or on the skin. A fungal infection is more likely in a person with a weakened immune system or who has taken antibiotics.

Useful fungi: Most fungi are not dangerous, and some can even be helpful—for example, penicillin, bread, wine, and beer all use ingredients made from fungi.

Health impacts: Some types of fungi can be harmful to health, and like bacteria and viruses, can act as pathogens or toxins. Only about half of all types of fungi are harmful. Fungal diseases are often caused by fungi that are common in the environment.

- Fungal infections can be mild, such as a rash or a mild respiratory illness. More common fungal infections include athlete's foot or thrush (a yeast infection).
- Other fungal infections can be severe, such as fungal pneumonia or bloodstream infection, and can lead to serious complications such as meningitis or death.

The symptoms of fungal diseases depend on the type of infection and location within the body.

PATHOGENS: FUNGI

Visual 8.3.19 (Continued)

Mycotic (fungal) infections pose an increasing threat to public health for several reasons. Categories of fungal infections being studied include:

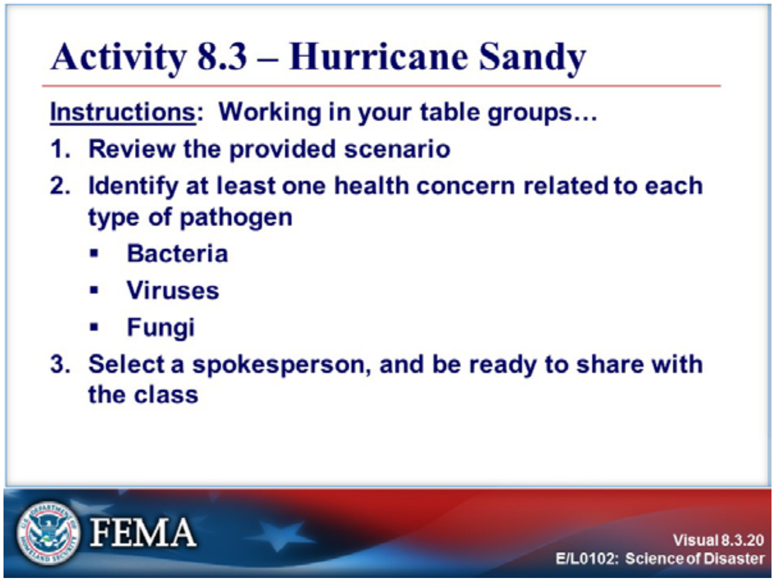
- **Opportunistic infections** such as cryptococcosis and aspergillosis. These infections are becoming increasingly problematic as the number of people with weakened immune systems rises, including cancer patients, transplant recipients, and people with HIV/AIDS.
- **Hospital-associated infections** such as candidemia. These infections are a leading cause of bloodstream infections in the United States.
- **Community-acquired infections** such as coccidioidomycosis (valley fever), blastomycosis, and histoplasmosis. Fungi that cause these infections live in the soil, on plants, or in compost heaps, and are endemic (native and common) throughout much of the United States.

Treatment: Fungi can be difficult to kill. For skin and nail infections, medicine can be applied directly to the infected area. Oral antifungal medicines are also available for serious infections.

(Source: CDC and NIH: National Institute of Allergy and Infectious Diseases)

ACTIVITY 8.3 – HURRICANE SANDY

Visual 8.3.20



Key Points

Instructions: Working in your table groups…

1. Review the provided scenario.
2. Identify at least one health concern related to each type of pathogen
    - Bacteria
    - Viruses
    - Fungi
3. Select a spokesperson, and be ready to share with the class**.**

ACTIVITY 8.3 – HURRICANE SANDY

Visual 8.3.20 (Continued)

Activity 8.3 Worksheet

Scenario: In October 2012, Hurricane Sandy struck the Northeast, causing major flooding, disruption, structural damage, and power outages.

Instructions: Working in your teams, identify at least one health concern related to each type of pathogen:

- **Bacteria:**
- **Viruses:**
- **Fungi:**

BIOTERRORISM

Visual 8.3.21

Key Points

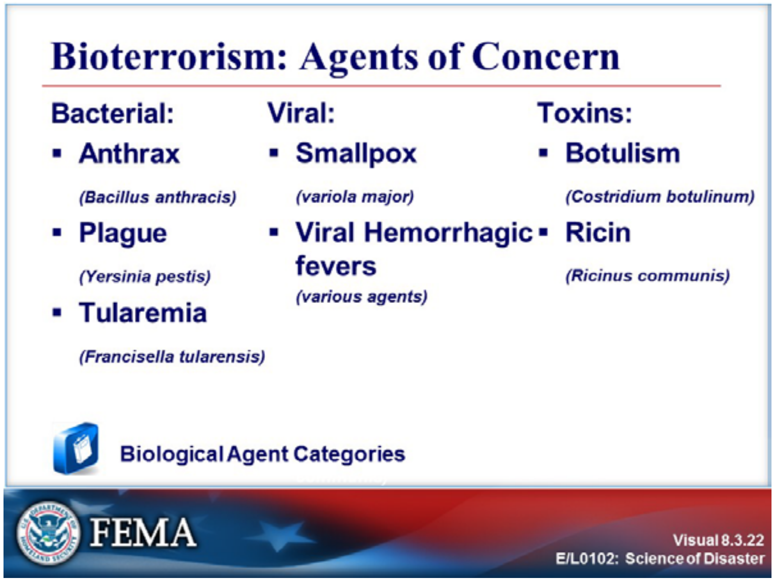
Now that we have reviewed the various types of biological agents, next we will consider how they have been—or could be—used as weapons of terror.

Bioterrorism is the deliberate release of viruses, bacteria, or other germs (agents) used to cause illness or death in people, animals, or plants.

- These agents are typically found in nature, but it is possible that they could be changed to:
  - Increase their ability to cause disease
  - Make them resistant to current medicines
  - Increase their ability to be spread into the environment
- Biological agents can be spread through the air, through water, or in food.
- Terrorists may use biological agents because they can be extremely difficult to detect and do not cause illness for several hours to several days.
- Some bioterrorism agents, like the smallpox virus, can be spread from person to person and some, like anthrax, cannot.

BIOTERRORISM

Visual 8.3.22



Alt Text for Visual 8.3.22
Bioterrorism: Agents of Concern
Bacterial:
- Anthrax *(Bacillus anthracis)*
- Plague *(Yersinia pestis)*
- Tularemia *(Francisella tularensis)*

Viral:
- Smallpox *(variola major)*
- Viral Hemorrhagic fevers *(various agents)*

Toxins:
- Botulism *(Costridium botulinum)*
- Ricin *(Ricinus communis)*

Biological Agent Categories

Key Points

Agents of concern fall into three types: bacterial, viral, and toxins. These are examples of each. We will go into more detail on some of these examples.

Categories: Biological agents fall into one of three categories based on the level of risk (i.e., how easily they can spread, the severity of illness caused, etc.). Category A agents have the highest risk, and Category C agents are emerging threats.

The following job aid summarizes these categories.

BIOTERRORISM

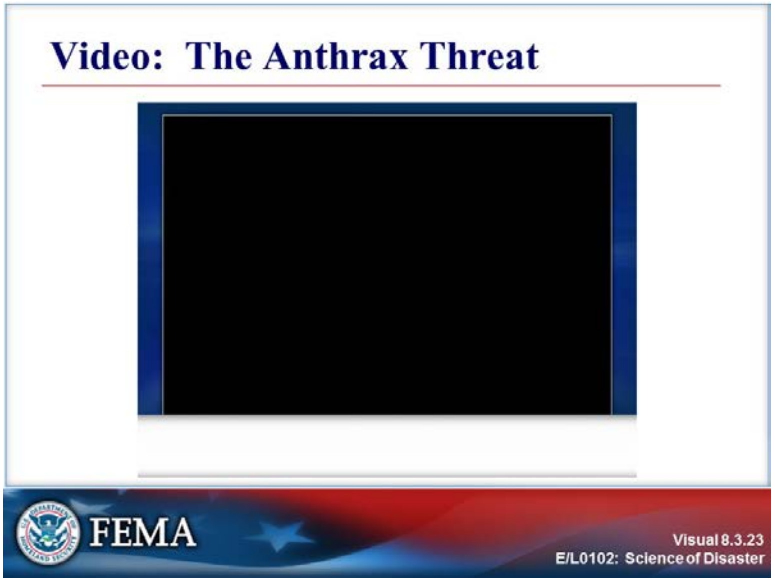
Visual 8.3.22 (Continued)

Biological Agent Categories

Category	CDC Definition	Agents/Diseases
A	The United States public health system and primary healthcare providers must be prepared to address various biological agents, including pathogens that are rarely seen in the United States. High-priority agents include organisms that pose a risk to national security because they: • Can be easily disseminated or transmitted from person to person • Result in high mortality rates and have the potential for major public health impact • Might cause public panic and social disruption • Require special action for public health preparedness	• Anthrax (*Bacillus anthracis*) • Botulism (*Clostridium botulinum* toxin) • Plague (*Yersinia pestis*) • Smallpox (variola major) • Tularemia (*Francisella tularensis*) • Viral hemorrhagic fevers: o Filoviruses (e.g., Ebola, Marburg) o Arenaviruses (e.g., Lassa, Machupo)
B	Second highest priority agents include those that: • Are moderately easy to disseminate • Result in moderate morbidity rates and low mortality rates • Require specific enhancements of CDC's diagnostic capacity and enhanced disease surveillance.	• Brucellosis (*Brucella* species) • Epsilon toxin of *Clostridium perfringens* • Food safety threats (e.g., *Salmonella* species, *Escherichia coli* O157:H7, *Shigella)* • Glanders (*Burkholderia mallei*) • Melioidosis (*Burkholderia pseudomallei*) • Psittacosis (*Chlamydia psittaci*) • Q fever (*Coxiella burnetii*) • Ricin toxin from *Ricinus communis* (castor beans) • Staphylococcal enterotoxin B • Typhus fever (*Rickettsia prowazekii*) • Viral encephalitis (alphaviruses (e.g., Venezuelan equine encephalitis, eastern equine encephalitis, western equine encephalitis)) • Water safety threats (e.g., *Vibrio cholerae*, *Cryptosporidium parvum*)
C	Third-highest priority agents include emerging pathogens that could be engineered for mass dissemination in the future because of: • Availability • Ease of production and dissemination • Potential for high morbidity and mortality rates and major health impact	• Emerging infectious diseases, such as Nipah virus and hantavirus

BIOTERRORISM AGENTS

Visual 8.3.23



Key Points

Introduction: This video provides a brief overview of the history of the threat posed by anthrax.

Video Transcript:

Joanne Cono, MD, ScM, Centers for Disease Control and Prevention: The idea of using disease as a weapon gained a new level of sophistication in the early 1930s as nationally funded research programs on biological warfare were developed. The Japanese had a very active offensive biowarfare research program, which included a battalion known as 731. In their program, the Japanese conducted experiments on humans, using 15 to 20 different disease-causing agents, with anthrax being one of their favorites. Allied prisoners of war and innocent Manchurian civilians in nearby villages provided an almost endless supply of experimental subjects. When word of unit 731 leaked to the West, allied forces began their own programs, concerned that Japan and possibly Germany would gain a military advantage in biowarfare research.

Narrator: On the third day after exposure, the casualties begin. Dead sheep can be seen further down the line. It is, of course, necessary to confirm that they have died of anthrax.

BIOTERRORISM AGENTS

Visual 8.3.23 (Continued)

Ms. Cono: In 1942, on Gruinard Island off the coast of Scotland, the British conducted their first scientifically controlled biowarfare field trials. Scientists exploded anthrax bombs near immobilized sheep to determine if the spores would survive an explosion and retain the ability to infect anyone nearby. Test results showed that anthrax could, in fact, be effectively disbursed by explosive devices and could also remain viable in the soil for decades. This brought home the realization that if an anthrax bomb were dropped on a city like London, the results could have been catastrophic. Gruinard Island was declared off limits until it was decontaminated in the 1980s. It's now safe for both humans and animals.

Like our allies, the United States responded to the perceived threats from Germany and Japan. In 1943, we began an offensive biological program with a modest research and development facility at Camp Detrick, which is now Fort Detrick, Maryland. By the end of the program, we had weaponized a total of seven incapacitating or lethal human agents, including anthrax. In 1969, Richard Nixon renounced the use of biological weapons for the United States.

Richard Nixon: I have decided that the United States of America will renounce the use of any form of deadly biological weapons that either kill or incapacitate.

William C. Patrick III, Biological Warfare Consultant: President Nixon visited Fort Detrick on the 25th of November, 1969. I remember that date quite well because following his announcement of taking munitions and beating them into plowshares, we all lost our jobs and that was a very traumatic experience. But following his presidential announcement on this date, the entire United States offensive program on biological warfare came to a close within 2 years. We destroyed all of our seed stocks; we destroyed all of our production material at Pine Bluff, Arkansas; and we completely got out of the biological warfare business.

Ms. Cono: Even at its peak, the United States' offensive program paled compared to the Soviet Union's. The Soviets had a massive, extensive, sophisticated, top-secret program which employed tens of thousands of scientists and engineers in numerous research and production facilities. The Soviets signed the biological warfare convention in the 1970s and yet their program continued uninterrupted, and, in fact, intensified. Our worst fears were confirmed in 1979 when an accidental release of anthrax occurred at a biological research facility in the town of Sverdlovsk. Much of our recent knowledge about their joint military and civilian program comes from a Soviet defector, Dr. Ken Alibek, formerly known as Dr. Kanatjian Alibekov. He was the deputy director of Biopreparat, a cover organization for their civilian bioweapon and production facilities. Although we had suspected for years that they had continued their offensive program, some of the information he provided was a real wake-up call for the United States.

Prior to the Gulf War, the intelligence community suspected that the Iraqis had done research on anthrax, but they didn't know just how extensive their program was. So as a precautionary measure during the war, about 150,000 United States service members were vaccinated against anthrax. And more would have been immunized if the war hadn't ended so quickly. After the war, the Iraqis admitted to producing and weaponizing anthrax, although the weapons were never used.

BIOTERRORISM AGENTS

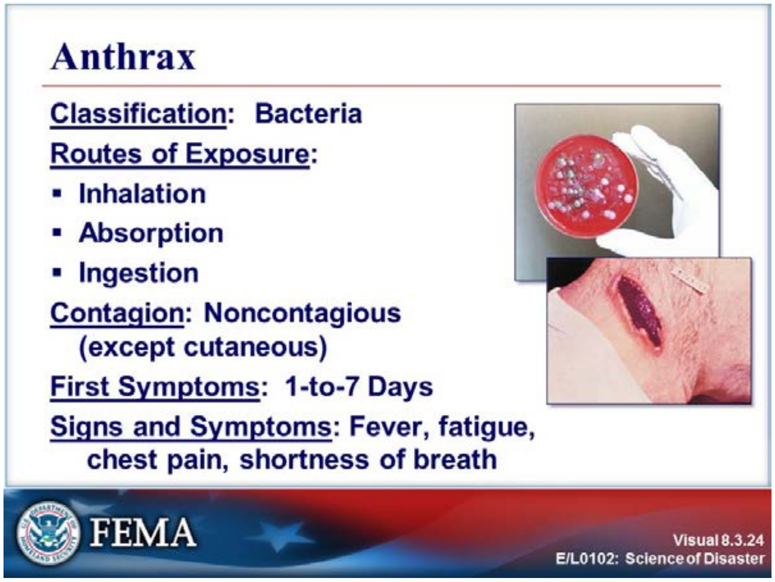
Visual 8.3.23 (Continued)

Ms. Cono: This past decade, anthrax moved from being an agent of concern for biological warfare to the top of the threat list for terrorism. The Aum Shinrikyo cult in Japan, which released the nerve agent sarin from the Tokyo subway in 1995, allegedly made multiple unsuccessful attempts to infect people with anthrax. In October of 2001, the United States experienced anthrax attacks using powder sent through the United States postal service. Twenty-two people got sick and five people died from this attack. We learned just how dangerous anthrax could be.

But there are things we can do. The best defense against a bioterrorism attack is knowledge and preparation. The Web page ready.gov is a good resource for preparedness information. It can be found at www.ready.gov. Visit this Web page for detailed guidelines, facts, and what you can do to be ready in the event of an emergency. A small amount of time spent becoming informed, developing a plan, and preparing yourself against terrorist threats now can prove to be invaluable, should the need arise. Don’t be afraid, be ready.

BIOTERRORISM AGENTS

Visual 8.3.24



Alt Text for Visual 8.3.24
Anthrax
Classification: Bacteria
Routes of Exposure:

- Inhalation
- Absorption
- Ingestion

Contagion: Noncontagious
(except cutaneous)
First Symptoms: 1-to-7 Days
Signs and Symptoms: Fever, fatigue, chest pain, shortness of breath

Key Points

We have seen the history of anthrax as a weapon of terror. What, exactly, is anthrax? Below is a brief summary:

Classification—bacteria: Anthrax is a serious disease caused by *Bacillus anthracis*, a bacterium that forms spores. There are three types of anthrax: cutaneous, inhalation, and gastrointestinal.

Routes of exposure: There are three routes of exposure, correlating with the types of anthrax: Absorption—cutaneous anthrax is absorbed through the skin.

- Inhalation—inhalation anthrax is contracted by breathing it into the lungs (the most hazardous route).
- Ingestion—gastrointestinal anthrax is contracted by eating contaminated food.

BIOTERRORISM AGENTS

Visual 8.3.24 (Continued)

Contagion: Anthrax is not known to spread from one person to another. Humans can become infected with anthrax by handling products from infected animals or by breathing in anthrax spores from infected animal products (e.g., wool). People also can become infected with gastrointestinal anthrax by eating undercooked meat from infected animals.

First symptoms: Symptoms can appear within 7 days of coming in contact with the bacterium for all three types of anthrax. However, for inhalation anthrax, symptoms can appear within a week or can take up to 42 days to appear.

Signs and symptoms: The symptoms (warning signs) of anthrax are different depending on the type of the disease:

- Cutaneous: The first symptom is a small sore that develops into a blister. The blister then develops into a skin ulcer with a black area in the center. The sore, blister, and ulcer do not hurt.
- Gastrointestinal: The first symptoms are nausea, loss of appetite, bloody diarrhea, and fever, followed by bad stomach pain.
- Inhalation: The first symptoms of inhalation anthrax are like cold or flu symptoms and can include a sore throat, mild fever, and muscle aches. Later symptoms include cough, chest discomfort, shortness of breath, tiredness, and muscle aches. Because the symptoms are generic and flu-like, victims may miss the window of opportunity for effective treatment.

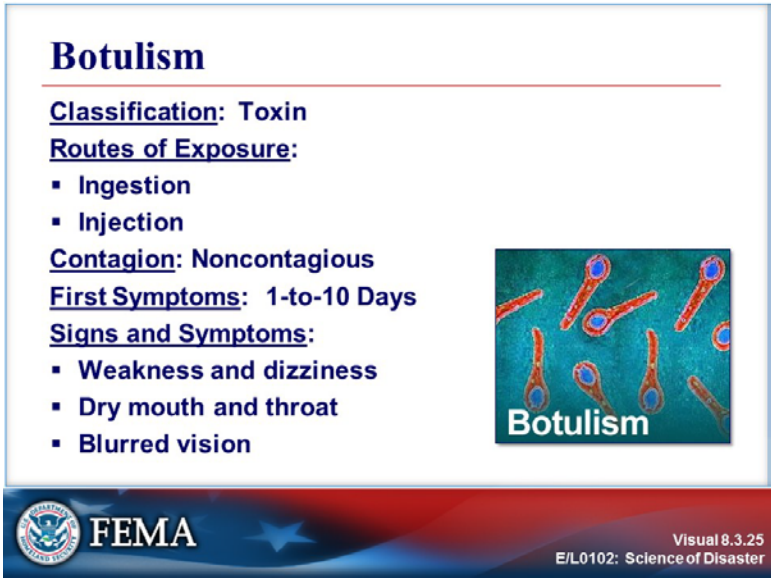
Treatment and prevention: In most cases, early treatment with antibiotics can cure cutaneous anthrax. Even if untreated, 80 percent of people who become infected with cutaneous anthrax do not die. Gastrointestinal anthrax is more serious: between one-fourth and more than half of cases lead to death. Inhalation anthrax is much more severe. In 2001, about half of the cases of inhalation anthrax ended in death.

There is a vaccine to prevent anthrax, but it is not yet available for the general public.

(Source: CDC)

BIOTERRORISM AGENTS

Visual 8.3.25



Alt Text for Visual 8.3.25
Botulism
Classification: Toxin
Routes of Exposure:

- Ingestion
- Injection

Contagion: Noncontagious
First Symptoms: 1-to-10 Days
Signs and Symptoms:

- Weakness and dizziness
- Dry mouth and throat
- Blurred vision

Key Points

Classification—toxin: Botulism is a muscle-paralyzing disease caused by a toxin made by a bacterium called *Clostridium botulinum*. There are five main kinds of botulism.

- **Foodborne botulism** is caused by eating foods that contain the botulinum toxin. Foodborne botulism is a public health emergency because the contaminated food may still be available to other persons besides the patient.
- **Infant botulism** is caused by consuming the spores of the botulinum bacteria, which then grow in the intestines and release toxin.
- **Wound botulism** is caused by toxin produced from a wound infected with *C. botulinum*.
- **Adult intestinal toxemia botulism** is a very rare kind of botulism that occurs among adults by the same route as infant botulism.
- **Iatrogenic botulism** can occur from accidental overdose of botulinum toxin.

BIOTERRORISM AGENTS

Visual 8.3.25 (Continued)

Routes of exposure: The main routes of exposure are ingestion (from food) and injection (through wounds).

Contagion: Botulism is not spread from one person to another. Foodborne botulism can occur in all age groups.

First symptoms: With foodborne botulism, symptoms begin within 6 hours to 10 days (most commonly between 12 and 36 hours) after eating food that contains the toxin.

Signs and symptoms: Symptoms of botulism include:

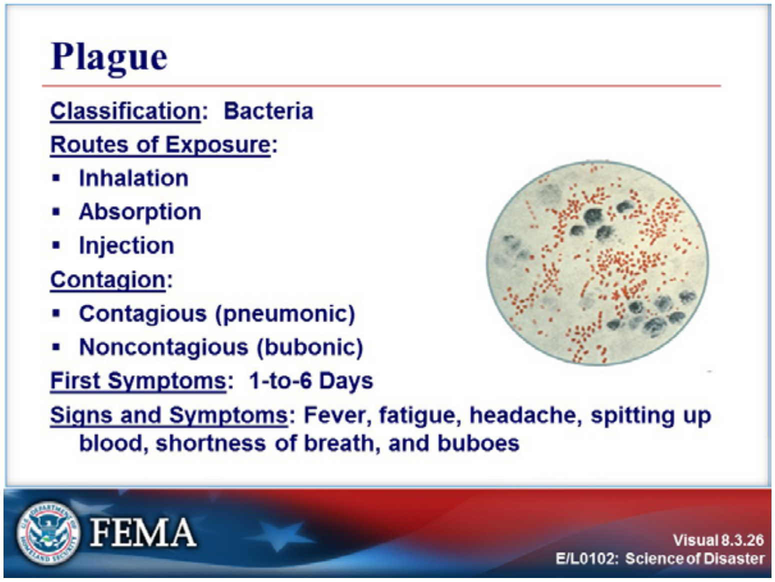
- Double or blurred vision
- Drooping eyelids
- Slurred speech
- Difficulty swallowing
- Dry mouth
- Muscle weakness that moves down the body, usually affecting the shoulders first, then the upper arms, lower arms, thighs, calves, etc. Paralysis of breathing muscles can cause a person to stop breathing and die, unless assistance with breathing (mechanical ventilation) is provided.

Treatment: Antitoxins are used to reduce the severity of symptoms. Most patients eventually recover after weeks to months of supportive care.

(Source: CDC)

BIOTERRORISM AGENTS

Visual 8.3.26



Alt Text for Visual 8.3.26
Plague
Classification: Bacteria
Routes of Exposure:
- Inhalation
- Absorption
- Injection

Contagion:
- Contagious (pneumonic)
- Noncontagious (bubonic)

First Symptoms: 1-to-6 Days
Signs and Symptoms: Fever, fatigue, headache, spitting up blood, shortness of breath, and buboes

Key Points

Classification—bacteria: Plague is a disease caused by *Yersinia pestis* (*Y. pestis*), a bacterium found in rodents and their fleas in many areas around the world. Two types of plague are pneumonic plague and bubonic plague.

Routes of exposure:

- Pneumonic plague: Exposure occurs through inhalation. This could happen in an aerosol release during a bioterrorism attack or by breathing in respiratory droplets from a person (or animal) with pneumonic plague, usually from coughing or sneezing within 6 feet.
- Bubonic plague: Exposure occurs through absorption or injection—through the bite of an infected flea or exposure to infected material through a break in the skin.

Contagion: Pneumonic plague can be transmitted from person to person; bubonic plague cannot.

First symptoms: A person usually becomes ill with bubonic plague 2 to 6 days after being infected. Someone exposed to *Yersinia pestis* through the air would become ill within 1 to 3 days.

BIOTERRORISM AGENTS

Visual 8.3.26 (Continued)

Signs and symptoms:

- Pneumonic plague: Patients usually have fever, weakness, and rapidly developing pneumonia with shortness of breath, chest pain, cough, sometimes bloody or watery sputum, and buboes (swollen lymph glands). Nausea, vomiting, and abdominal pain may also occur. Without early treatment, pneumonic plague usually leads to respiratory failure, shock, and rapid death.
- Bubonic plague: Symptoms include swollen, tender lymph glands called buboes. If bubonic plague is not treated, however, the bacteria can spread through the bloodstream and infect the lungs, causing a secondary case of pneumonic plague.

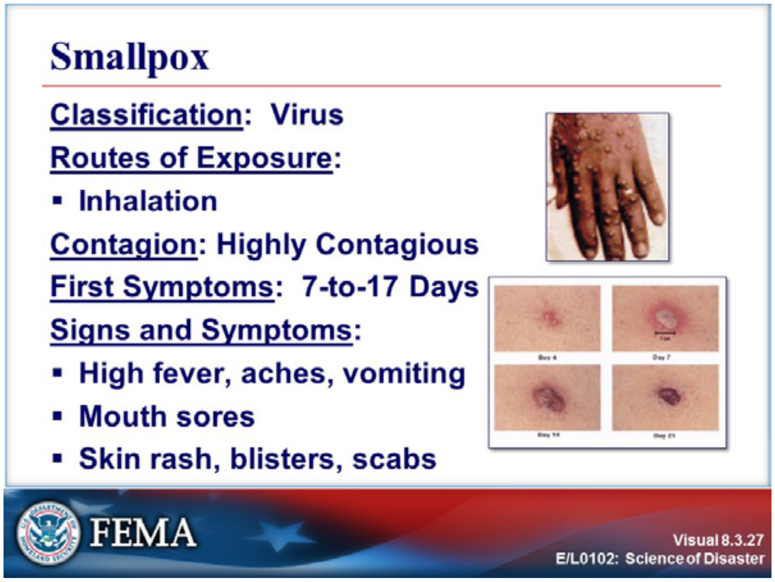
Treatment: People who have had close contact with an infected person can greatly reduce the chance of becoming sick if they begin treatment within 7 days of their exposure. Treatment consists of taking antibiotics for at least 7 days. Currently, no plague vaccine is available in the United States.

Bioterrorism concern: *Yersinia pestis* used in an aerosol attack could cause cases of the pneumonic form of plague. Because of the delay between being exposed to the bacteria and becoming sick, people could travel over a large area before becoming contagious and possibly infecting others. Controlling the disease would then be more difficult.

(Source: CDC)

BIOTERRORISM AGENTS

Visual 8.3.27



Alt Text for Visual 8.3.27
Smallpox
Classification: Virus
Routes of Exposure:

- Inhalation

Contagion: Highly Contagious
First Symptoms: 7-to-17 Days
Signs and Symptoms:

- High fever, aches, vomiting
- Mouth sores
- Skin rash, blisters, scabs

Key Points

Classification—virus: Smallpox is a serious and sometimes fatal infectious disease caused by the variola virus. The *pox* part of *smallpox* is derived from the Latin word for “spotted” and refers to the raised bumps that appear on the face and body of an infected person. There are two clinical forms of smallpox: variola major and variola minor. Variola major—the severe and most common form of smallpox—includes four types:

- Ordinary (the most frequent type, accounting for 90 percent or more of cases)
- Modified (mild and occurring in previously vaccinated persons)
- Flat
- Hemorrhagic (both rare and very severe)

Historically, variola major has an overall fatality rate of about 30 percent; however, flat and hemorrhagic smallpox usually are fatal. Variola minor is a less common and much less severe disease, with death rates historically of 1 percent or less.

BIOTERRORISM AGENTS

Visual 8.3.27 (Continued)

Routes of exposure: Smallpox is transmitted by inhalation.

- Generally, direct and fairly prolonged face-to-face contact is required to spread smallpox from one person to another.
- Smallpox also can be spread through direct contact with infected bodily fluids or contaminated objects such as bedding or clothing.
- Rarely, smallpox has been spread by virus carried in the air in enclosed settings such as buildings, buses, and trains.
- Humans are the only natural hosts of variola. Smallpox is not known to be transmitted by insects or animals.

Contagion: Smallpox is highly contagious. A person with smallpox is sometimes contagious with onset of fever but becomes most contagious with the onset of rash. At this stage the infected person is usually very sick and not able to move around in the community. The infected person is contagious until the last smallpox scab falls off.

First symptoms: The incubation period is 7 to 17 days (average 12 to 14 days), during which the person is not contagious.

Signs and symptoms: The signs and symptoms of smallpox come in phases.

- The first symptoms of smallpox include fever, malaise, head and body aches, and sometimes vomiting. The fever is usually high (2 to 4 days' duration).
- This stage is followed by a rash sequence (about 21 days, during which the person is quite contagious) that includes emergence of mouth sores, skin rash, formation of blisters, crusting, scabbing, and scabs falling off leaving scars.

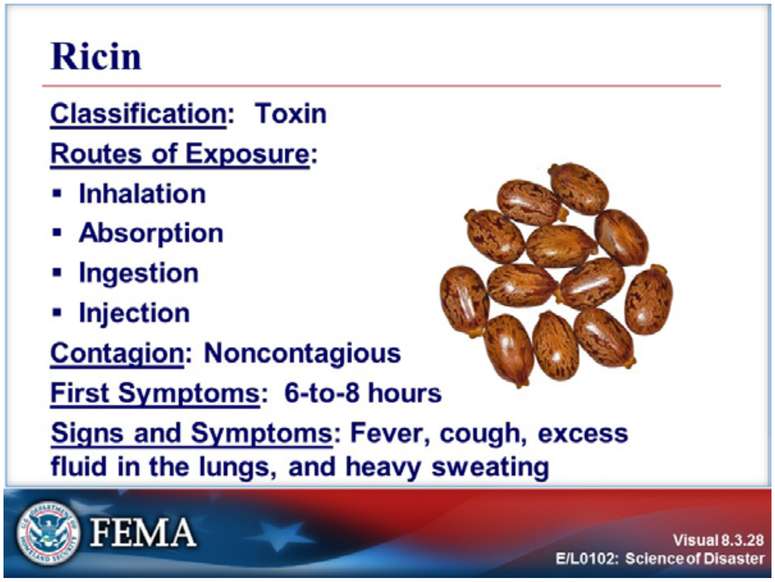
Treatment: There is no specific treatment for smallpox disease, and the only prevention is vaccination.

Bioterrorism concern: Except for laboratory stockpiles, the variola virus has been eliminated. The last case of smallpox in the United States was in 1949. The last naturally occurring case in the world was in Somalia in 1977. However, the deliberate release of smallpox as an epidemic disease is a remote possibility.

(Source: CDC)

BIOTERRORISM AGENTS

Visual 8.3.28



Alt Text for Visual 8.3.28
Ricin
Classification: Toxin
Routes of Exposure:

- Inhalation
- Absorption
- Ingestion
- Injection

Contagion: Noncontagious
First Symptoms: 6-to-8 hours
Signs and Symptoms: Fever, cough, excess fluid in the lungs, and heavy sweating

Key Points

Classification—toxin: Ricin is a poison that can be made from the waste left over from processing castor beans. Depending on the route of exposure, as little as 500 micrograms of ricin could be enough to kill an adult. A 500-microgram dose of ricin would be about the size of the head of a pin. A greater amount would likely be needed to kill people if the ricin were swallowed.

Routes of exposure: Ricin poisoning can occur through:

- Inhalation
- Absorption
- Ingestion
- Injection

Contagion: Ricin poisoning is not contagious. It cannot be spread from person to person through casual contact.

BIOTERRORISM AGENTS

Visual 8.3.28 (Continued)

First symptoms: Initial symptoms of ricin poisoning by inhalation (breathing in the ricin) may occur within 8 hours of exposure. Following ingestion (swallowing) of ricin, initial symptoms typically occur in less than 6 hours.

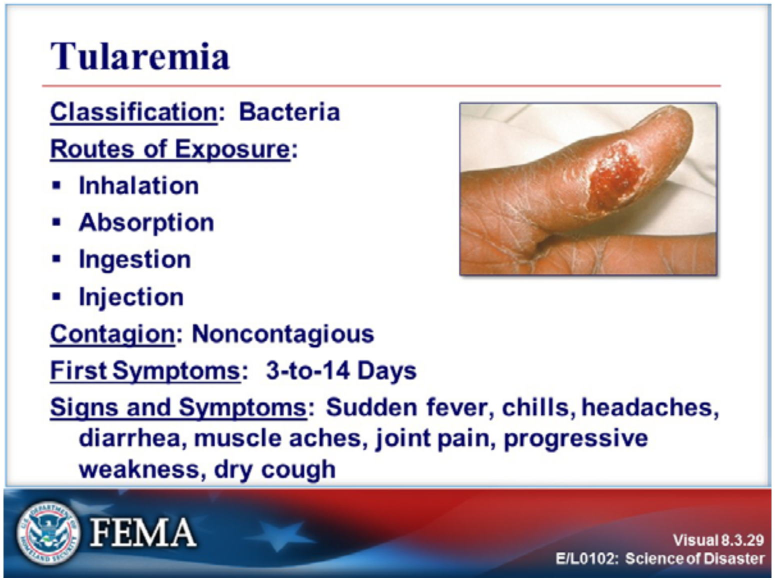
Signs and symptoms: The major symptoms of ricin poisoning depend on the route of exposure and the dose received, though many organs may be affected in severe cases.

- Inhalation: Within a few hours of inhaling significant amounts of ricin, the likely symptoms would be:
  - Respiratory distress (fluid buildup in the lungs, difficulty breathing)
  - Fever, heavy sweating
  - Cough
  - Nausea
  - Tightness in the chest
  - Low blood pressure and respiratory failure, leading to death
- Ingestion: A person who swallowed a significant amount of ricin would develop vomiting and diarrhea that may become bloody, resulting in severe dehydration and low blood pressure. Other signs or symptoms may include hallucinations, seizures, and blood in the urine. Within several days, the person’s liver, spleen, and kidneys might stop working, and the person could die.
- Absorption: Ricin in powder or mist form can cause redness and pain of the skin and the eyes.

Death from ricin poisoning could take place within 36 to 72 hours of exposure, depending on the route of exposure and the dose received. If death has not occurred in 3 to 5 days, the victim usually recovers.

BIOTERRORISM AGENTS

Visual 8.3.29



Alt Text for Visual 8.3.29
Tularemia
Classification: Bacteria
Routes of Exposure:

- Inhalation
- Absorption
- Ingestion
- Injection

Contagion: Noncontagious
First Symptoms: 3-to-14 Days
Signs and Symptoms: Sudden fever, chills, headaches, diarrhea, muscle aches, joint pain, progressive weakness, dry cough

Key Points

Classification—bacteria: Tularemia is a potentially serious illness that occurs naturally in the United States. It is caused by the bacterium *Francisella tularensis* found in animals (especially rodents, rabbits, and hares).

Routes of exposure: People can get tularemia many different ways:

- Inhalation: Breathing in contaminated dusts or aerosols
- Absorption—skin or eye: Handling infected animal carcasses
- Ingestion: Eating or drinking contaminated food or water
- Injection: Being bitten by an infected tick, deerfly, or other insect

First symptoms: Symptoms usually appear 3 to 5 days after exposure to the bacteria, but can take as long as 14 days.

Contagion: Although the bacterium that causes tularemia is highly infectious, tularemia is not known to be spread from person to person. People who have tularemia do not need to be isolated.

BIOTERRORISM AGENTS

Visual 8.3.29 (Continued)

Signs and symptoms: Symptoms of tularemia vary with the route of exposure and can include:

- Sudden fever, chills, and headaches
- Diarrhea
- Muscle aches, joint pain.
- Dry cough
- Progressive weakness

People can also catch pneumonia and develop chest pain, bloody sputum, and difficulty in breathing.

Other symptoms of tularemia depend on how a person was exposed to the tularemia bacteria. These symptoms can include ulcers on the skin or mouth, swollen and painful lymph glands, swollen and painful eyes, and a sore throat.

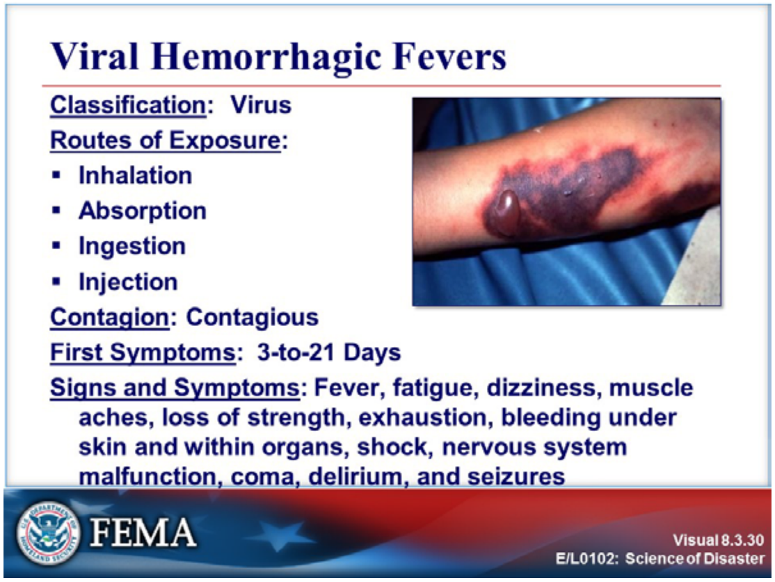
Treatment: Tularemia is treated with antibiotics. People who have been exposed to the tularemia bacteria should be treated as soon as possible. The disease can be fatal if it is not treated with the right antibiotics.

Bioterrorism concern: The bacteria that cause tularemia occur widely in nature and could be isolated and grown in quantity in a laboratory, although manufacturing an effective aerosol weapon would require considerable sophistication. Because *Francisella tularensis* is very infectious, a small number (10–50 or so organisms) can cause disease. If *F. tularensis* were used as a weapon, the bacteria would likely be made airborne for exposure by inhalation.

(Source: CDC)

BIOTERRORISM AGENTS

Visual 8.3.30



Alt Text for Visual 8.3.30
Viral Hemorrhagic Fevers
Classification: Virus
Routes of Exposure:

- Inhalation
- Absorption
- Ingestion
- Injection

Contagion: Contagious
First Symptoms: 3-to-21 Days
Signs and Symptoms: Fever, fatigue, dizziness, muscle aches, loss of strength, exhaustion, bleeding under skin and within organs, shock, nervous system malfunction, coma, delirium, and seizures

Key Points

Classification—virus: Viral hemorrhagic fevers (VHFs) refer to a group of illnesses that are caused by several distinct families of viruses. In general, the term “viral hemorrhagic fever” is used to describe a severe multisystem syndrome (multisystem in that multiple organ systems in the body are affected). Examples of VHFs include:

- Ebola
- Marburg
- Hantavirus
- Lassa fever
- Crimean-Congo hemorrhagic fever
- Tick-borne encephalitis

Viruses associated with most VHFs are zoonotic, meaning they naturally reside in an animal host or arthropod (e.g., flea, tick, or mosquito) vector and can cross over to humans.

BIOTERRORISM AGENTS

Visual 8.3.30 (Continued)

Routes of exposure: Routes of exposure for VHFs include:

- Inhalation—breathing air contaminated with the virus (e.g., when rodent urine, droppings, or nesting materials are stirred up)
- Absorption—e.g., through contact with infected rodent urine, feces, saliva, or other body excretions, or through close contact with infected people or their body fluids
- Ingestion—eating food contaminated by urine, droppings, or saliva from an infected host
- Injection—from mosquito or tick bites, or from contaminated syringes and needles

Vectors may also spread the virus to animals (e.g., livestock). Humans then become infected when they care for or slaughter the animals.

Contagion: Some viruses that cause hemorrhagic fever, such as Ebola, Marburg, Lassa, and Crimean-Congo hemorrhagic fever, can spread from one person to another once an initial person has become infected.

First symptoms: Onset of symptoms varies with the disease. For example, the incubation period for Ebola is 3 to 21 days; for Marburg, 5 to 10 days; for hantavirus, symptoms may appear in 1 to 5 weeks.

Signs and symptoms: Specific signs and symptoms vary by the type of VHF, but initial signs and symptoms often include:

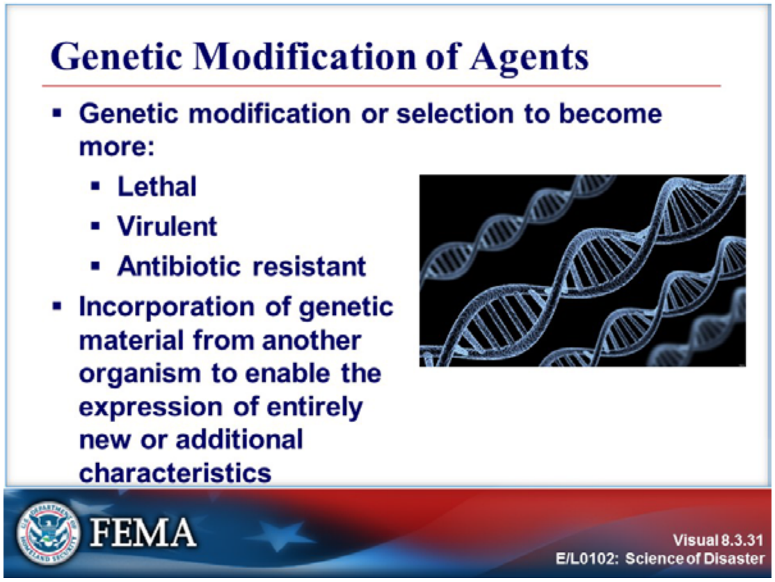
- Marked fever
- Fatigue
- Dizziness
- Muscle aches
- Loss of strength
- Exhaustion

Patients with severe cases of VHF often show signs of bleeding under the skin, in internal organs, or from body orifices, such as the mouth, eyes, or ears. However, patients rarely die because of blood loss. Severely ill patients may also show shock, nervous system malfunction, coma, delirium, seizures, and kidney failure. Lassa fever can cause deafness.

(Source: CDC)

BIOTERRORISM METHODS AND TARGETS

Visual 8.3.31



Alt Text for Visual 8.3.31
Genetic Modification of Agents

- Genetic modification or selection to become more:
  - Lethal
  - Virulent
  - Antibiotic resistant
- Incorporation of genetic material from another organism to enable the expression of entirely new or additional characteristics

Key Points

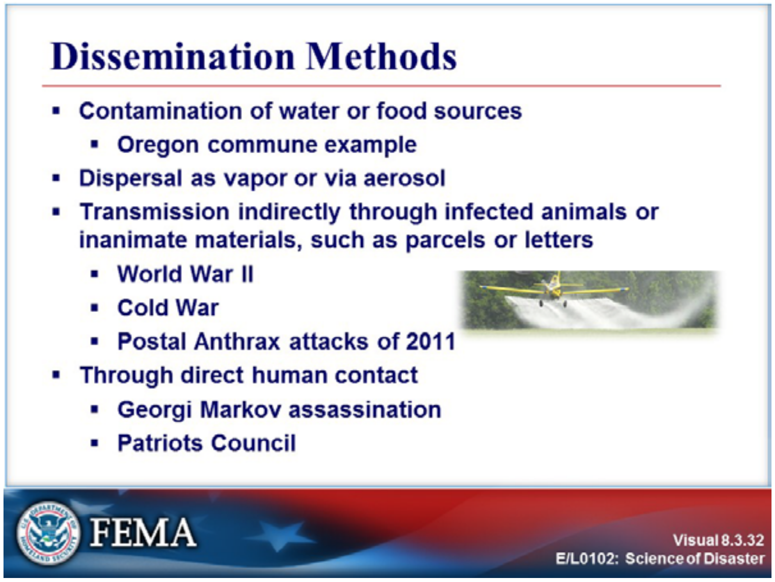
Biological agents can be altered genetically to make them more effective weapons. A terrorist's goals for genetic modification of organisms may include:

- Making them more lethal or virulent
- Making diagnosis difficult by altering the clinical signs or symptoms
- Making the pathogen resistant to vaccine protection or treatment

Genetically modified organisms are also of concern because genetically modified crops released into agricultural systems could invade natural ecosystems due to their hardiness and rapid reproductive rates.

BIOTERRORISM METHODS AND TARGETS

Visual 8.3.32



Alt Text for Visual 8.3.32
Dissemination Methods

- Contamination of water or food sources
  - Oregon commune example
- Dispersal as vapor or via aerosol
- Transmission indirectly through infected animals or inanimate materials, such as parcels or letters
  - World War II
  - Cold War
  - Postal Anthrax attacks of 2011
- Through direct human contact
  - Georgi Markov assassination
  - Patriots Council

Key Points

Specialists agree that for mass destruction purposes, effective delivery of a biological agent is more problematic than its production. Means of dissemination may include the following:

- **Contamination of water supply:** It is virtually impossible to poison a large water supply. Most lethal biological agents become less viable when transmitted in water and would be further debilitated by the purification system.
- **Contamination of food sources:** Foods are vulnerable to contamination. Unintentional food-borne diseases cause about 5,000 deaths and 325,000 hospitalizations each year, according to CDC.

BIOTERRORISM METHODS AND TARGETS

Visual 8.3.32 (Continued)

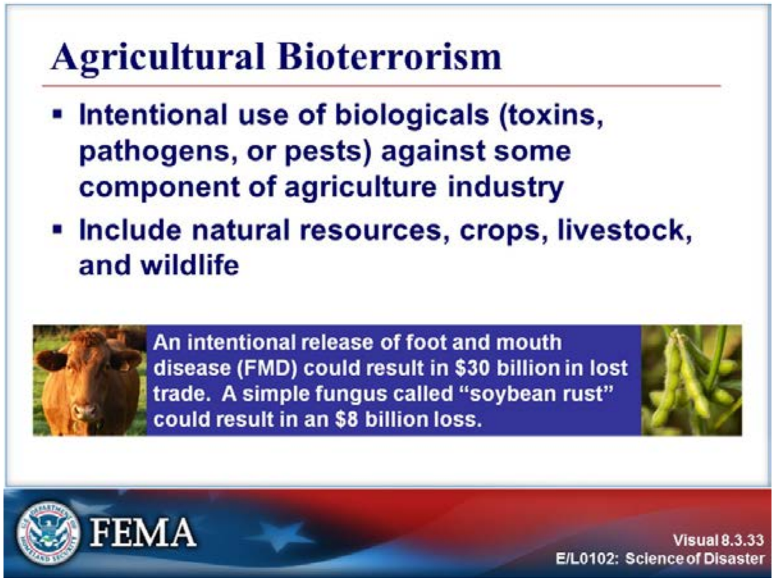
In 1984, members of an Oregon religious commune—followers of Bhagwan Shree Rajneesh—tried to influence a local election by poisoning salad bars with *Salmonella* bacteria to sicken voters. Although no one died, 751 people became ill. The Oregon attack took place at local restaurants, but an attack could occur at any point between farm and table. Imported food could be tainted with biological or chemical agents before entering the United States, or toxins could be introduced at a domestic food-processing plant.

- **Aerosolization:** The aerosol dissemination of a biological agent is difficult. To work, the agent in suspension would need to be small (< 5µm) particles or droplets in the air, and the agent must survive long **enough** to infect the intended target. Factors such as mechanical stresses in the aerosolization process, moisture, sunlight, temperature changes, and others may reduce the amount or strength of the agent. The most successful aerosolization transmission occurs naturally through coughing, sneezing, talking, or breathing. It is more feasible to spread a chemical agent in a vapor or aerosol.
- **Infected animals and insects:** The release of infected rats, insects, etc., could spread certain diseases to a target location. The animals and insects act as a vector, infecting any person or animal they might bite. During World War II, the Japanese experimented with plague-infected fleas and cholera-coated flies. During the Cold War, the United States conducted research on the use of yellow fever-infected mosquitoes.
- **Inanimate materials:** Some pathogens and toxins are able to survive on inanimate objects. For example, the smallpox virus lives longer in scabs than in the droplets spread from person to person. According to Dr. Inger Damon, a researcher and epidemiologist at CDC, viruses stored in a smallpox scab in a humidity-controlled environment can survive for a year or longer. The postal anthrax attacks of 2001—the worst biological attacks in United States history—are another example of inanimate objects being used to transmit a biological threat.

Human contact: Ricin was used in the assassination of Bulgarian dissenter, Georgi Markov, who died several days after being jabbed by a poison-tipped umbrella injector designed by the Soviet intelligence agency, KGB. In Minnesota, four members of the Patriots Council planned to mix the ricin with the solvent dimethyl sulfoxide and then smear it on the door handles of a United States. Marshal’s vehicle. The plan was discovered and averted, and the men were convicted.

BIOTERRORISM METHODS AND TARGETS

Visual 8.3.33



Alt Text for Visual 8.3.33
Agricultural Bioterrorism

- Intentional use of biologicals (toxins, pathogens, or pests) against some component of agriculture industry
- Include natural resources, crops, livestock, and wildlife

An intentional release of foot and mouth disease (FMD) could result in $30 billion in lost trade. A simple fungus called "soybean rust" could result in an $8 billion loss.

Key Points

The United States Department of Agriculture defines **agricultural bioterrorism** as "the intentional use of biologicals (toxins, pathogens, or pests) against some component of agriculture in such a way as to adversely impact the agriculture industry or any component thereof, the economy, or the consuming public."

- An act of agricultural terrorism causing billions of dollars in damage could be produced by a limited infection of pathogens delivered by simple methods.
- There are fewer controls monitoring the possession of microorganisms that infect only plants or livestock, compared to those that infect humans.
- Terrorist attacks on agriculture are difficult to distinguish from naturally occurring outbreaks.

History: The United States has not experienced a major agricultural disaster in recent memory. However, history is full of examples of intentional introductions of pests and diseases.

- During World War I, Germany used anthrax and glanders to target horses, mules, cattle, sheep, and reindeer in the United States, Romania, Spain, France, Norway, and Argentina.
- By World War II, Japan, Russia, Great Britain, France, and the United States had active biological weapons programs. The weapons program by the United States began in response to the threat posed by other countries.

BIOTERRORISM METHODS AND TARGETS

Visual 8.3.33 (Continued)

- In more recent times, Rhodesian and South African forces used anthrax to target cattle. In addition to thousands of cattle dying, there were more than 10,000 human cases with 334 known deaths.
- In 1997, New Zealand farmers, dissatisfied with the Government's lack of action in controlling the exploding rabbit population, developed simple methods for extracting and concentrating particles of viral hemorrhagic fever which they used to contaminate carrots and other food sources for rabbits. The plan experienced limited effectiveness. **Potential impact:** The impact of an intentional introduction of foot and mouth disease (FMD) would be staggering. The sheer numbers of livestock and wildlife at risk are enormous: 100 million cattle, 70 million swine, 10 million sheep, and 40 million wildlife.

The consequences of a major attack on the livestock industry would be felt almost immediately by consumers. No major city has more than a 7-day supply of food. Such an attack could easily cause widespread fear and panic and undermine public confidence in government. The economic costs could potentially be devastating, resulting in a loss of billions in trade, and costs for diagnostics, surveillance, slaughter, cleaning, disinfection, and indemnities.

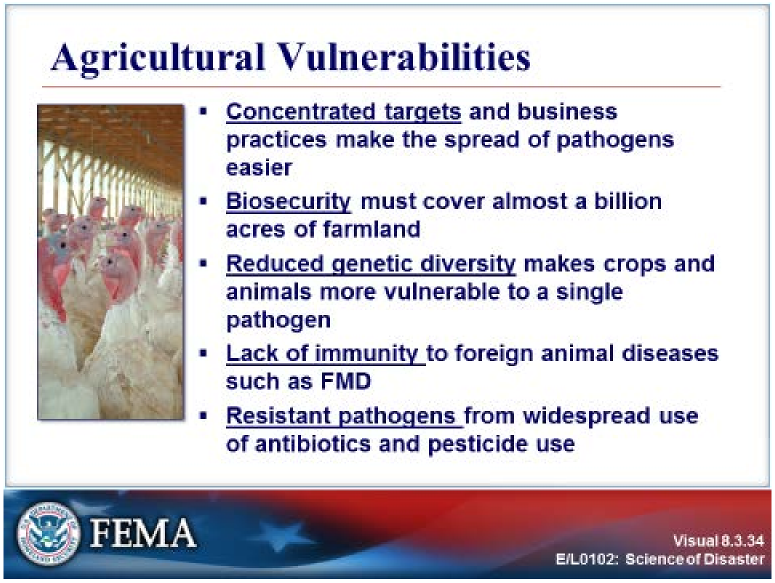
An attack on crops would have a similar impact. Plant targets include:

- Food crops:
  - Corn
  - Wheat
  - Soybeans
  - Citrus
  - Sugarcane
- Fiber:
  - Cotton
- Timber:
  - Northwest United States

The threat posed by soybean rust (one of the select agents) alone is estimated at $8 billion if it enters the mainland United States. Soybean rust causes huge production losses in Asia and South America. It is present in Hawaii and Puerto Rico.

BIOTERRORISM METHODS AND TARGETS

Visual 8.3.34



Alt Text for Visual 8.3.34
Agricultural Vulnerabilities

- Concentrated targets and business practices make the spread of pathogens easier
- Biosecurity must cover almost a billion acres of farmland
- Reduced genetic diversity makes crops and animals more vulnerable to a single pathogen
- Lack of immunity to foreign animal diseases such as FMD
- Resistant pathogens from widespread use of antibiotics and pesticide use

Key Points

The following factors make U.S. agriculture vulnerable to bioterrorism:

- **Concentrated targets.** Livestock and crops are found in concentrated areas throughout the United States.
- **Business practices.** Large agribusiness companies control production, processing, and distribution, making the spread of pathogens easier.
- **Security challenges.** Farm biosecurity measures must cover a large area (compare 6,000 miles of national borders with almost a billion acres of farmland).
- **Reduced genetic diversity.** As crops and animals become more similar in their genetic makeup, they become more vulnerable to a single pathogen.
- **Lack of immunity.** The absence of foreign animal diseases means that our livestock have no natural immunity to many diseases.
- **Resistant pathogens.** Widespread use of antibiotics can make livestock susceptible to resistant strains of pathogens. Pesticide use may create resistant strains of exotic plant pests.

BIOTERRORISM EXPERTS

Visual 8.3.35

Key Points

A variety of experts are working to better understand biological threats and develop strategies for controlling them. The following are some of them:

- **Industrial hygienists** use environmental monitoring and analytical methods to anticipate, recognize, evaluate, and control workplace conditions that may cause worker injury or illness.
- **Toxicologists** plan and carry out laboratory and field studies to identify, monitor, and evaluate the impact of toxic materials and radiation on human and animal health, the environment, and the impact of future technology. In general, toxicologists:
  - Conduct laboratory studies on substances (e.g., drugs, food additives, solvents, herbicides) or on energy (e.g., radiation) to determine their effects on laboratory animals, plants, and human tissue
  - Conduct research to develop new tests for use in toxicological studies
  - Evaluate potential risks based on levels and periods of exposure
  - Analyze and evaluate data gathered from studies and reliable scientific publications to determine appropriate controls for various chemical and physical hazards
  - Develop standards or guidelines for safe levels of chemical and physical agents in workplaces, air, food, or drinking water
  - Provide advice and scientific information to policy and program developers concerning the health and legal aspects of chemical use

BIOTERRORISM EXPERTS

Visual 8.3.35 (Continued)

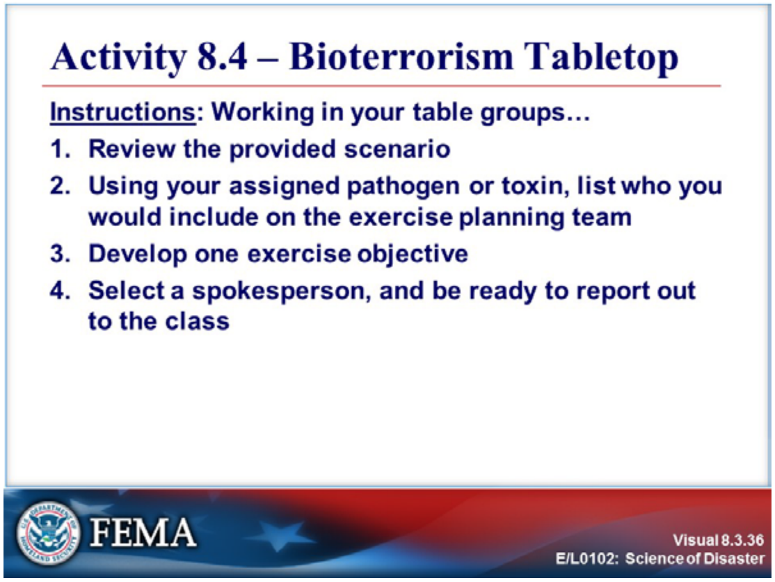
- **Epidemiologists** investigate and describe the determinants and distribution of disease, disability, or health outcomes. Epidemiologists may:
  - Develop or refine methods of measuring and evaluating disease occurrences
  - Develop and recommend public health policy
  - Study chronic diseases, infectious diseases, disease outbreaks, injuries, occupations, and environments
  - Develop the means for prevention and control
- **Public Health Officers** protect and improve the health of families and communities through promotion of healthy lifestyles, research for disease and injury prevention, and detection and control of infectious diseases. Overall, public health is concerned with protecting the health of entire populations using such methods as implementing educational programs, recommending policies, administering services, and conducting research. Public health officials also work to limit health disparities by promoting healthcare equity, quality, and accessibility.

  Local public health officers may:

  - Make periodic sanitary inspections of school buildings, restaurants, dairies, grocery stores, meat markets, and public gathering places.
  - Disseminate information on the causes, nature, and prevention of prevalent diseases and the preservation and improvement of health.
  - Enforce the health laws, rules, and regulations of the State Board of Health, the state, and the city, including the laws relating to contagious disease.
  - Take steps to secure prompt and full reports by physicians of communicable diseases and prompt and full registration of births and death.

ACTIVITY 8.4 – BIOTERRORISM TABLETOP

Visual 8.3.36



Key Points

Instructions: Working in your table groups…

1. Review the provided scenario.
2. Using your assigned pathogen or toxin, list who you would include on the exercise planning team.
3. Develop one exercise objective.
4. Select a spokesperson, and be ready to report out to the class.

ACTIVITY 8.4 – BIOTERRORISM TABLETOP

Visual 8.3.36 (Continued)

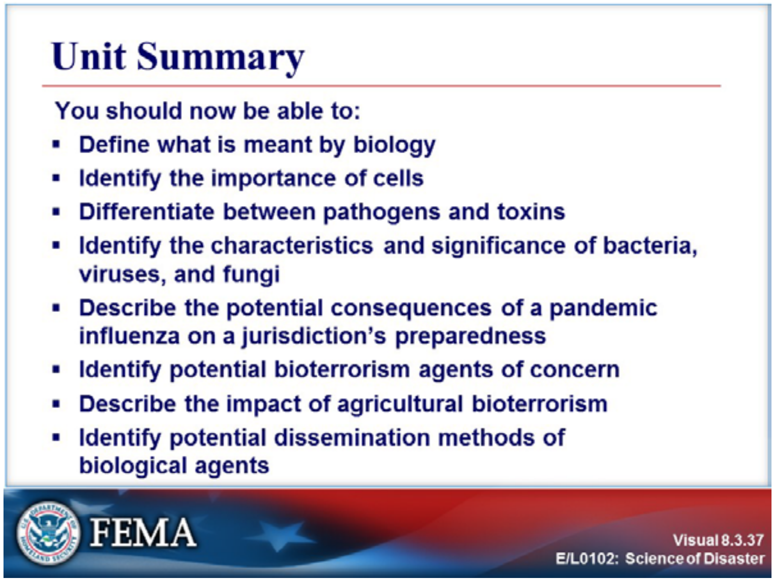
Activity 8.4 Worksheet

Scenario: You are working on developing a tabletop exercise that involves the intentional release of a pathogen or toxin. You want to involve the whole community including the private sector.

1. Pathogen or toxin:
2. Who would you include on the exercise planning team?
3. Develop one exercise objective:

UNIT SUMMARY

Visual 8.3.37



Alt Text for Visual 8.3.37
Unit Summary
You should now be able to:

- Define what is meant by biology
- Identify the importance of cells
- Differentiate between pathogens and toxins
- Identify the characteristics and significance of bacteria, viruses, and fungi
- Describe the potential consequences of a pandemic influenza on a jurisdiction's preparedness
- Identify potential bioterrorism agents of concern
- Describe the impact of agricultural bioterrorism
- Identify potential dissemination methods of biological agents

Key Points

UNIT 4. EXPLOSIVES

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INTRODUCTION

Visual 8.4.1

Key Points

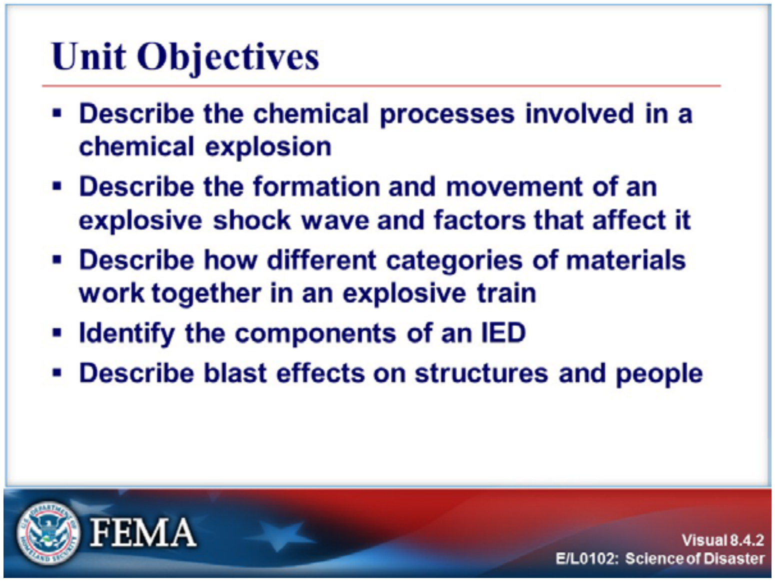
This unit will cover the explosive process, explosive materials (including the use of explosive materials for terrorist purposes), and blast effects.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Explosive Process and Materials: Process	15 minutes
Explosive Process and Materials: Materials	15 minutes
Improvised Explosive Devices	10 minutes
Blast Effects	10 minutes
Activity 8.5 – Prevention & Mitigation of Explosives	30 minutes
Unit Summary	5 minutes
Activity 8.6 – Module 8 IAW	10 minutes
Total Time	**1 hour 40 minutes**

INTRODUCTION

Visual 8.4.2



Alt Text for Visual 8.4.2
Unit Objectives

- Describe the chemical processes involved in a chemical explosion
- Describe the formation and movement of an explosive shock wave and factors that affect it
- Describe how different categories of materials work together in an explosive train
- Identify the components of an IED
- Describe blast effects on structures and people

Key Points

Review the unit objectives as shown on the visual.

INTRODUCTION

Visual 8.4.3

Video description: The video is a simulation of what occurs during an explosion and the impact it has on the structure, interior of the building, and personal in the building.

Key Points

This short video demonstrates the force of an explosion.

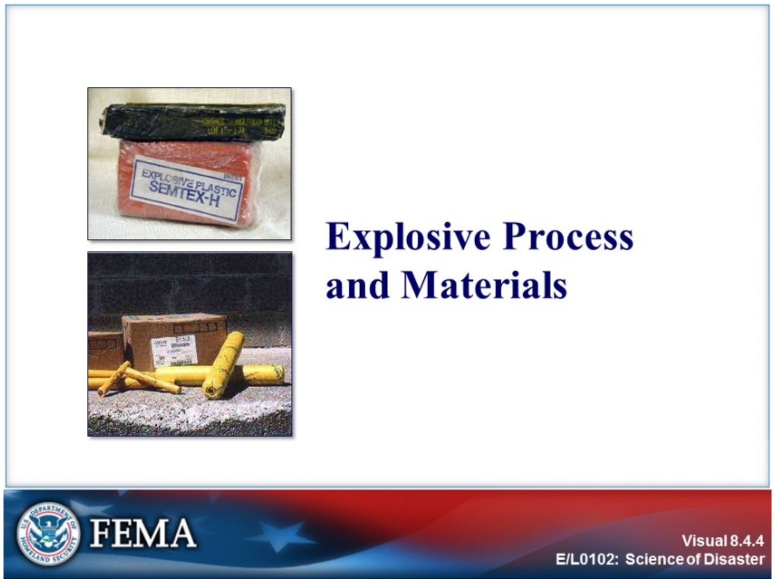
Discussion Questions:

- **What do you see happening?**

- **What do you think the effects would be on the people? On the building structure?**

EXPLOSIVE PROCESS AND MATERIALS

Visual 8.4.4

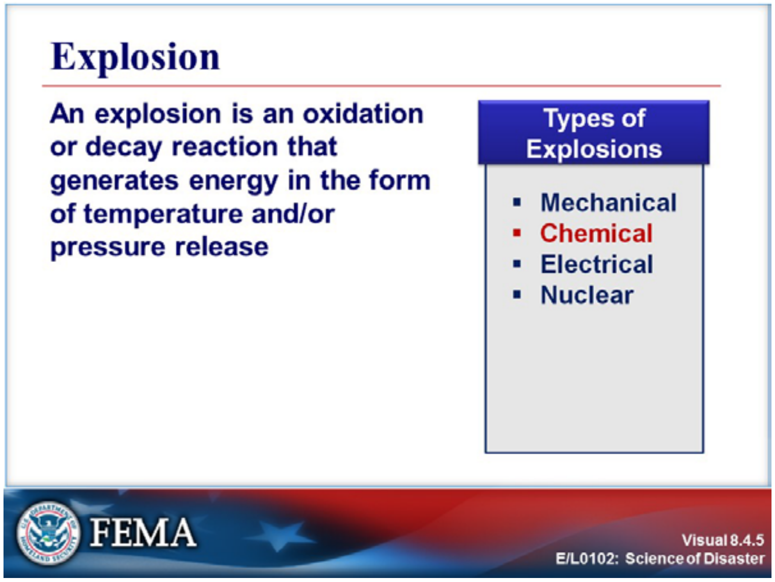


Key Points

We will begin with an overview of the explosive process, followed by the characteristics and classifications of explosive materials.

EXPLOSIVE PROCESS

Visual 8.4.5



Key Points

An explosion is an oxidation or decay reaction generating an increase in temperature (**exothermic change**) or pressure (**positive entropy change**), or both simultaneously.

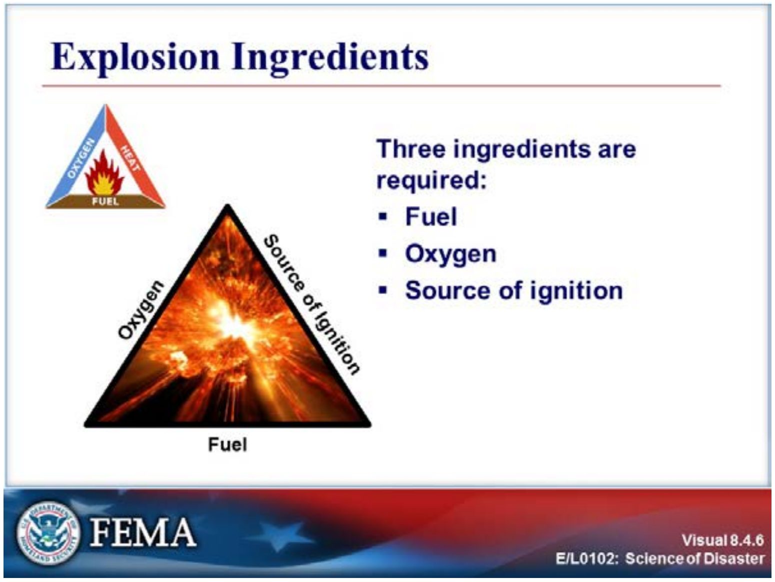
Put more simply, an explosion is a sudden escape of gases from a confined space accompanied by high temperatures, a violent shock, and a loud noise.

There are four types of explosion:

- **Mechanical:** Caused by gas expanding inside a closed space until it exceeds the strength of the container (typically accidental). There is no chemical reaction. The explosion may be followed by fire. An exploding oxygen cylinder is an example.
- **Chemical:** Caused by uncontrolled chemical reaction between two or more materials that releases energy
- **Electrical:** Caused by weakening of air resistance around a high-voltage source, allowing electricity to escape and travel to a nearby conductor or ground
- **Nuclear:** Caused by splitting of nuclei of atoms by fission, or joining of nuclei of atoms by fusion. (This is discussed in a later unit.)

EXPLOSIVE PROCESS

Visual 8.4.6



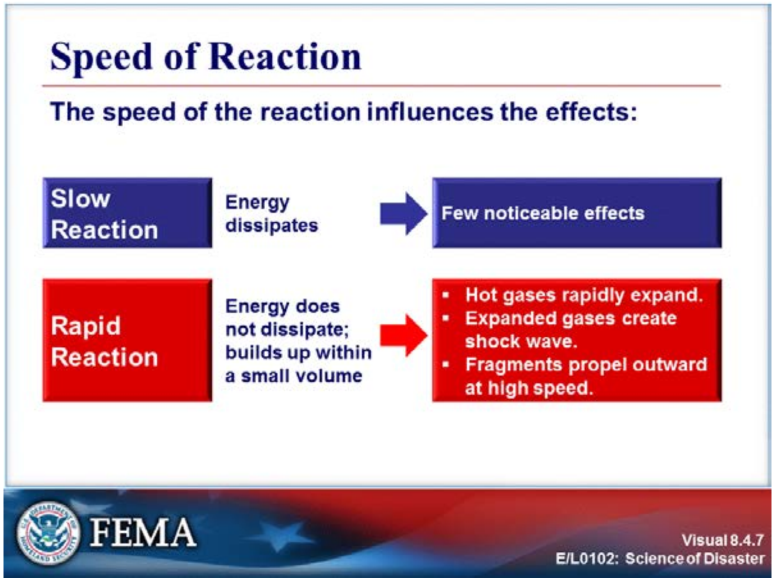
Key Points

For fire to occur, three ingredients are needed—fuel, oxygen, and heat. The same is true for an explosion, but that third ingredient is somewhat broader: **a source of ignition.** (As you will see, explosions can be triggered by shock, friction, or heat.)

If any ingredient is missing, an explosion cannot occur.

EXPLOSIVE PROCESS

Visual 8.4.7



Alt Text for Visual 8.4.7
Speed of Reaction
The speed of the reaction influences the effects:
Diagram illustrating speed of reaction.
Slow reaction energy dissipates and there are few noticeable effects.
Rapid reaction energy does not dissipate; builds up within a small volume. Hot gases expand, creating shock waves, and fragments propel

Key Points

There are many chemical reactions that will release energy through exothermic (heat-producing) reactions. The speed of the reaction influences the effects:

- **Slow reaction:** If the reaction proceeds slowly, the released energy will be dissipated and there will be few noticeable effects other than an increase in temperature.
- **Rapid reaction:** If the reaction proceeds very rapidly, then the energy won't dissipate and will build up.

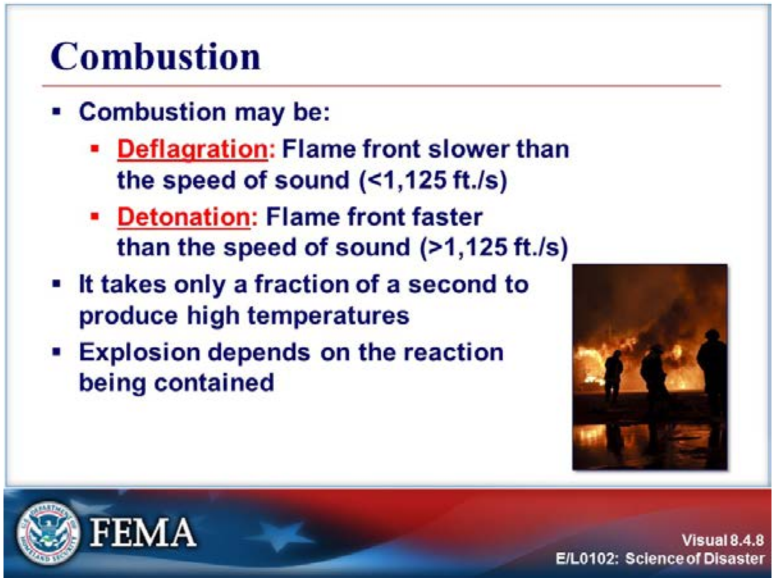
  When a great quantity of energy builds up in a small volume, it causes hot gases to expand rapidly. This creates a violent reaction—a very sharp (short duration, high pressure) shock wave and fragments blown outwards at high speed. If an explosion is restrained initially, it can build up a large pressure and achieve the same effect.

  This rapidity of reaction is called the **brisance**, or shattering potential of the explosion, and is one way that explosive materials are classified.

  Chemical explosions may be distinguished from other exothermic reactions by the extreme rapidity of their reactions.

EXPLOSIVE PROCESS

Visual 8.4.8



Alt Text for Visual 8.4.8
Combustion

- Combustion may be:
  - Deflagration: Flame front slower than the speed of sound (<1,125 ft./s)
  - Detonation: Flame front faster
    than the speed of sound (>1,125 ft./s)
- It takes only a fraction of a second to produce high temperatures
- Explosion depends on the reaction being contained

Key Points

In a chemical explosion, combustion may be of two types, depending on the speed of the reaction—deflagration or detonation.

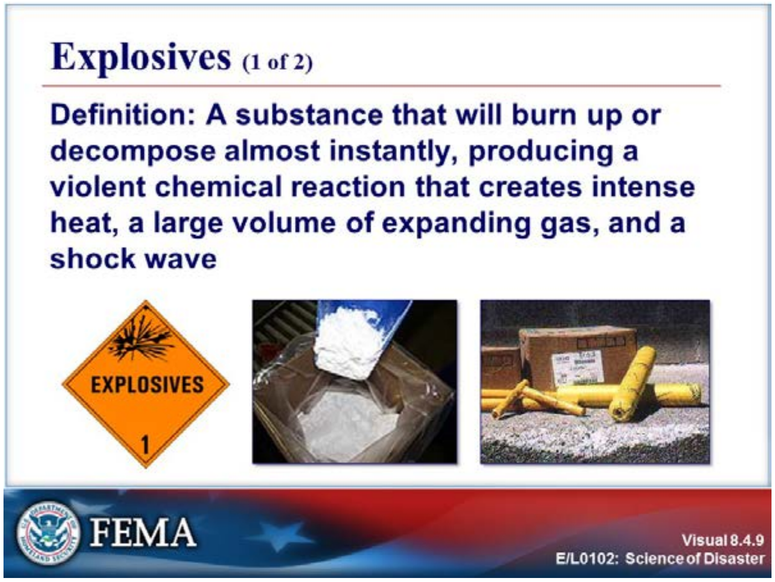
- **Deflagration** is a term describing subsonic combustion that usually propagates through thermal conductivity (heat transfer across materials, where hot burning material heats the next layer of cold material and ignites it). With deflagration, the flame front moves more slowly than the speed of sound, which is 1,125 feet per second.
- **Detonation** involves a supersonic (faster than the speed of sound) exothermic front accelerating through a medium that eventually drives a shock front directly in front of it. Detonations occur with both conventional solid and liquid explosives, as well as reactive gases.

Explosion depends on the reaction being contained so the pressure can build up.

The sound from an explosion is caused by air waves set in motion by the blast.

EXPLOSIVE MATERIALS

Visual 8.4.9

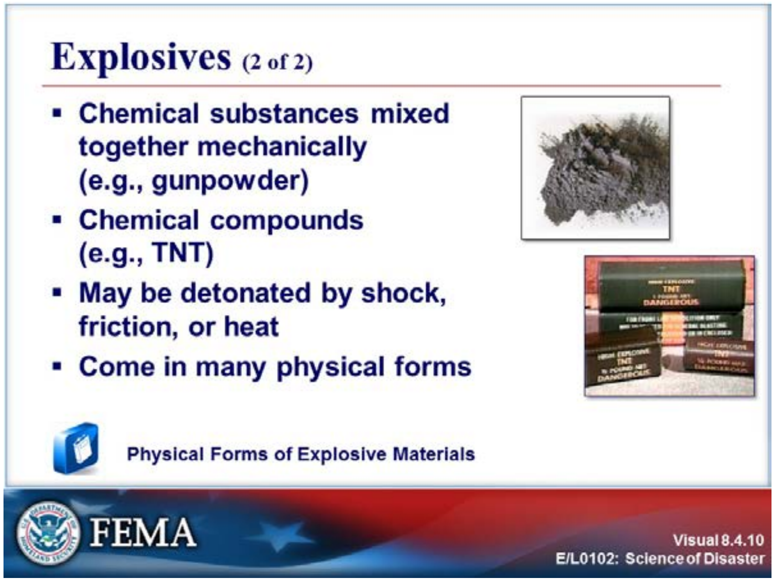


Key Points

An explosive is anything that, once ignited, burns extremely rapidly and produces a violent chemical reaction that creates intense heat, a large volume of expanding gas, and a shock wave.

EXPLOSIVE MATERIALS

Visual 8.4.10



Key Points

In the context of chemical hazards, we spoke of the differences between chemical mixtures and chemical compounds. The same holds true for explosives. Explosives may be:

- **Chemical mixtures** (composed of distinct substances that are mechanically conglomerated in varying proportions), such as black powder.
- **Chemical compounds** (homogeneous substances whose molecules contain within themselves the oxygen, carbon, and hydrogen necessary for combustion).

Explosives may be detonated by shock (hitting, shaking), friction (rubbing surfaces together to produce a spark), or heat.

Explosive materials come in many physical forms. Many are known by their commercial names. Examples are described in the following table.

EXPLOSIVE MATERIALS

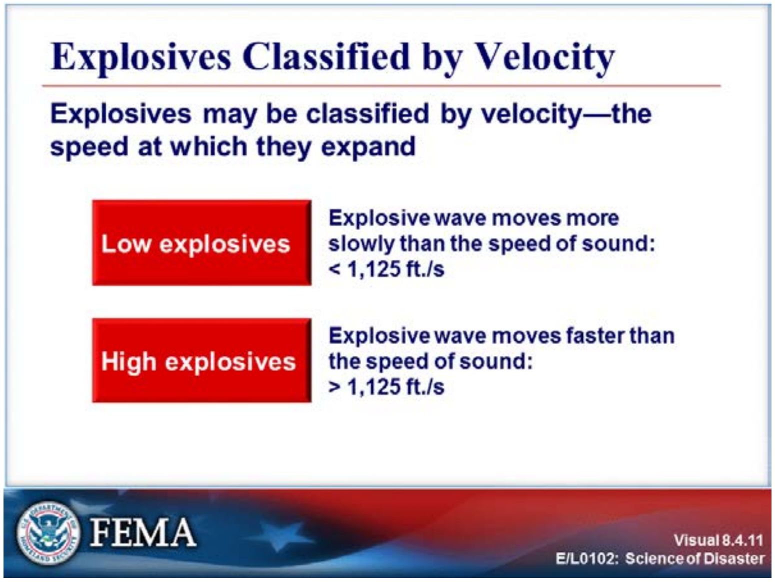
Visual 8.4.10 (Continued)

Physical Forms of Explosive Materials

Form	Description
Binary Explosives	Two-part mixtures based on ammonium nitrate plus a volatile fuel that are shipped separately and combined onsite into a slurry or a liquid containing solids. Unlike ANFO, they can be detonated by blasting caps. Examples include Kinestik and Marine Pac.
Blasting Agents	Explosive materials or mixtures that are not detonatable by standard #8 blasting caps. They may be prepackaged, like ANFO, or made onsite from fertilizer grade ammonium nitrate and fuel oil. Other examples include Carbomite and Dynatex.
Castable Explosives	Contain at least one component (typically TNT) that can be melted at a temperature at which it is safe to handle the other components. Produced by casting or pouring the molten mixture or material into a form or use container.
Dynamites	An absorbent mixture soaked in nitroglycerin and compressed into cylinders and wrapped in paper. Dynamites, which have a limited shelf life, are used in mining, quarrying, construction, and demolition.
Extrudable Explosives	Viscous liquids similar to caulk. They can be extruded out a nozzle into thin cracks, holes, or along surfaces. Some will remain viscous; others can be hardened using a heat curing process. Examples include Demex-400 and LX-13.
Polymer Bonded Explosives (PBX)	A relatively solid and inflexible explosive form containing a powdered explosive material and a polymer (plastic) binder. Often a very thin coating of the polymer is placed onto the powder grains of the explosive material and then hot pressed to form dense solid blocks of PBX material. Most are based on RDX, HMX, or TATB explosives. There are many different kinds, most used in nuclear weapons.
Putties (Plastic Explosives)	Thick, flexible, moldable, clay-like solid material that can be shaped and will retain that shape after forming. Putties normally contain mostly RDX explosive, but may include some PETN. Examples include C-4, Semtex, and PE-4.
Rubberized Explosives	Flat sheets of solid but flexible material made from a mixture of a powdered explosive such as RDX or PETN and a synthetic or natural rubber compound. Rubberized explosives can be cut to shape, bent around objects, affixed in place, or simply laid on relatively flat surfaces. They are commonly used for explosive welding and for other industrial and military applications. Examples include Primasheet and Detasheet.
Slurries and Gels	Fuel-sensitized explosive mixtures containing an aqueous ammonium nitrate solution that acts as the oxidizer and a thickener. They may be pourable or solid. An example is Tovex.

EXPLOSIVE MATERIALS

Visual 8.4.11



Alt Text for Visual 8.4.11
Explosives Classified by Velocity
Explosives may be classified by velocity—the speed at which they expand
Low Explosives: Explosive wave moves more slowly than the speed of sound: less than 1,125 ft./s
High Explosives: Explosive wave moves faster than the speed of sound: more than 1,125 ft./s

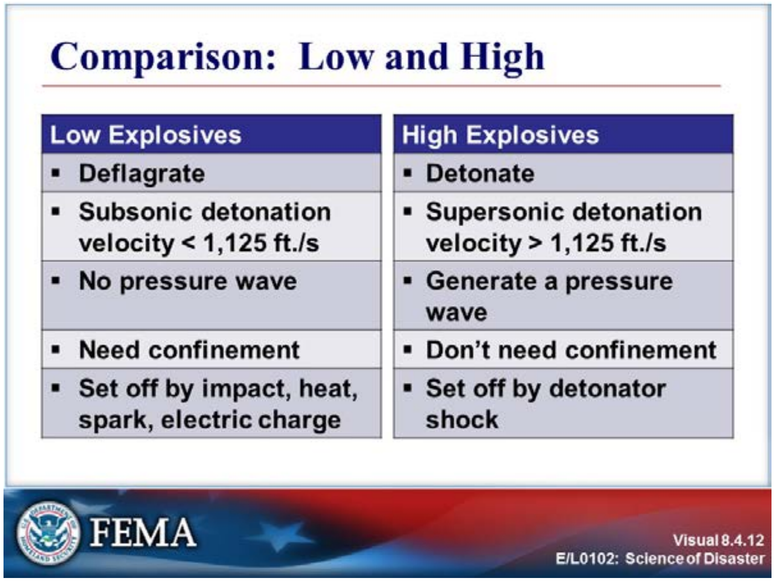
Key Points

Explosives may be classified by velocity, or the speed at which they expand. There are two classifications: low and high.

- **Low explosives** are those that deflagrate. The explosive wave moves more slowly than the speed of sound—that is, less than 1,125 feet per second or 343 meters per second. Low explosives release a large amount of energy but, due to the relatively slow rate of reaction, the energy is more useful as a propellant where the expansion of the gases is used to move projectiles.
- **High explosives** are those that detonate. The explosive wave moves faster than the speed of sound—at over 1,125 ft./s (343 m/s). These materials react very violently (are brisant) and are used solely for their destructive power.

EXPLOSIVE MATERIALS

Visual 8.4.12



Alt Text for Visual 8.4.12
Comparison: Low and High

Low Explosives
Deflagrate
Subsonic detonation velocity < 1,125 ft./s
No pressure wave
Need confinement
Set off by impact, heat, spark, electric charge

High Explosives
Detonate
Supersonic detonation velocity > 1,125 ft./s
Generate a pressure wave
Don't need confinement
Set off by detonator shock

Key Points

EXPLOSIVE MATERIALS

Visual 8.4.12 (Continued)

Let’s compare the characteristics of low and high explosives.

- **Low explosives** deflagrate—That is, they have a subsonic detonation velocity (less than 3,300 f/s). Low explosives do not create a pressure wave. The combustion propagates through the explosive material by hot burning material heating next layer of cold material and igniting it. Low explosives need confinement in order to build up the pressure to explode. They are easily set off by impact, heat, spark, or electric charge. When set off, low explosives have a greater pushing or shoving effect.
- **High explosives** detonate—That is, they have a supersonic detonation velocity (greater than 3,300 f/s). Because they have an extremely fast burn rate, they do not need confinement to build up the pressure to explode. Rather, they generate a shock wave that compresses the material, thus increasing the temperature to the point of ignition. High explosives are more difficult to set off, requiring a detonator to provide sufficient shock. When set off, they have a ripping and tearing effect.

EXPLOSIVE MATERIALS

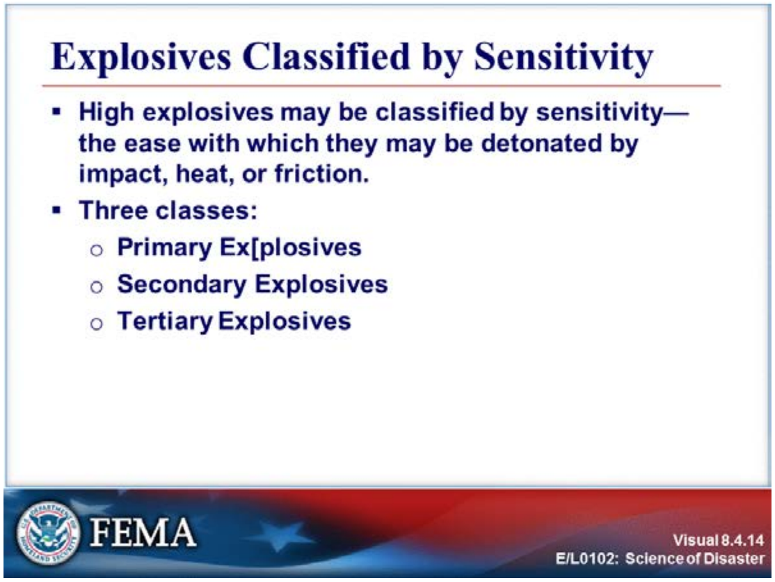
Visual 8.4.13

Key Points

Low explosives are usually a mixture of a combustible substance and an oxidant. Examples of low explosives include gun powders, fireworks, and flares.

EXPLOSIVE MATERIALS

Visual 8.4.14

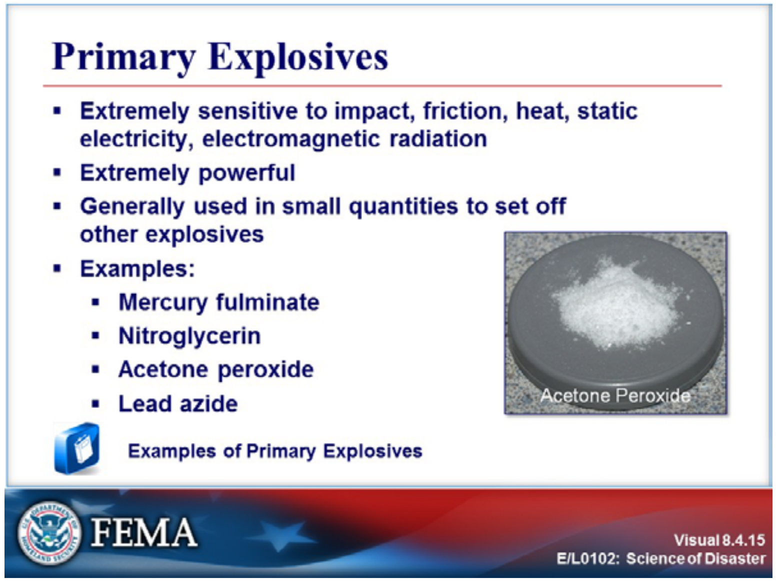


Key Points

High explosives may be classified by sensitivity or the ease with which they can be detonated. There are three classes: primary, secondary, and tertiary.

EXPLOSIVE MATERIALS

Visual 8.4.15



Alt Text for Visual 8.4.15
Primary Explosives

- Extremely sensitive to impact, friction, heat, static electricity, electromagnetic radiation
- Extremely powerful
- Generally used in small quantities to set off
  other explosives
- Examples:
  - Mercury fulminate
  - Nitroglycerin
  - Acetone peroxide
  - Lead azide

Book reference: Examples of Primary Explosives

Key Points

Primary explosives are extremely sensitive to stimuli such as impact, friction, heat, static electricity, and electromagnetic radiation. A small amount of energy, such as the blow of a hammer, will usually set them off. Some are so sensitive that they can't be handled without detonating them.

Because of their sensitivity, primary explosives are often used in small quantities as detonators to set off less sensitive explosives. They are commonly used in blasting caps and percussion caps.

There are many primary high explosives. Examples of a few common ones are listed in the following table.

EXPLOSIVE MATERIALS

Visual 8.4.15 (Continued)

Examples of Primary Explosives

Explosive	Description
Acetone Peroxide (TATP)	• Triacetone triperoxide (TATP); peroxyacetone (TCAP) • White crystalline powder with a distinctive bleach-like odor • Improvised primary explosive that is relatively easy to synthesize • Made of a mixture of hydrogen peroxide and acetone with the addition of an acid, such as sulfuric, nitric, or hydrochloric acid • Very unstable and sensitive to heat, shock, and friction • Not easily soluble in water. It is more stable and less sensitive when wet
DDNP	• Diazodinitrophenol (DDNP) • Yellowish brown powder • Soluble in acetic acid, acetone, strong hydrochloric acid, and most solvents. Insoluble in water. May be desensitized by immersing it in water • Less sensitive to impact and friction but more powerful than mercury fulminate • Used with other materials to form priming mixtures, particularly where a high sensitivity to flame or heat is desired.
HMTD	• Hexamethlene Triperoxide Diamine (HMTD) • Improvised primary explosive prepared from hexamine, a weak acid, and hydrogen peroxide • Highly sensitive to friction, impact, and electrostatic discharge • Corrosive in contact with metals • Can degrade quickly if improperly synthesized or stored
Lead Azide	• Crystalline, cream-colored compound • High temperature of ignition. Sensitive to both flame and impact, but less so than mercury fulminate • Practically insoluble in water • Must not be exposed to copper, zinc, or metal alloys because of the possible formation of other, more sensitive azides. • Used in detonating fuses and in priming mixtures
Lead Styphnate	• Orange or brown crystals • Easily ignited by heat and static discharge but cannot be used to initiate secondary high explosives reliably • May be mixed with other materials and then pressed into a metallic container (detonators and primers) • Stored under water (or if there is danger of freezing, under a mixture of water and alcohol) • Used as an igniting charge for lead azide and as an ingredient in priming mixtures for small arms ammunition

EXPLOSIVE MATERIALS

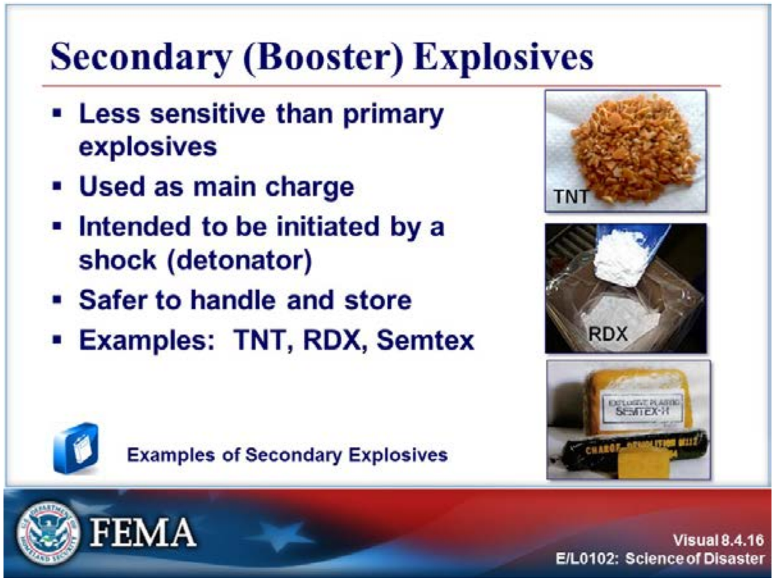
Visual 8.4.15 (Continued)

Examples of Primary Explosives (Continued)

Explosive	Description
Mercury Fulminate	• White or gray crystal. • Extremely sensitive to initiation by heat, friction, spark or flame, and impact • Stored under water (or if there is danger of freezing, under a mixture of water and alcohol) • Gradually becomes inert when stored continuously above 100 °F • Can be pressed into containers, usually at 3,000 psi, for use in detonators and blasting caps. When "dead pressed" (compressed at greater and greater pressure (up to 30,000 psi)), it can only be exploded by another initial detonating agent.
Nitroglycerin	• Heavy, colorless, oily, explosive liquid. It is most commonly produced by treating glycerol with nitric acid under conditions appropriate to the formation of the nitric acid ester. • In undiluted form, it is one of the world's more powerful explosives. Detonates at 30 times the speed of sound • Sensitive to physical shock, heat, and flame (so sensitive that a slight jolt, friction, or impact may cause it to detonate) • Degrades over time to even more unstable forms • Used as an active ingredient in the manufacture of explosives (mostly dynamite) used in the construction, demolition, and mining industries Also used as a propellant in firearm.

EXPLOSIVE MATERIALS

Visual 8.4.16



Alt Text for Visual 8.4.16
Secondary (Booster) Explosives
- Less sensitive than primary explosives
- Used as main charge
- Intended to be initiated by a shock (detonator)
- Safer to handle and store
- Examples: TNT, RDX, Semtex

Book reference: Examples of Secondary Explosives

Key Points

Secondary explosives are less sensitive than primary explosives. As such, they are safer to handle and store. These explosives are used as the main charge and require a detonator to set them off.

Examples of secondary explosives are listed in the following table.

EXPLOSIVE MATERIALS

Visual 8.4.16 (Continued)

Examples of Secondary Explosives

Explosive	Description
TNT	• Trinitrotoluene (TNT) • Light yellow, brown, or light gray. • A constituent of many explosives, such as amatol, pentolite, tetrytol, torpex, tritonal, picratol, ednatol, and composition B. It has been used under such names as Triton, Trotyl, Trilite, Trinol, and Tritolo • Relatively insensitive to blows or friction. In a refined form, it is one of the most stable of high explosives and can be stored over long periods of time. • Non-water soluble; neither absorbs nor dissolves in wate. • Does not form sensitive compounds with metals, but it is readily acted upon by alkalies to form unstable compounds that are very sensitive to heat and impact. • May exude a flammable oily brown liquid • Can be used as a booster or as a bursting charge for high-explosive shells and bombs
RDX	• The name RDX stands for Research Department Explosive, also known as cyclonite, hexogen, and T4. • Obtained by reacting white fuming nitric acid (WFNA) with hexamine • Its pure, synthesized state is a white, crystalline solid. • One of the most powerful and brisant of the military high explosives. When exploded in air it has about 1.5 times the explosive power of TNT per unit weight. • Often used in mixtures with other explosives, plasticizers, or desensitizers • Very stable stored at room temperature. It burns rather than explodes and detonates only with a detonator. • Widely used in military and industrial applications. • Also used by terrorists—e.g., 1993 Bombay bombings, 2006 Mumbai train bombings, 2010 Moscow Metro bombings.
Semtex	• General-purpose plastic explosive • Contains RDX, PETN, plasticizer, binder, and antioxidant • Used in commercial blasting, demolition, and in certain military applications • Also used by terrorists—e.g., Pan Am Flight 103

EXPLOSIVE MATERIALS

Visual 8.4.16 (Continued)

Examples of Secondary Explosives (Continued)

Explosive	Description
C-4	• A common variety of Composition C, a plastic explosive • Off-white solid with a texture similar to modeling clay • Composed of RDX, plastic binder, plasticizer, a small amount of motor oil. May contain a chemical tag to help detect the explosive and identify its source • Very stable and insensitive to most physical shocks. Detonation can only be initiated by a combination of extreme heat and a shockwave, such as when a detonator inserted into it is fired • Can be molded into any desired shape, pressed into gaps, and used in shaped charges
PETN	• Pentaerythritoltetranitrate (PETN. • One of the strongest known high explosives • More sensitive to shock or friction than TNT • Never used alone as a booster. It is primarily used in booster and bursting charges of small caliber ammunition, in upper charges of detonators in some land mines and shells, and as the explosive core of primacord.

EXPLOSIVE MATERIALS

Visual 8.4.17

Alt Text for Visual 8.4.17
Tertiary Explosives

- Insensitive to shock
- Require an intermediate explosive booster of a secondary explosive
- Used in mining and construction operations
- Used in terrorist attacks because of readily available precursors
- Example: ammonium nitrate and fuel oil (ANFO)

Key Points

Tertiary explosives, also called blasting agents, are very insensitive to shock. They can’t be reliably detonated by practical quantities of primary explosive, so they require an intermediate explosive booster of secondary explosive.

The main users are large-scale mining and construction operations. These materials have also been used for terrorist attacks (e.g., the first attempt on the World Trade Center in 1993 and the 1995 Oklahoma City bombing) because of the sometimes ready availability of large quantities of precursors (e.g., nitrate fertilizers).

ANFO is an example of a tertiary explosive. (Image source: Halen on Wikimedia Commons)

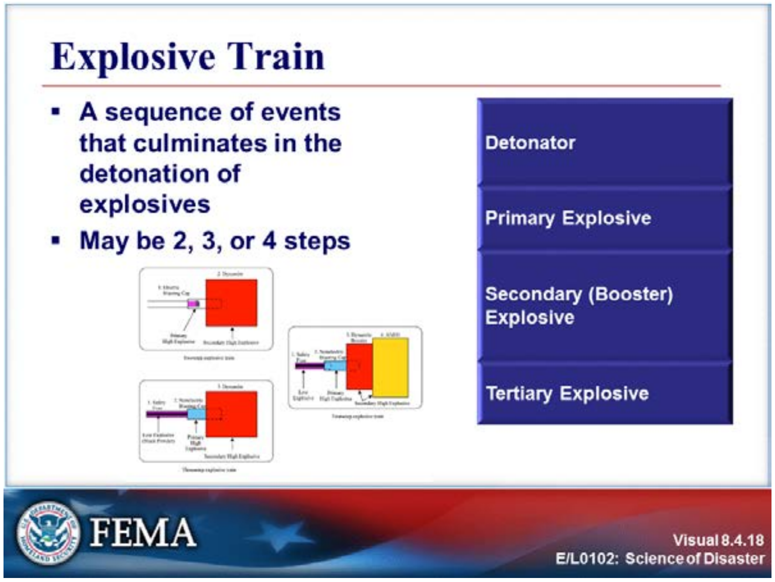
EXPLOSIVE MATERIALS

Visual 8.4.17 (Continued)

ANFO
• Ammonium Nitrate/Fuel Oil (ANFO) • A widely used bulk blasting agent because it is readily available and cheap • Contains 94 percent porous prilled ammonium nitrate that acts as the oxidizing agent and absorbent for the fuel oil • Is highly stable and insensitive. Under most conditions it cannot be detonated with a #8 blasting cap. It generally requires a booster to ensure continuation of the detonation • Decomposes through detonation rather than deflagration with a moderate velocity of about 3,200 meters per second in 5-inch diameter, unconfined, at ambient temperature • Requires confinement for efficient detonation and brisance. The optimum blend for ANFO (if properly prepared) could yield greater explosive power than TNT • Readily absorbs water from air and is dangerous when stored in humid environments, as any absorbed water interferes with its explosive function • Is water soluble

EXPLOSIVE MATERIALS

Visual 8.4.18



Alt Text for Visual 8.4.18

Explosive Train

- A sequence of events that culminates in the detonation of explosives
- May be 2, 3, or 4 steps

Images of the steps in an explosive train

Diagram of an explosive train - detonator, primary explosive, secondary (booster) explosive, and tertiary explosive

Key Points

An explosive train (also called a triggering sequence or firing train) is a sequence of events that starts with low-level energy followed by a chain reaction to initiate the final explosive material or main charge. **All explosives need a firing train to work.**

Because most widely used high explosives are difficult to detonate, a primary explosive of higher sensitivity is used to trigger a uniform and predictable detonation of the main body of the explosive. Although the primary explosive itself is generally a more sensitive and expensive compound, it is only used in small quantities and in relatively safely packaged forms.

High-explosive trains can be either two-step (e.g., detonator and dynamite) or three-step (e.g., detonator, booster of primary explosive, and main charge of secondary or tertiary explosive).

EXPLOSIVE MATERIALS

Visual 8.4.19

Key Points

We have talked about two important properties of explosives—velocity and sensitivity. Other important properties of explosive materials are described in the table below.

Property	Description
Brisance	Shattering effect. The rapidity with which an explosive reaches its peak pressure (power) is a measure of its brisance.
Density of load	The mass of an explosive per unit volume. High-load density can reduce sensitivity by making the mass more resistant to internal friction. Increased load density also permits the use of more explosive, thereby increasing the available power.
Hygrosopicity	A material's moisture-absorbing tendencies. Moisture promotes decomposition and can cause corrosion. It can also reduce the sensitivity, strength, and velocity of detonation of the explosive.
Power, performance, and strength	Ability to do the work intended (i.e., deliver the needed energy).
Stability	Ability of an explosive to be stored without deterioration. Stability may be affected by chemical constitution, rate of decomposition, storage temperature, exposure to ultraviolet light, and electrical discharge.
Toxicity	The decomposition products of an explosion may be hazardous (e.g., carcinogens). Examples of harmful byproducts are lead, mercury, and nitric oxides.
Volatility	The readiness with which a substance vaporizes. Too much volatility may affect chemical composition and reduce stability.

IMPROVISED EXPLOSIVE DEVICES

Visual 8.4.20

Alt Text for Visual 8.4.20

Improvised Explosive Devices (IEDs)

- "Homemade" bombs or destructive devices used to destroy, incapacitate, harass, or distract
- Many forms—from simple pipe bombs to sophisticated devices
- Many methods of delivery:
    - On persons
    - In Delivered packages
    - In vehicles
    - Concealed in public places
    - On Aircraft as weapon

Key Points

An improvised explosive device (IED) attack is the use of a "homemade" bomb and/or destructive device to destroy, incapacitate, harass, or distract. The term IED came into common usage during the Iraq War that began in 2003. IEDs are used by criminals, vandals, terrorists, suicide bombers, and insurgents.

Forms: Because they are improvised, IEDs can come in many forms, ranging from a small pipe bomb to a sophisticated device capable of causing massive damage and loss of life.

Delivery: There are many methods of delivery—for example:

- Carried, placed, or thrown by a person (briefcase, book bag, suicide vest, parcel, luggage, etc.)
- Delivered in a package (by mail, delivery service, messenger)
- Carried or delivered in a vehicle (bicycle, street cart, automobile, van, large truck, airplane.

Concealed in public places (transit systems, public gathering places, public events, on the roadside)

IMPROVISED EXPLOSIVE DEVICES

Visual 8.4.21

Alt Text for Visual 8.4.21
Elements of an IED
- Initiator
- Power source
- Switches and timers
- Main charge
- Container
- Sometimes shrapnel

Book reference: Predicted Damage Radius of Selected IEDs

Key Points

IEDs consist of a variety of components, including:

- An initiator, either electric or nonelectric. An electrical detonator uses a brief electric charge to set off small amounts of explosive material in the center and tip of the detonator
- A power source to trigger the initiator (e.g., batteries)
- A switch and/or delay mechanism (timer):
  - A switch can either be a complex electronic component, or as simple as two intersecting loops of wire.
  - Anti-handling switches are designed to activate when the IED is lifted, moved, opened, or disturbed.
  - Delay switches time the explosion by clockwork, digital, thermal, chemical, or electro-chemical mechanisms.
  - Switches can also detonate a device by remote control.
- The main charge
- A container

IEDs may also include additional materials such as nails, nuts and bolts, steel ball-bearings, glass, or metal fragments designed to increase the amount of shrapnel propelled by the explosion and cause greater injuries.

IMPROVISED EXPLOSIVE DEVICES

Visual 8.4.21 (Continued)

The extent of damage caused by an IED depends on its size, construction, and placement, and whether it incorporates a high explosive or propellant. The following table predicts the damage radius based on the volume or weight of explosive (TNT equivalent) and the type of bomb. Vehicle bombs, also known as vehicle-borne IEDs, can carry significantly more explosive material, and therefore do more damage.

Predicted Damage Radius of Selected IEDs

Threat Description	Explosive Capacity	Building Evacuation Distance	Outdoor Evacuation Distance
Small package/letter	1 lb.	40 ft.	900 ft.
Pipe bomb	5 lbs.	70 ft.	1,200 ft.
FedEx package	10 lbs.	90 ft.	1,080 ft.
Vest/container bombs	20 lbs.	110 ft.	1,700 ft.
Parcel package	50 lbs.	150 ft.	1,850 ft.
Compact car	500 lbs.	320 ft.	1,900 ft.
Full-size car/minivan	1,000 lbs.	400 ft.	2,400 ft.
Van/SUV/pickup truck	4,000 lbs.	640 ft.	3,800 ft.
Delivery truck	10,000 lbs.	860 ft.	5,100 ft.

IMPROVISED EXPLOSIVE DEVICES

Visual 8.4.22

Alt Text for Visual 8.4.22
Commonly Available Materials
Many commonly available materials can be used as explosive materials in IEDs—such as:

- Fertilizer
- Gunpowder
- Hydrogen peroxide

Book reference: Commonly Available Materials and IED Uses

Key Points

As noted earlier, explosives must contain a fuel and an oxidizer, which provides the oxygen needed to sustain the reaction. Many commonly available materials, such as fertilizer, gunpowder, and hydrogen peroxide, can be used as explosive materials in IEDs.

Concern about explosives created from liquid components and transported in a stable form and mixed at the attack site is the reason behind the Department of Homeland Security (DHS) restriction on liquids that passengers can carry on commercial aircraft.

In the 1995 attack on the Alfred P. Murrah building in Oklahoma City, the bombers used 108 bags of high-grade ammonium nitrate fertilizer, three 55-gallon drums of liquid nitromethane, several crates of explosive Tovex, 17 bags of ANFO, and spools of shock tube and cannon fuse loaded into a rental truck.

The following table lists some of the commonly available materials known to have been used in terrorist attacks.

IMPROVISED EXPLOSIVE DEVICES

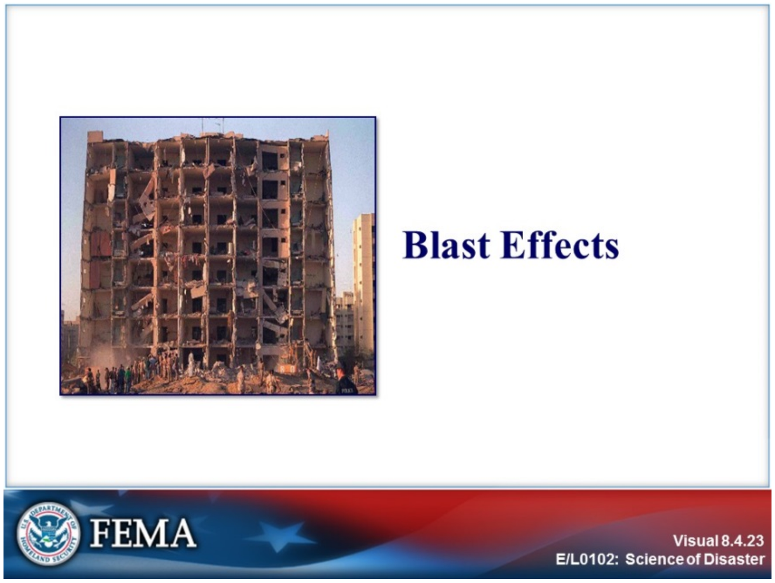
Visual 8.4.22 (Continued)

Commonly Available Materials and IED Uses

	Common Uses	Common Form	Known IED Uses
High Explosives			
Ammonium nitrate and fuel oil (ANFO)	Mining and blasting (Ammonium nitrate without fuel oil is used as fertilizer.)	Solid	Oklahoma City bombing
Triacetone Triperoxide (TATP)	No common uses; mixed from other materials	Crystalline solid	2005 bombings in London
Semtex, C-4	Primarily military	Plastic solid	Irish Republican Army bombings
Ethylene glycol dinitrate (EGDN)	Component of low-freezing dynamite	Liquid	Millennium Bomber, intended for Lost Angeles Airport, 1999
Urea nitrate	Fertilizer	Crystalline solid	World Trade Center 1993
Low Explosives			
Smokeless powder	Ammunition	Solid	Olympic Park bombing 1996

BLAST EFFECTS

Visual 8.4.23

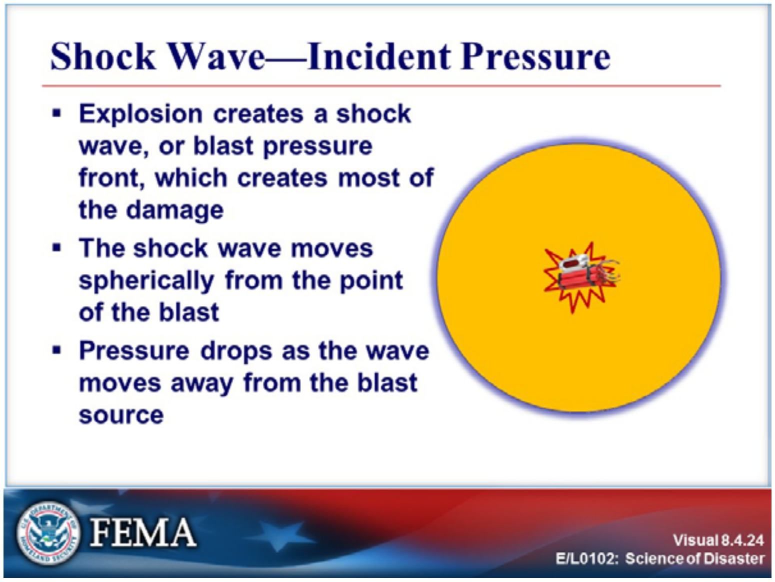


Key Points

This section will discuss blast effects of explosives on structures and people.

BLAST EFFECTS

Visual 8.4.24



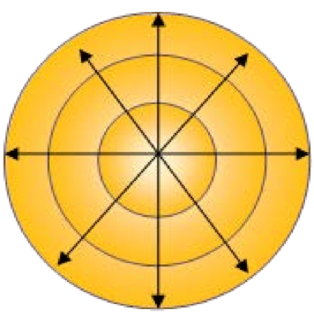
Alt Text for Visual 8.4.24
Shock Wave—Incident Pressure

- Explosion creates a shock wave, or blast pressure front, which creates most of the damage
- The shock wave moves spherically from the point of the blast
- Pressure drops as the wave moves away from the blast source

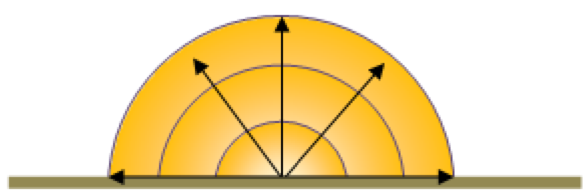
Key Points

In an explosion, about one-third of the explosive material contributes to the detonation. At this point, several things happen:

- **Creation of pressure wave:** Hot, expanding gases from the explosion compress surrounding air to form a constant-velocity bubble of air or shock wave. Heat generated by chemical reactions supports the shock wave.
- **Movement of the pressure wave:** The shock wave, or blast pressure wave, moves spherically away from source of the explosion at supersonic speed at peak pressure. Objects (such as the ground) may alter the shape of the wave.



Pressure Wave



Pressure Wave

BLAST EFFECTS

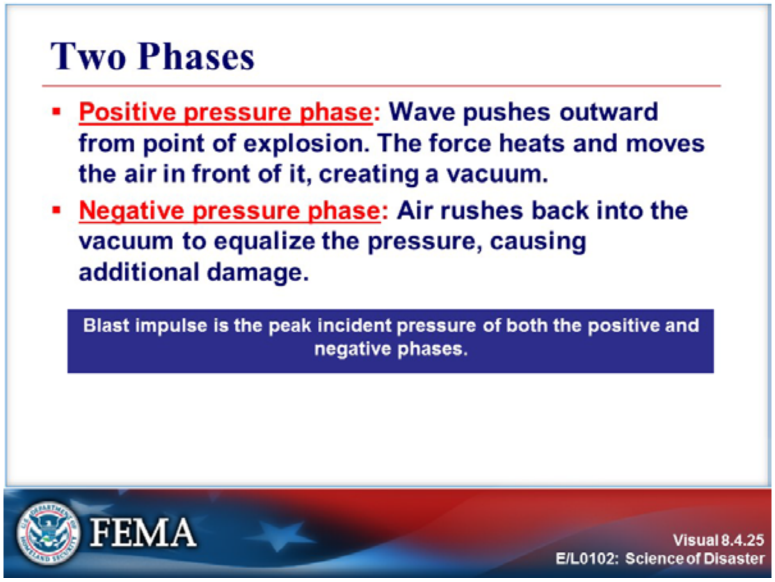
Visual 8.4.24 (Continued)

- **Pressure drop:** As it reaches a point in space, such as a person or building, the pressure of the wave goes rapidly from atmospheric to peak pressure in very little time. The pressure at this point decays rapidly as the supersonic bubble moves on, its pressure reducing exponentially as the surface area of the bubble increases, expending energy over an ever-increasing area.

  The pressure also drops off due to the completion of the chemical reaction of the explosive mixture (burning of the remaining two-thirds of the material). If the explosion occurs within a **confined space,** the gases generated by the burning of the explosive are contained and keep the pressure elevated over a longer period of time.

BLAST EFFECTS

Visual 8.4.25



Alt Text for Visual 8.4.25
Two Phases

- Positive pressure phase: Wave pushes outward from point of explosion. The force heats and moves the air in front of it, creating a vacuum.
- Negative pressure phase: Air rushes back into the vacuum to equalize the pressure, causing additional damage.

Blast impulse is the peak incident pressure of both the positive and negative phases.

Key Points

There are two phases in the movement of the pressure wave:

- **Positive phase:** The positive phase is the process just described—the shock wave pushing outward from the point of explosion. The force heats and moves the air in front of it, creating a vacuum.
- **Negative phase:** The negative phase of the blast wave is the ambient air rushing in behind the blast wave to return to a stable pressure. Although the negative phase has much less energy than the positive phase, it can hit structures at the most inopportune moment in their vibration, resulting in unexpected consequences—increased damage or having windows blow OUT of the building rather than into it.

Impulse is a measure of the energy from an explosion imparted to a building. Both the negative and positive phases of the pressure-time waveform contribute to impulse.

BLAST EFFECTS

Visual 8.4.26

Key Points

Video description:

Image of shock wave. This animation depicts the positive and negative phases of a blast wave.

<u>Discussion Questions</u>:

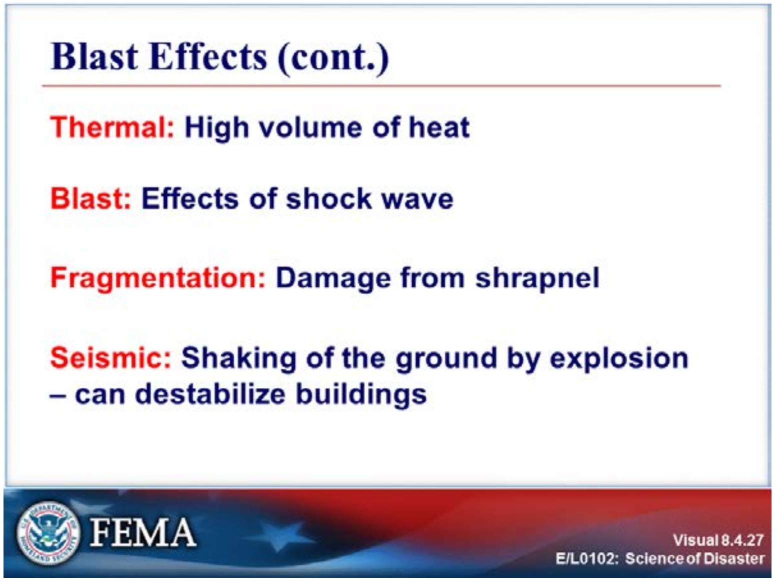
What do you notice about the shape of the blast wave?

When does most of the damage occur?

What happens after the negative phase?

BLAST EFFECTS

Visual 8.4.27



Alt Text for Visual 8.4.27
Blast Effects (cont.)
Thermal - High volume of heat
Blast - Effects of shock wave
Fragmentation - Damage from shrapnel
Seismic - Shaking of the ground by explosion – can destabilize buildings

Key Points

Now that we have seen what happens during the blast process, let's look at the effects.

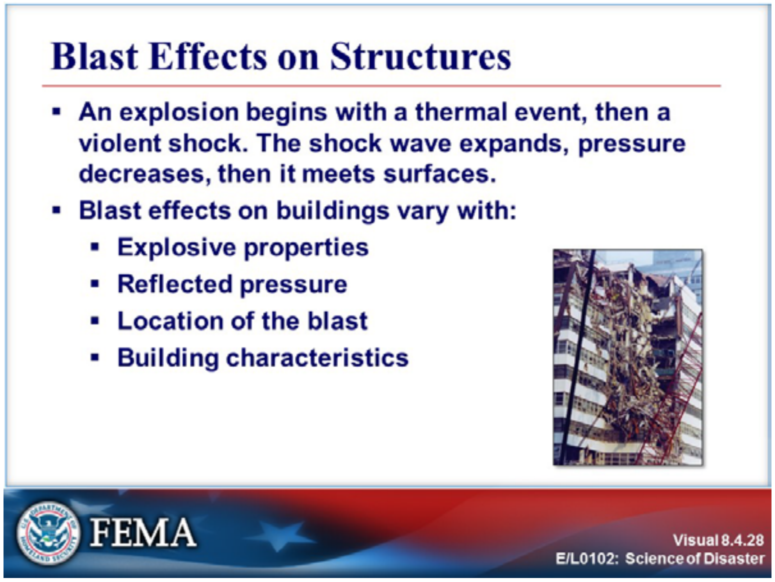
There are four main types of effects from an explosion:

- **Thermal:** First there is a high volume of heat generated by the combustion in the chemical reaction.
- **Blast:** Second, there is overpressure—the effects of the shockwave.
- **Fragmentation:** Next, the explosive device itself and objects in the path of the pressure wave fragment, which can cause damage from shrapnel (flying pieces of material). Due to the force of the explosion, shrapnel can fly a great distance.
- **Seismic:** Large explosions can also have a seismic effect. The downward pressure of the air bubble can shake the ground, and if the blast is large enough, this shaking can destabilize buildings.

Because of the supersonic speed of an explosion, all of these effects may appear to happen at once.

BLAST EFFECTS ON STRUCTURES

Visual 8.4.28



Alt Text for Visual 8.4.28
Blast Effects on Structures

- An explosion begins with a thermal event, then a violent shock. The shock wave expands, pressure decreases, then it meets surfaces.
- Blast effects on buildings vary with:
    - Explosive properties
    - Reflected pressure
    - Location of the blast
    - Building characteristics

Key Points

How do these blast effects impact buildings and other structures in the path of the explosion?

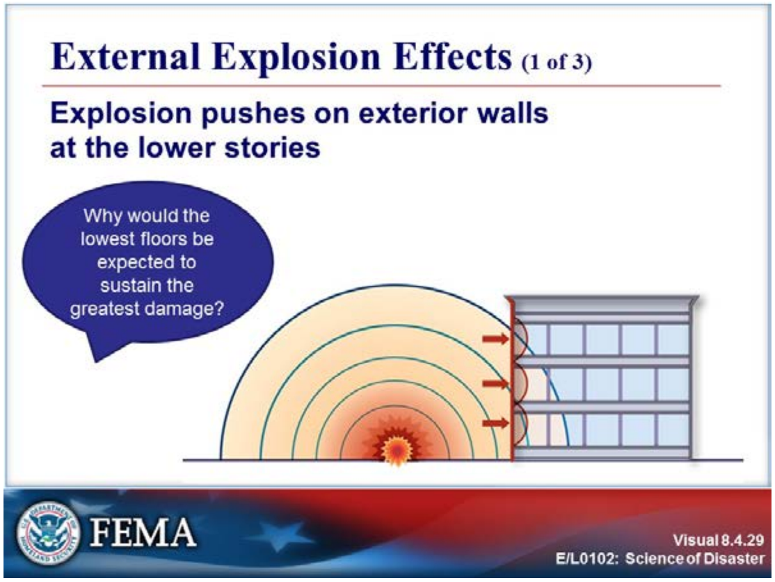
As we have seen, an explosion begins with a thermal event, then a violent shock. The shock wave expands, pressure decreases, and then it meets surfaces. The energy (blast impulse) from an explosion imparted to a building includes both the negative and positive phases of the pressure-time waveform.

The magnitude and distribution of blast loads on a structure vary greatly with several factors:

- **Explosive properties**—type of material, energy output, and quantity of explosive. The amount of explosive is usually expressed as TNT equivalent weight.
- **Reflected pressure**—reinforcement of the pressure pulse through its interaction with the ground or structure (reflections)
- **Location** of the detonation relative to the structure—the stand-off distance between the explosive and the building
- **Building characteristics**—the exterior envelope construction (walls and windows) and the framing or load-bearing system used
  The reflected pressure and the reflected impulse are the forces to which the building ultimately responds. These forces vary in time and space over the exposed surface of the building, depending on the location of the detonation in relation to the building.

BLAST EFFECTS ON STRUCTURES

Visual 8.4.29



Key Points

Now let's take a closer look at what happens when a pressure wave hits a structure.

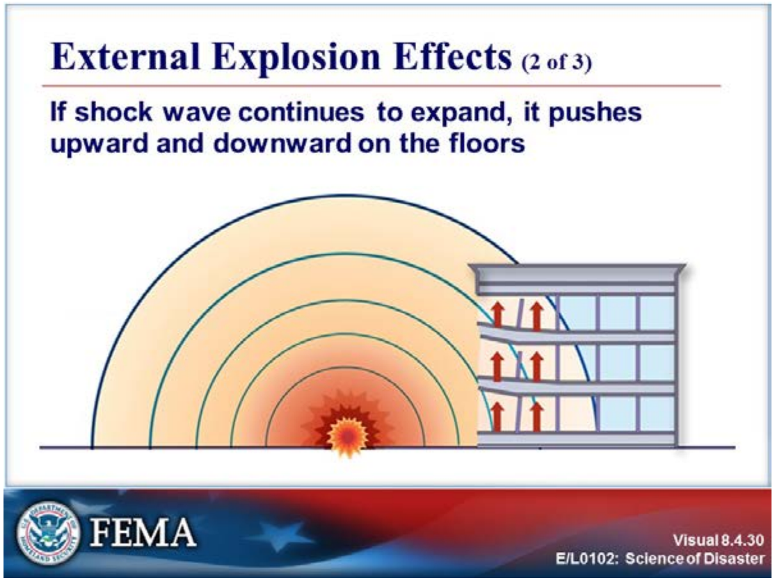
- The air blast strikes the exterior wall, and the weakest component will fail first—usually the windows, which saves the walls and columns but causes much nonstructural damage inside the building. Note that unreinforced masonry walls can actually be weaker than windows, especially if they are non-load bearing.
- If the explosive is close enough, the walls can breach and one or more columns can fail in addition to the windows.
- Based upon the reflection angle, one can expect the lowest or lower floors (1 to 3) to receive the greatest damage.

Discussion Question: Ask the participants: Why would the lowest floors be expected to sustain the greatest damage?

- If the blast wave strikes the whole surface of the exposed side simultaneously, breaching (puncture) of walls and failure of columns is less likely. This is what is sought by achieving a large stand-off distance.

BLAST EFFECTS ON STRUCTURES

Visual 8.4.30



Key Points

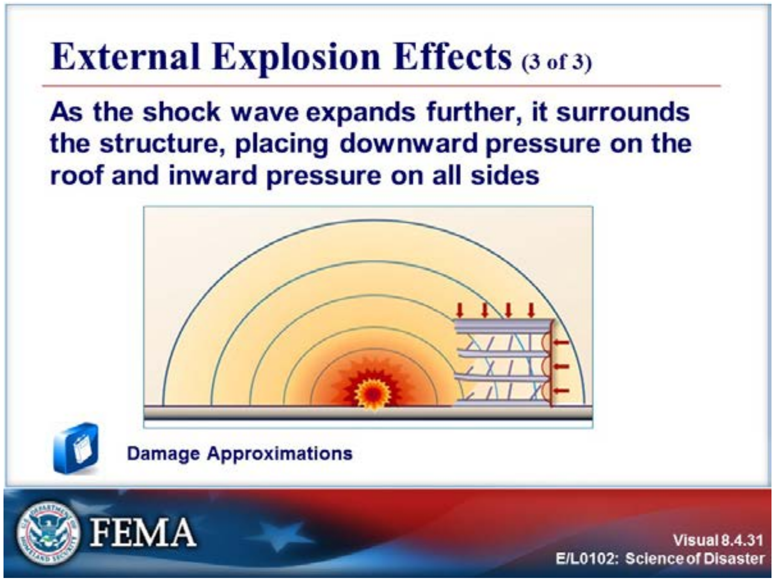
Once the blast wave enters the building, it is trapped, and more air enters the building, further increasing the pressure. Structural components, such as flooring and shear walls now are **moving in directions for which they were not designed**.

Floor failure can result in three effects:

- Concrete chunks rain down, causing injury and possibly death.
- Whole floors give way and pancake downward with obviously more serious consequences. (Remember the devastation caused by the collapsing floors of the World Trade Center.)
- If the building has flat slab construction (thickened floors that act as beams in the framing system), the floors can disconnect from the columns, resulting in floor AND column failure.

BLAST EFFECTS ON STRUCTURES

Visual 8.4.31



Key Points

The blast wave continues to engulf the building.

- Any building component that traps the blast wave, like an overhanging roof, can expect increased damage, based upon how it is constructed and attached.
- The roof and sides parallel to the blast wave movement will experience incident pressure only, which should result in little or no damage.
- Once the blast wave has passed the building, the far side of the building will experience increased pressure as a slight vacuum forms and the ambient air rushes back in to achieve equilibrium.
- Reflections of the blast wave off other buildings behind this one can also increase the pressure on the far side of the structure.

The table on the next page shows damage approximations for various levels of pressure.

BLAST EFFECTS ON STRUCTURES

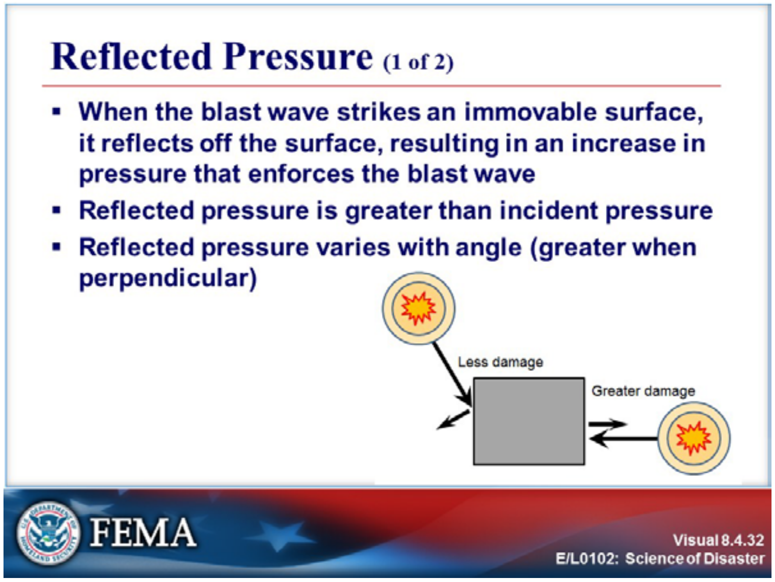
Visual 8.4.31 (Continued)

Damage Approximations

Incident Overpressure (psi)	Damage
0.15 – 0.22	Typical window glass breakage
0.5 – 1.1	Minor damage to some buildings
1.1 – 1.8	Panels of sheet metal buckled
1.8 – 2.9	Failure of concrete block walls
Over 5.0	Collapse of wood-framed buildings
4 – 7	Serious damage to steel-framed buildings
6 – 9	Severe damage to reinforced-concrete structures
10 - 12	Probable total destruction of most buildings

BLAST EFFECTS ON STRUCTURES

Visual 8.4.32



Alt Text for Visual 8.4.32
Reflected Pressure (1 of 2)

- When the blast wave strikes an immovable surface, it reflects off the surface, resulting in an increase in pressure that enforces the blast wave
- Reflected pressure is greater than incident pressure
- Reflected pressure varies with angle (greater when perpendicular)

A graphic illustrating the importance of the angle at which the pressure hits the building: Greater damage results from a perpendicular angle of the blast wave.

Key Points

When the incident pressure wave hits an immovable surface that is not parallel to the direction of the wave's travel, the wave reflects off the surface and is reinforced, resulting in an increase in pressure.

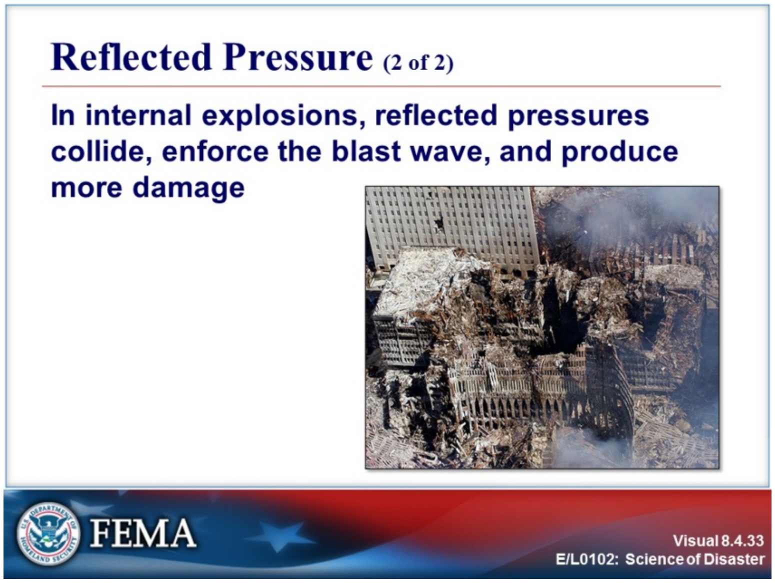
This reflected pressure actually causes the damage to the building. A very high reflected pressure may punch a hole in a wall or cause a column to fail, while a low reflected pressure will try to push over the whole building.

The reflected pressure is always greater than the incident pressure at the same distance from the explosion and varies with the incident angle.

The worst case is when the direction of travel for the blast wave is perpendicular to the surface of the structure, and the incident pressure is very high.

BLAST EFFECTS ON STRUCTURES

Visual 8.4.33

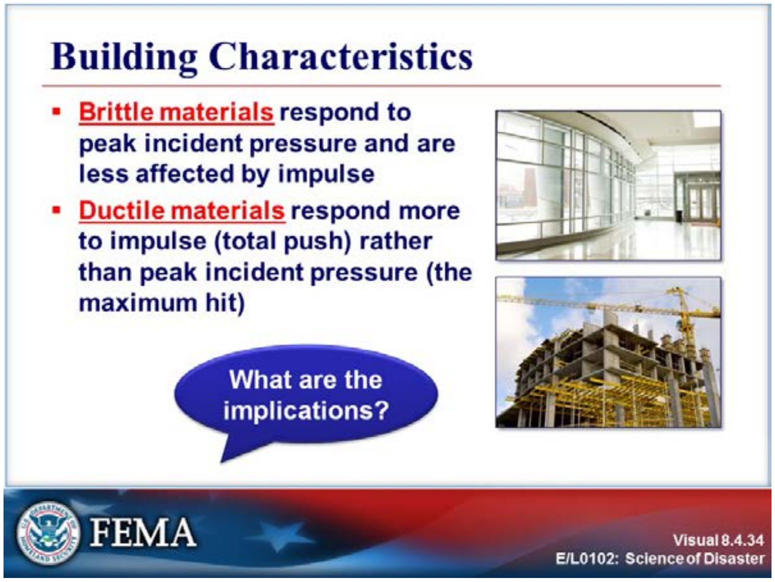


Key Points

In internal explosions, reflected pressures inside the structure collide, enforcing the blast wave and greatly increasing the pressure. The increase in pressure produces even more damage.

BLAST EFFECTS ON STRUCTURES

Visual 8.4.34



Alt Text for Visual 8.4.34
Building Characteristics

- Brittle materials respond to peak incident pressure and are less affected by impulse
- Ductile materials respond more to impulse (total push) rather than peak incident pressure (the maximum hit)

What are the implications?

Key Points

Building characteristics relate to the exterior envelope construction (walls and windows) and the framing or load-bearing system used.

- Brittle materials (such as glass) respond to peak incident pressure and are less affected by impulse.
- Ductile materials (like most building structures), on the other hand, respond more to impulse (the total push) rather than peak incident pressure (the maximum hit).

<u>Discussion Question</u>: What are the implications of these response tendencies?

In most, but not all cases, the glass is the weakest component of the building envelope. Conversely, the columns, whether concrete or steel, are usually the strongest components of the building envelope.

A direct air blast, especially from a close-in explosion, may result in component failure of walls, windows, columns, and beams/girders. Once the exterior envelope is breached, the blast wave causes additional structural and nonstructural damage inside the building.

BLAST EFFECTS ON STRUCTURES

Visual 8.4.34 (Continued)

Collapse is a primary cause of death and injury if an explosive blast occurs.

- In a **localized collapse,** a load-bearing wall, or portion thereof, on one side of the building may fall to the ground, or a single column may fail causing the surrounding floors to fall with it.
- In a **progressive collapse,** the result is more disastrous. A single component failure, such as a wall or column, may result in the failure of more walls and columns so that more of the building falls to the ground than what the explosive initially affected.

BLAST EFFECTS ON PEOPLE

Visual 8.4.35

Key Points

A blast injury is a complex type of physical trauma resulting from direct or indirect exposure to an explosion. Blast injuries occur with the detonation of high-order explosives as well as the deflagration of low order explosives. These injuries are compounded when the explosion occurs in a confined space.

Injuries and casualties during an explosive blast vary based on the different phases of the blast. The four phases of blast injuries are:

- Primary
- Secondary
- Tertiary
- Quaternary

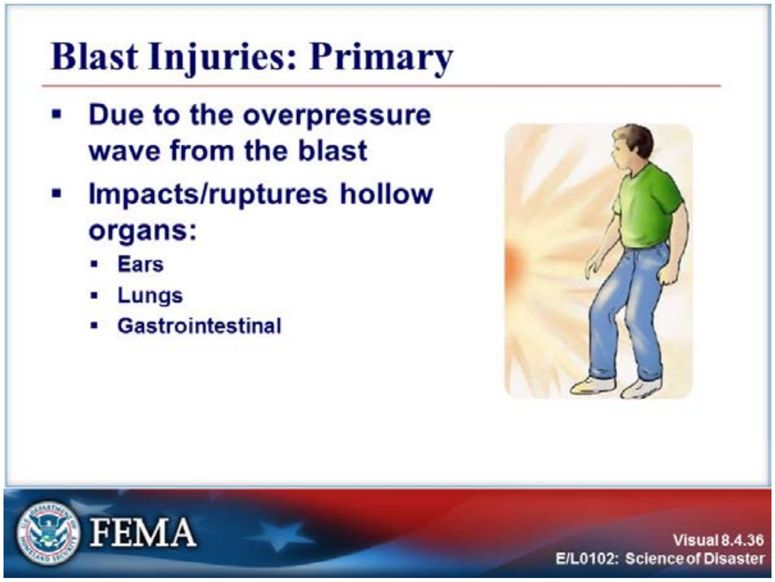
BLAST EFFECTS ON PEOPLE

Visual 8.4.35 (Continued)

The distance from the detonation affects the type of injuries likely to be sustained.

BLAST EFFECTS: PRIMARY

Visual 8.4.36



Key Points

Primary injuries are caused by blast overpressure waves, or shock waves. These are especially likely when a person is close to an exploding munition, such as a land mine.

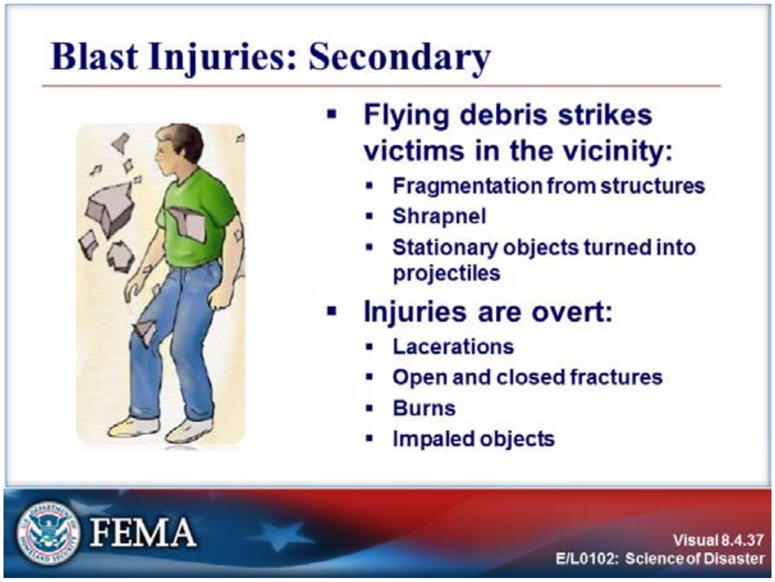
Overpressure causes eardrum rupture first, which is normally not lethal. Overpressure can also overdrive the lungs, causing injury or death. The relationship between pressure and impulse is very evident in lung response, where the threshold of lethality for incident pressure is:

- 102 psi for 3 milliseconds
- 23 psi for 18.5 milliseconds

Thermal and blast injuries include burns and injuries sustained when the blast wave picks up and throws a person against a surface or object (translation). The result may be blunt trauma, lacerations, and impalement from the impact.

BLAST EFFECTS: SECONDARY

Visual 8.4.37



Alt Text for Visual 8.4.37
Blast Injuries: Secondary

- Flying debris strikes victims in the vicinity:
  - Fragmentation from structures
  - Shrapnel
  - Stationary objects turned into projectiles
- Injuries are overt:
  - Lacerations
  - Open and closed fractures
  - Burns
  - Impaled objects

Key Points

Secondary injuries are caused by fragmentation and other objects propelled by the explosion. These injuries may affect any part of the body and sometimes result in penetrating trauma with visible bleeding. At times, the propelled object may become embedded in the body, obstructing the loss of blood to the outside. However, there may be extensive blood loss within the body cavities.

BLAST EFFECTS: SECONDARY

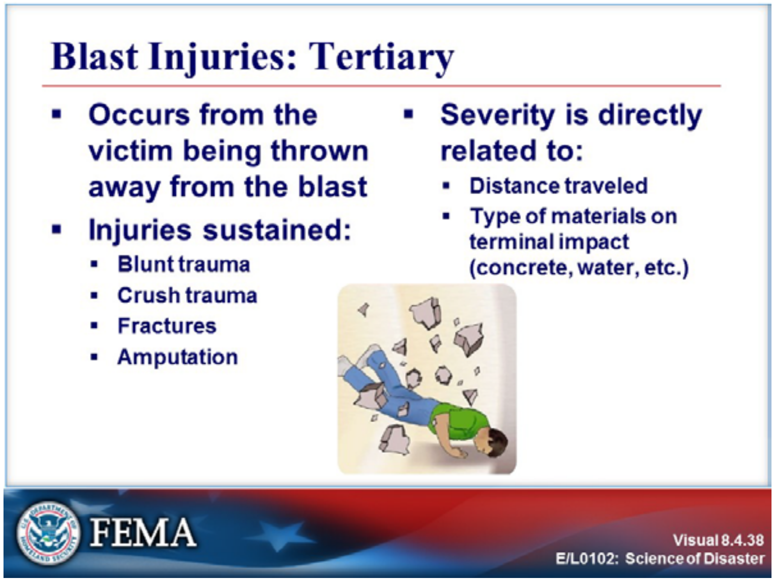
Visual 8.4.37

Fragmentation from any source can result in blunt trauma, impact, penetration, or laceration injuries.

- More than 80 percent of all injuries from explosive blasts can be attributed to lacerations caused by broken glass. The fragments can come from around the bomb or from the bomb container (e.g., parts of the vehicle used in a car bomb, or shrapnel incorporated into the bomb).
- Objects can be picked up either intact or damaged by the blast wave as it travels along (e.g., street furniture or jersey barriers).
- Building component failure also causes material fragments with sufficient velocity to injure or kill. When portions of a building collapse, people commonly suffer crushing or falling injuries.

BLAST EFFECTS: TERTIARY

Visual 8.4.38



Alt Text for Visual 8.4.38
Blast Injuries: Tertiary

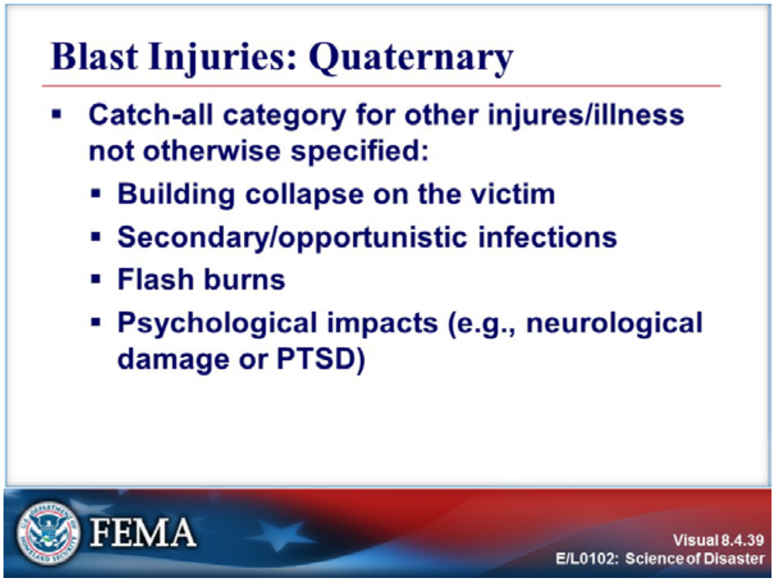
- Occurs from the victim being thrown away from the blast
- Injuries sustained:
    - Blunt trauma
    - Crush trauma
    - Fractures
    - Amputation
- Severity is directly related to:
    - Distance traveled
    - Type of materials on terminal impact (concrete, water, etc.)

Key Points

Displacement of air by the explosion creates a blast wind that can throw victims against solid objects Injuries resulting from this type of traumatic impact are referred to as tertiary blast injuries. Tertiary injuries may present as some combination of blunt and penetrating trauma, including bone fractures and coup contre-coup injuries. Children are at a particularly higher risk of tertiary injury due to their relatively smaller body weight.

BLAST EFFECTS: QUATERNARY

Visual 8.4.39



Alt Text for Visual 8.4.39
Blast Injuries: Quaternary

- Catch-all category for other injures/illness not otherwise specified:
  - Building collapse on the victim
  - Secondary/opportunistic infections
  - Flash burns
  - Psychological impacts (e.g., neurological damage or PTSD)

Key Points

Quaternary injuries, or other miscellaneous named injuries, are all other injuries not included in the first three classes. These include flash burns, crush injuries, and respiratory injuries.

Delayed effects: Some health effects caused by explosions, including eye injuries and abdominal injuries, may not be apparent initially, but they can cause symptoms and even fatalities hours to months after the event.

Psychological effects: Psychological effects in attack survivors, first responders, and others are not unusual in the aftermath of a high-casualty event. While most symptoms diminish with time, in some cases assistance and guidance from mental health professionals may be required.

BLAST VIDEO

Visual 8.4.40

Key Points

Introduction: This video depicts a bombing carried out by the Irish Republican Army (IRA) in Manchester, England, in 1996. The blast was in the center of the city's business district (an area well covered by closed-circuit TV). The IRA gave advance notification about 1 hour prior to detonation to newspapers, radio stations, and at least one hospital.

Video description:

Introduction: This video depicts a bombing carried out by the Irish Republican Army (IRA) in Manchester, England, in 1996. The blast was in the center of the city's business district (an area well covered by closed-circuit TV). The IRA gave advance notification about 1 hour prior to detonation to newspapers, radio stations, and at least one hospital.

Things to notice:

The police began clearing the street 40 minutes before the blast, but people are still walking past the suspected truck within 17 minutes of the explosion.

A robot is sent in to identify the bomb and possibly disarm it, without success.

The bomb goes off with a great noise (audible over 8 miles away), then the explosion is shown in slow motion. (Note that one-third of the explosive provides the supersonic shock wave followed by the two-thirds of the explosive adding to the blast wave but also supporting the fireball.)

Aftermath: No buildings have collapsed. Some walls remain intact. Almost all glass has been shattered (the bomb smashed almost every window in a half-mile radius). There is a huge amount of debris—less in areas farther from the bomb.

BLAST VIDEO (Continued)

Visual 8.4.40

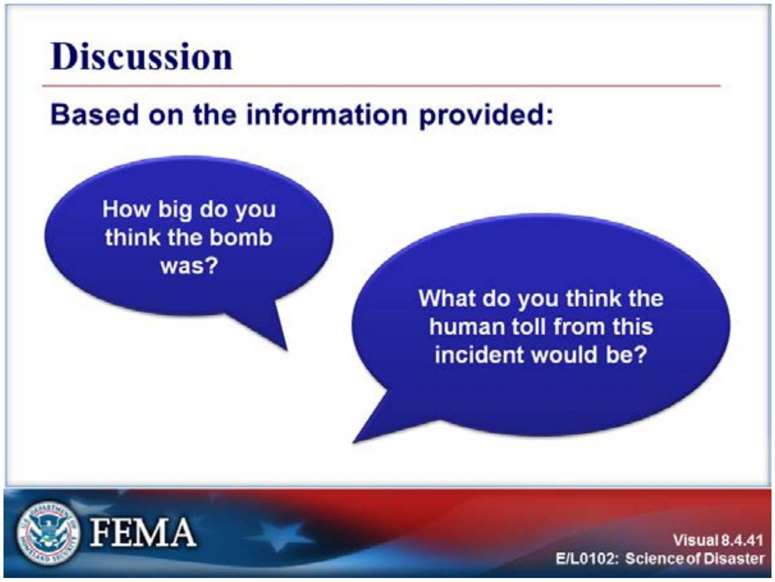
Things to notice:

- The police began clearing the street 40 minutes before the blast, but people are still walking past the suspected truck within 17 minutes of the explosion.
- A robot is sent in to identify the bomb and possibly disarm it, without success.
- The bomb goes off with a great noise (audible over 8 miles away), then the explosion is shown in slow motion. (Note that one-third of the explosive provides the supersonic shock wave followed by the two-thirds of the explosive adding to the blast wave but also supporting the fireball.)

Aftermath: No buildings have collapsed. Some walls remain intact. Almost all glass has been shattered (the bomb smashed almost every window in a half-mile radius). There is a huge amount of debris—less in areas farther from the bomb.

BLAST VIDEO

Visual 8.4.41



Key Points

Discussion Question: How big do you think this bomb was?

Discussion Question: Based on the provided information, what do you think the human toll from this incident would be?

BUFFER ZONES – LINES OF DEFENSE

Visual 8.4.42

Alt Text for Visual 8.4.42
Buffer Zones – Lines of Defense

- A layered approach to defense.
  - o More rings/layers = increased distance = more protection
- Utilized to protect key infrastructure and high-value targets
- Buffer zones integrate evacuation distances into the engineered layers

Book reference: Bomb Threat Stand-Off Chart

Key Points

Buffer zones are engineered protective rings that aid in the prevention of successful bombings. In theory, buffer zones incorporate a ring of engineered protection, often bollards, to force explosive materials away from the primary target at a distance that minimizes the impact.

BUFFER ZONES – LINES OF DEFENSE

Visual 8.4.42 (Continued)

Bomb Threat Stand-off Chart

BOMB THREAT STAND-OFF CHART

Threat Description Improvised Explosive Device (IED)	Explosives Capacity[1] (TNT Equivalent)	Building Evacuation Distance[2]	Outdoor Evacuation Distance[3]
Pipe Bomb	5 LBS	70 FT	1200 FT
Suicide Bomber	20 LBS	110 FT	1700 FT
Briefcase/Suitcase	50 LBS	150 FT	1850 FT
Car	500 LBS	320 FT	1500 FT
SUV/Van	1,000 LBS	400 FT	2400 FT
Small Moving Van/ Delivery Truck	4,000 LBS	640 FT	3800 FT
Moving Van/ Water Truck	10,000 LBS	860 FT	5100 FT
Semi-Trailer	60,000 LBS	1570 FT	9300 FT

1. These capacities are based on the maximum weight of explosive material that could reasonably fit in a container of similar size.
2. Personnel in buildings are provided a high degree of protection from death or serious injury; however, glass breakage and building debris may still cause some injuries. Unstrengthened buildings can be expected to sustain damage that approximates five percent of their replacement cost.
3. If personnel cannot enter a building to seek shelter they must evacuate to the minimum distance recommended by Outdoor Evacuation Distance. These distance is governed by the greater hazard of fragmentation distance, glass breakage or threshold for ear drum rupture.

Link to bomb threat stand-off chart: (This link can also be accessed at the following URL: https://www.nctc.gov/docs/2006_calendar_bomb_stand_chart.pdf)

BUFFER ZONES

Visual 8.4.43

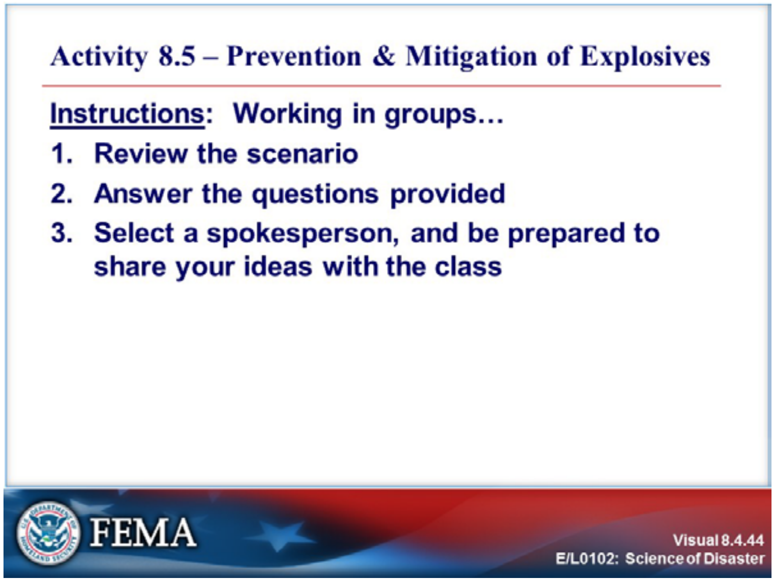
Key Points

The visual shows a photograph of the headquarters for the Bureau of Alcohol, Tobacco, Firearms, and Explosives. See if you can identify the multiple buffer zones, both overt and disguised, in the engineering.

Discussion Question: Which side the engineers thought was most vulnerable?

ACTIVITY 8.5 – PREVENTION & MITIGATION OF EXPLOSIVES

Visual 8.4.44



Key Points

Instructions: Working in groups…

1. Review the scenario.
2. Answer the questions provided.
3. Select a spokesperson and be prepared to share your ideas with the class.

Scenario: You are the emergency manager for a county in your local community. Within your jurisdiction you have two major hospitals, including University Medical Center (UMC), the regional trauma center that has a capacity to bed up to 300 patients.

At 16:30 hours today, county law enforcement received a tip that a family member of recently deceased patient at UMC was angry with the hospital and staff. The tipster informed law enforcement that the family member made threats on social media that he planned to “hunt down” the staff at the hospital for “killing his father.” Photos of potential bomb electronics and chemical precursors for explosives were also posted to the site.

A law enforcement officer visited the family member’s house and confirmed the presence of Ammonium Nitrate/Fuel Oil, blasting caps, wiring, and other bomb making components. Law enforcement has advised county, state, and federal partners that they believe the threat is credible and there is evidence indicating the family member intends to utilize his Dodge pickup truck as a vehicle-borne IED against the hospital within the next 24 hours.

ACTIVITY 8.5 – PREVENTION & MITIGATION OF EXPLOSIVES

Visual 8.4.44 (Continued)

Questions

1. What agencies, resources, and subject matter experts would you expect in to assist with the investigation?

2. What agencies, resources, and subject matter experts would you request to assist with the response to the threat?

3. Given the threat, what protective actions would you recommend for the hospital and surrounding buildings?

    a. What buffer zone distance might you try to implement? How?

    b. What resources would aid in protecting the hospital?

4. Would you consider evacuating the hospital or sheltering in place?

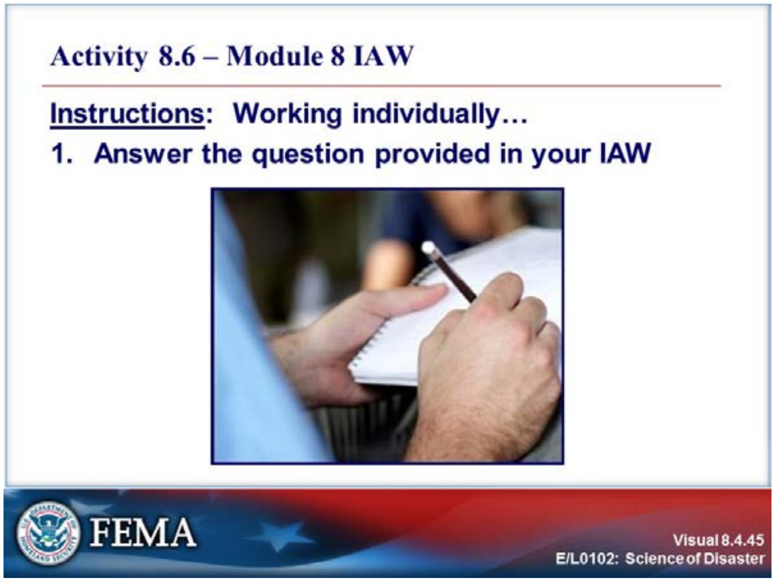
    a. If so, discuss your strategy:

        i. Who would conduct the evacuation?

        ii. Who would be evacuated and who would shelter in place?

ACTIVITY 8.6 – PREVENTION & MITIGATION OF EXPLOSIVES

Visual 8.4.45



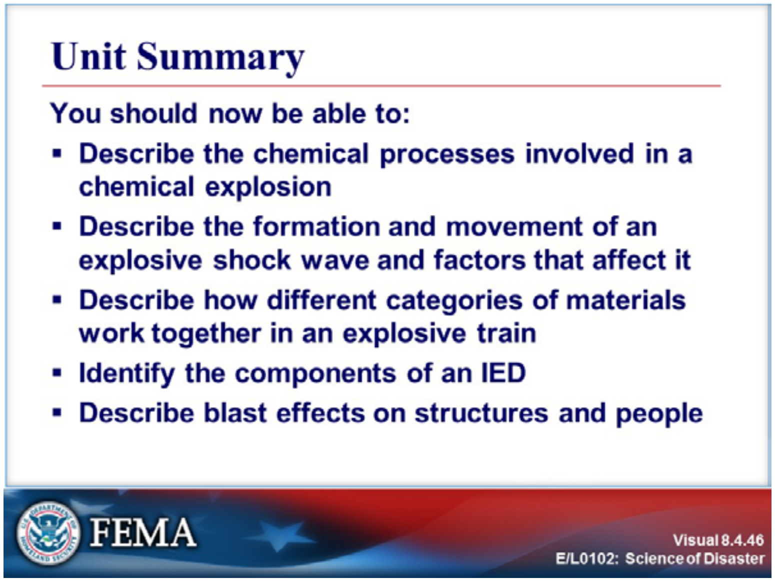
Key Points

Instructions: Working individually…

1. Answer the question provided in your IAW.

UNIT SUMMARY

Visual 8.4.46



Alt Text for Visual 8.4.46
Unit Summary
You should now be able to:

- Describe the chemical processes involved in a chemical explosion
- Describe the formation and movement of an explosive shock wave and factors that affect it
- Describe how different categories of materials work together in an explosive train
- Identify the components of an IED
- Describe blast effects on structures and people

Key Points

Do you have any questions about the content covered in this unit?

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UNIT 5. CHEMICAL BASICS

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INTRODUCTION

Visual 8.5.1

Key Points

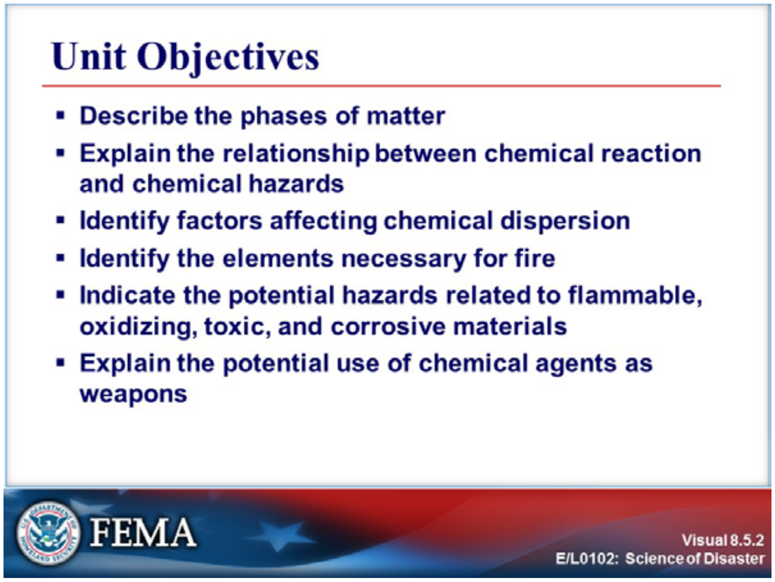
This unit will explore the scientific basis for chemical hazards and threats.

A suggested time plan for this unit is shown below.

Topic	Time
Introduction	5 minutes
Chemistry Basics	20 minutes
Types of Chemical Hazards	40 minutes
Chemical Agents as Weapons	20 minutes
Activity 8.7 –Chemical Response Resources	30 minutes
Unit Summary	5 minutes
Activity 8.8 – Chemical Response In Your Community	10 minutes
Total Time	**2 hour 10 minutes**

INTRODUCTION

Visual 8.5.2



Alt Text for Visual 8.5.2
Unit Objectives

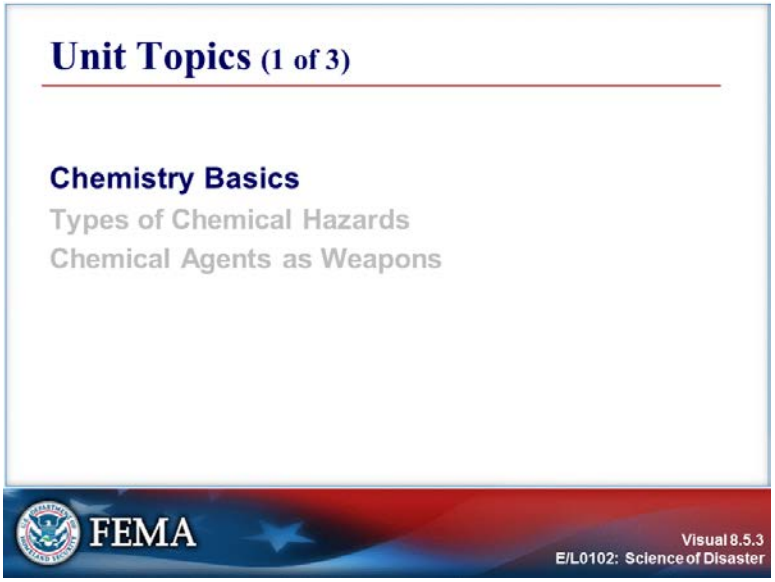
- Describe the phases of matter
- Explain the relationship between chemical reaction and chemical hazards
- Identify factors affecting chemical dispersion
- Identify the elements necessary for fire
- Indicate the potential hazards related to flammable, oxidizing, toxic, and corrosive materials
- Explain the potential use of chemical agents as weapons

Key Points

Review the unit objectives as shown on the visual.

CHEMISTRY BASICS

Visual 8.5.3

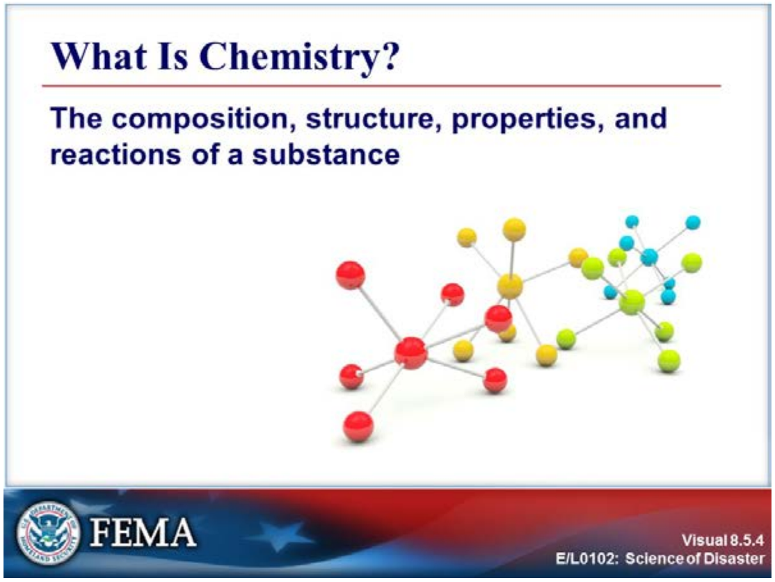


Key Points

This unit will discuss three main topics: chemistry basics, types of chemical hazards, and chemical agents used as weapons. We'll begin with chemistry basics.

CHEMISTRY BASICS

Visual 8.5.4



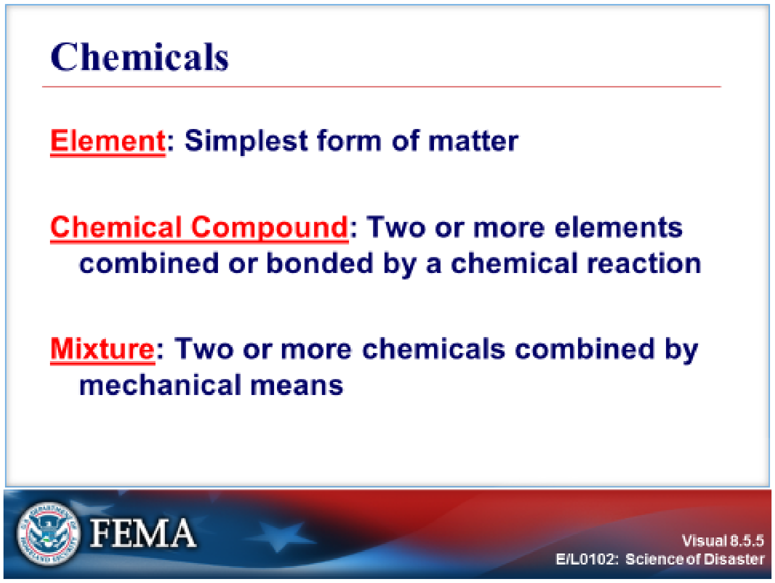
Key Points

Chemistry, a branch of the physical sciences, studies the composition, structure, properties, and reactions of matter, or substances.

Understanding some basic chemical principles and processes will help you understand the potential hazards and threats associated with chemicals.

CHEMISTRY BASICS

Visual 8.5.5



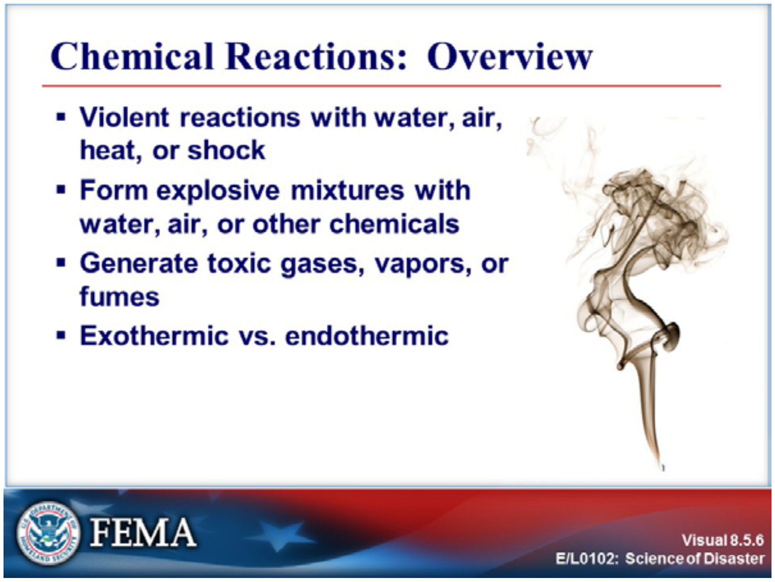
Key Points

Next, we'll consider the building blocks of chemical substances.

- An **element**—the simplest form of matter—is a pure chemical substance consisting of one type of atom. There are currently 118 known elements in the periodic table, and new elements continue to be discovered. Examples of elements are aluminum, carbon, chlorine, hydrogen, mercury, and oxygen.
- A **chemical compound** is a substance consisting of two or more elements combined or bonded together so that its constituent elements are always present in the same proportions. A compound can only be created by a chemical reaction, and the components of a compound can only be separated by a chemical reaction.
- A **mixture** is any combination of two or more chemicals if the combination is NOT, in whole or in part, the result of a chemical reaction. Mixtures can be created by mechanical means alone, and the constituents of a mixture can usually be separated by simple mechanical means, such as filtering, evaporation, or magnetic force.

CHEMISTRY BASICS

Visual 8.5.6



Key Points

Chemistry helps us understand how different substances react. Chemicals have the ability to react when exposed to other chemicals or certain physical conditions. The reactive properties of chemicals vary widely, and they play a vital role in the production of many chemical, material, pharmaceutical, and food products we use daily.

Some chemicals change phase or react violently when exposed to water, air, heat, or shock.

When chemical reactions are not properly managed, they can have harmful, or even catastrophic consequences, such as fires, explosions, or the generation of toxic gases, vapors, and fumes. These reactions may result in death and injury to people, damage to physical property, and severe effects on the environment.

Some **incompatible groups** of chemicals include:

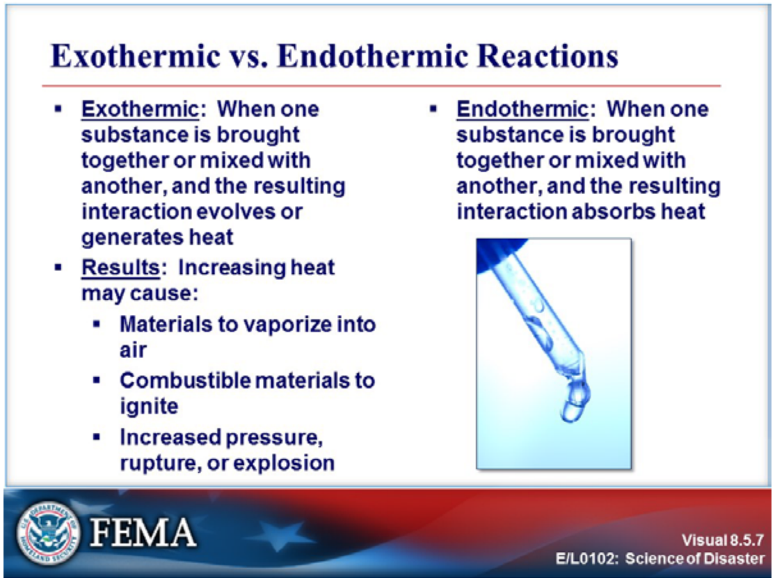
- Acids and bases.
- Flammables and toxics.
- Flammables and oxidizers.
- Oxidizers and reducers.

(Source: OSHA)

Chemical reactions are either exothermic or endothermic. Typically, as emergency management professionals, exothermic chemical reactions are the ones of particular concern for us.

CHEMISTRY BASICS

Visual 8.5.7



Alt Text for Visual 8.5.7

- Exothermic vs. Endothermic Reactions
- Exothermic: When one substance is brought together or mixed with another, and the resulting interaction evolves or generates heat
- Results: Increasing heat may cause:
    - Materials to vaporize into air
    - Combustible materials to ignite
    - Increased pressure, rupture, or explosion
- Endothermic: When one substance is brought together or mixed with another, and the resulting interaction absorbs heat

Key Points

Definition: When one substance is combined with another and the resulting interaction absorbs heat, the process is referred to as an **endothermic reaction** (endo- is a prefix meaning “within” or “inner”).

Definition: When one substance is combined with another and the resulting interaction generates heat, the process is referred to as an **exothermic reaction** (exo- is a prefix meaning “out of”). An exothermic reaction is one where the energy flows out of the system into the environment. When heat is generated, it increases the volume and creates pressure.

Combustion reactions are exothermic. Some exothermic reactions may require heating just to get started, and will then proceed on their own.

CHEMISTRY BASICS

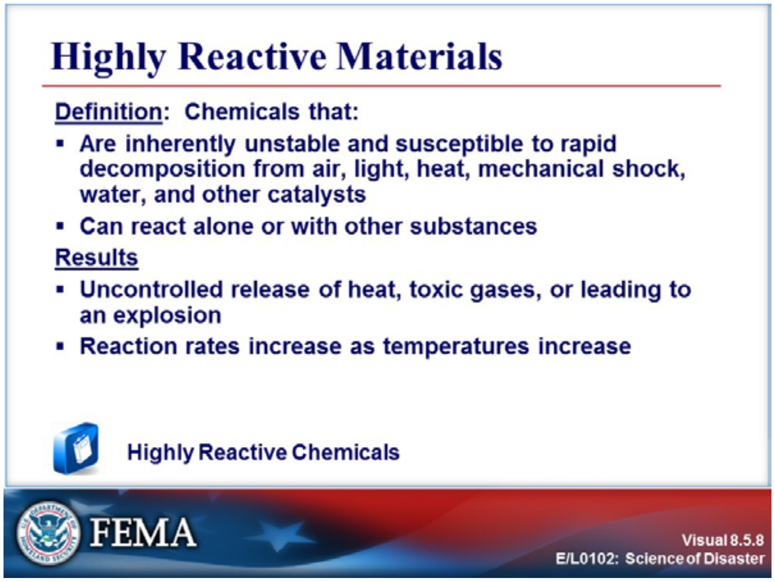
Visual 8.5.7 (Continued)

Results: Exothermic reactions pose special hazards whether they occur in the open environment or within a closed container.

- **Reactions in the open:** In the open, the heat that is produced will raise the temperature of the reactants, of any products of the reaction, and of surrounding materials. The resulting higher temperatures may affect how the materials involved behave in the environment.
  - Heat will increase the vapor pressures of hazardous materials and the rate at which they vaporize.
  - If very high temperatures are reached, nearby combustible materials may ignite.
  - Explosive materials, whether they are the reactants of the reaction or just nearby, may explode upon ignition or excessive heating.
- **Reactions in closed containers:** Exothermic reactions taking place in closed containers pose additional hazards. The increased internal temperatures plus the production of gases from the reaction may increase internal pressures to the point that the container explodes. The explosion suddenly releases large amounts of possibly flammable and/or toxic gases or vapors into the atmosphere.

CHEMISTRY BASICS

Visual 8.5.8



Alt Text for Visual 8.5.8
Highly Reactive Materials
Definition: Chemicals that:

- Are inherently unstable and susceptible to rapid decomposition from air, light, heat, mechanical shock, water, and other catalysts
- Can react alone or with other substances

Results

- Uncontrolled release of heat, toxic gases, or leading to an explosion
- Reaction rates increase as temperatures increase

Book Reference: Highly Reactive Chemicals

Key Points

When chemical reactions are considered safe, it is generally because the reaction rate is relatively slow or can be easily controlled. However, certain reactions proceed at such a fast rate, and generate so much heat, that they may result in explosion.

Definition: Highly reactive or unstable materials are those that have the potential to vigorously polymerize, decompose, condense, or become self-reactive when exposed to shock, pressure, temperature, light, or contact with another material. Major types of highly reactive chemicals are:

- **Pyrophorics**—These substances will ignite spontaneously in air.
- **Water-reactives**—These substances react vigorously to water or moisture.
- **Peroxides**—Peroxides are shock-sensitive. Organic peroxides are even more shock-sensitive than explosives such as TNT or picric acid.
- **Polymers**—Many polymers generate large amounts of heat upon polymerization (a chemical process of combining single molecules into groups called polymers).
- **Explosives**—Explosives can release extremely large amounts of thermal or physical energy and can cause a true detonation (a shock wave traveling at supersonic speed).

CHEMISTRY BASICS

Visual 8.5.8

Results: When triggering conditions are present, the reaction can occur in a violent uncontrolled manner, liberating heat and/or toxic gases, or leading to an explosion.

Reaction rates almost always increase dramatically as the temperature increases. Therefore, if heat from a reaction is not dissipated, the reaction can accelerate out of control and possibly result in injuries or costly accidents.

CHEMISTRY BASICS

Visual 8.5.8 (Continued)

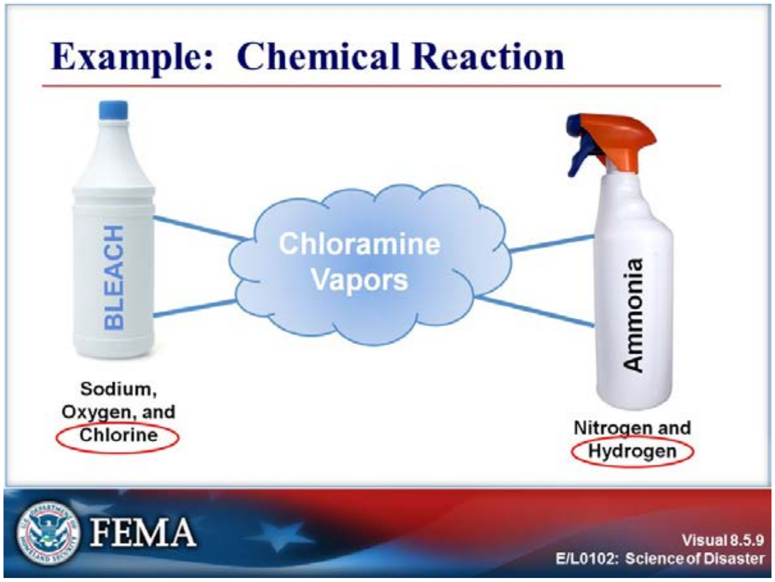
The table below provides additional information about chemicals that react with air, water, heat, or other substances.

Highly Reactive Chemicals

Type of Chemical	Description	Examples
Air Reactives (Pyrophorics)	• React violently in contact with air or oxygen or with compounds containing oxygen. • Do not need an ignition source to begin combustion, or to burn. • May be found in gas cylinders or packaged under nitrogen or some other inert atmosphere. • May produce a flame that is clear and not readily visible.	• Alkali metals (potassium, cesium) • Finely divided metal dusts (nickel, zinc, titanium) • Hydrides
Water Reactives	• Can react violently or vigorously in contact with water, wet surfaces, or even the moisture in the air. • May give off a flammable gas (such as hydrogen) or a toxic gas (such as phosgene) or spontaneously burn or explode. • Cannot be extinguished with water; require a class D fire extinguisher.	• Alkali metals • Anhydrides • Carbides • Halides • Hydrides • Organometallics • Oxides • Peroxides • Phosphides
Peroxide Formers	• Can form peroxide either upon aging, or upon contact with air or other substances. • May be shock sensitive and explode if handled roughly or upon heating. • May exist without problem in a solvent until the solvent is evaporated (during distillation, for example) and the peroxides concentrate.	• Ethers • 1,4-dioxane
Polymers	• May generate large amounts of heat upon polymerization. • Some may cause a runaway polymerization reaction that can explode. • May generate heat buildup that can cause bumping, over-booking (too much pressure), or rupture of the container, which can also cause explosive-like damage.	• Acrylic acid • Butadiene • Cyclopentadiene • Ethylene • Styrene • Vinyl chloride

CHEMISTRY BASICS

Visual 8.5.9



Key Points

An illustration: Let's look at a simple illustration of a chemical reaction.

Mixing bleach and ammonia illustrates a chemical reaction called single displacement. When bleach and ammonia are mixed:

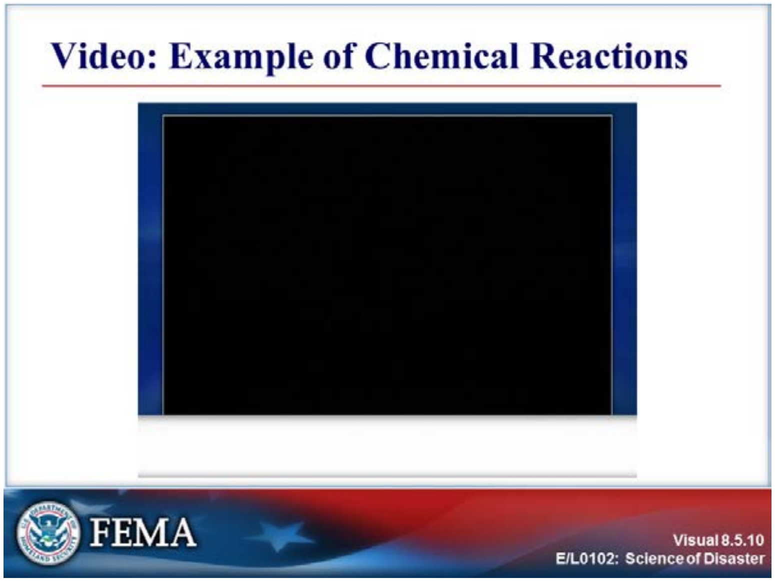
1. First, hydrochloric acid is formed.
2. Then the ammonia and chlorine gas react to form chloramine, which is released as a vapor.
3. If ammonia is present in excess (which it may or may not be, depending on the mixture), toxic and potentially explosive liquid hydrazine may be formed.

Key factors in this reaction include the following:

- Household bleach has one atom each of sodium, oxygen, and chlorine.
- Ammonia has a chemical formula of one atom of nitrogen and three atoms of hydrogen.
- When these two compounds are combined, one part chlorine gas—made up of diatomic (two-atom) molecules—is released from the bleach.
- Chloramines are derivatives of ammonia by substitution of one, two, or three hydrogen atoms with chlorine atoms.

CHEMISTRY BASICS

Visual 8.5.10



Key Points

Introduction: What can happen when chemicals react? The incident described in this video provides a vivid example.

A runaway exothermic chemical reaction was the likely cause of a fatal accident at T2 Laboratories, a chemical manufacturer in Jacksonville, Florida, according to the Chemical Safety & Hazard Investigation Board (CSB).

The 2007 accident was one of the most destructive ever investigated by the board, shattering nearby buildings and sending debris a mile away. The blast killed four of the company's 12 employees and injured four other workers and 28 community members. The plant was destroyed.

Transcript:

Narrator: On December 19, 2007, a powerful explosion and fire occurred at T2 Laboratories, a small chemical producer in Jacksonville, Florida. The blast killed and injured workers, destroyed T2 laboratories, and extensively damaged four nearby businesses. Windows blew into offices, striking workers with flying glass.

Gary Visscher, CSB Board Member: The explosion at T2 Laboratories is one of several accidents that the CSB has investigated caused by runaway chemical reactions. Accidents resulting from reactive hazards occur too frequently and often have serious consequences.

CHEMISTRY BASICS

Visual 8.5.10 (Continued)

Robert Hall, P.E., CSB Investigation Supervisor: Behind me on this concrete pad there used to stand a structure some 50 feet high that had a reactor vessel in it, in which the company that operated here, T2 Laboratories Incorporated, manufactured a chemical known as methylcyclopentadienyl manganese tricarbonyl, or MCMT for short. The entire structure and reactor vessel were blown away in the explosion.

Narrator: T2 produced MCMT, a gasoline additive, in batches using a 2,500-gallon reactor. An operator controlled the process with a computerized system in a nearby control room. In the first step, liquid chemicals and sodium metal were loaded into the reactor, heated, and then mixed with an agitator. The reaction produced hydrogen, which was vented to the atmosphere. In normal operations when the temperature reached 300 degrees Fahrenheit, the operator would turn off the heating system. But because this reaction was exothermic, or heat producing, the temperature inside the reactor would continue to rise. At 360 degrees, operators would begin to periodically fill the reactor's cooling jacket with water. As the water boiled, heat was removed, controlling the temperature.

However, on the day of the accident, the CSB found that the operator tried to cool the reactor as usual but the cooling system likely malfunctioned, perhaps due to a blockage in the water supply piping or a valve failure. The temperature and pressure inside the reactor began to rise uncontrollably, in a runaway chemical reaction. T2's co-owners returned to the plant after a worker called to report the cooling problem. While one owner searched for the plant mechanic, the other went to the control room. Concerned about a possible fire, he warned employees to move away from the reactor.

Inside the reactor the pressure was still increasing, reaching 400 pounds per square inch and bursting the rupture disk. Witnesses heard a sound like a jet engine as high-pressure gas began to vent from the reactor, but it was too late. Within 10 seconds there was a massive explosion, equivalent to about 1,400 pounds of TNT. The blast damaged buildings over 1,500 feet away. Debris rocketed up to a mile. The co-owner and the operator in the control room were killed. Two operators farther away died from flying debris. Thirty-two other people were injured, including 28 at nearby businesses.

Martin Senterfitt, Jacksonville Fire Chief: This facility housed multiple types of chemicals. It was a, kind of a mass storage of everything you can think of and it was all mixed together and it was all burning together, and from our perspective, from the hazardous material side, it makes kind of a worst case scenario.

TYPES OF CHEMICAL HAZARDS

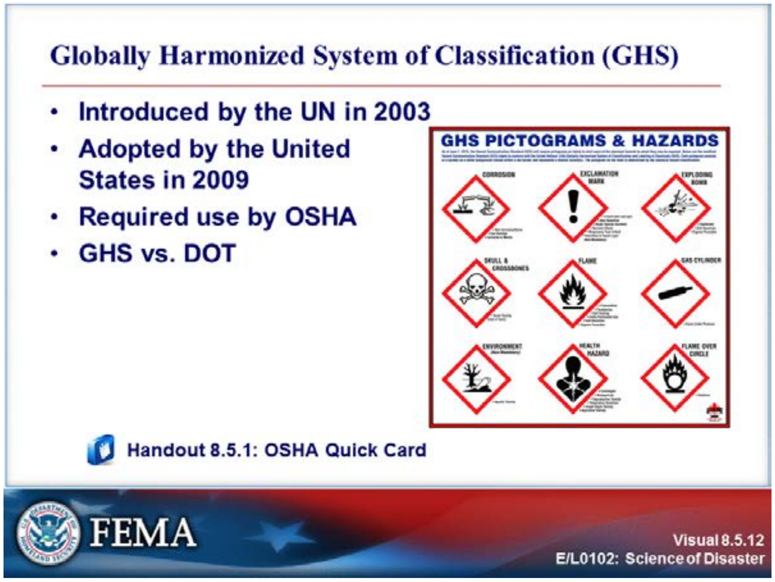
Visual 8.5.11

Key Points

This next section will discuss the various types of chemical hazards.

GHS

Visual 8.5.12



Key Points

After years of research on hazard communications and multiple incidents involving injuries or death where communication of the hazard was not effective, the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) was developed by the United Nations. The UN has identified the GHS as a multinational strategy and communication system to avoid future incidents.

The GHS includes criteria for the classification of health, physical and environmental hazards, as well as specifying what information should be included on labels of hazardous chemicals as well as safety data sheets.

Major changes to the DOT Hazard Communication Standard:

- **Hazard classification**: Chemical manufacturers and importers are required to determine the hazards of the chemicals they produce or import. Hazard classification under the new, updated standard provides specific criteria to address health and physical hazards as well as classification of chemical mixtures.
- **Labels:** Chemical manufacturers and importers must provide a label that includes a signal word, pictogram, hazard statement, and precautionary statement for each hazard class and category.
- **Safety Data Sheets**: The new format requires 16 specific sections, ensuring consistency in presentation of important protection information.
- **Information and training:** To facilitate understanding of the new system, the new standard requires that workers be trained by December 1, 2013 on the new label elements and safety data sheet format, in addition to the current training requirements.

GHS

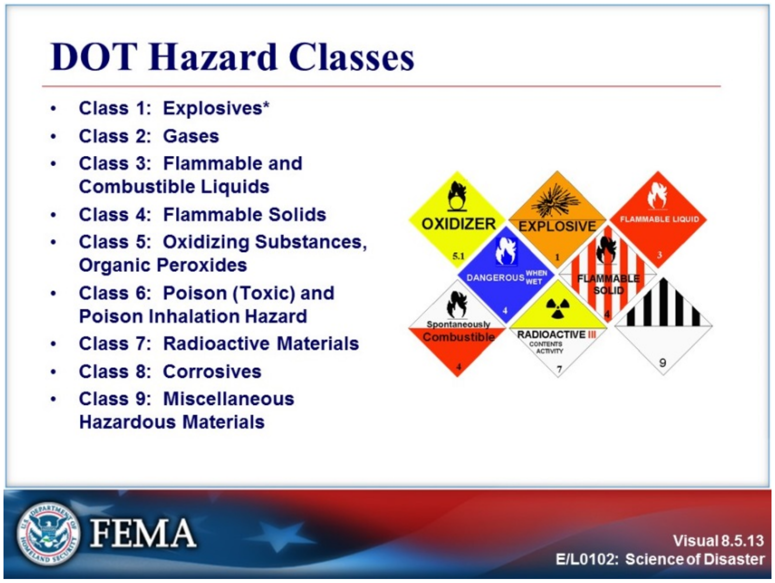
Visual 8.5.12 (continued)

Ever since OSHA implemented new chemical labeling requirements in June of 2015, there has been some confusion among chemical manufacturers in the U.S. In particular, they want to know if they should use the Global Harmonized System (GHS) of classification or U.S. Department of Transportation's (DOT) labeling system. OSHA agreed that there is no reason GHS labels cannot be included on containers that feature a DOT pictogram. The federal agency is currently in the process of revising the rule to reflect that recognition. While manufacturers wait for the official change, they are allowed to include both DOT and GHS pictograms on the same label of hazardous containers.

See Color Handout 8.5.1 OSHA Quick Card

TYPES OF CHEMICAL HAZARDS

Visual 8.5.13



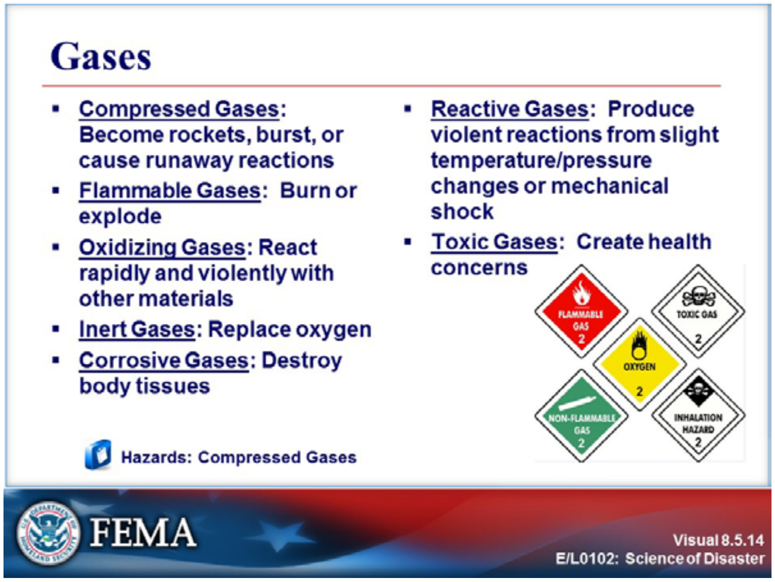
Key Points

The U.S. Department of Transportation organizes hazardous materials into nine classes. (There are other classification systems, such as the one used by the Occupational Safety and Health Administration (OSHA), which vary slightly.) The nine DOT groups are the standard classifications used by responders during a hazardous materials incident. The classes are:

- Class 1: Explosives
- Class 2: Gases
- Class 3: Flammable and Combustible Liquids
- Class 4: Flammable Solids
- Class 5: Oxidizing Substances, Organic Peroxides
- Class 6: Poison (Toxic) and Poison Inhalation Hazard
- Class 7: Radioactive Materials
- Class 8: Corrosives
- Class 9: Miscellaneous Hazardous Materials

GASES AND VAPORS

Visual 8.5.14



Alt Text for Visual 8.5.14

Gases

- Compressed Gases: Become rockets, burst, or cause runaway reactions
- Flammable Gases: Burn or explode
- Oxidizing Gases: React rapidly and violently with other materials
- Inert Gases: Replace oxygen
- Corrosive Gases: Destroy body tissues
- Reactive Gases: Produce violent reactions from slight temperature/pressure changes or mechanical shock
- Toxic Gases: Create health concerns

Key Points

Hazard Class 2, Compressed Gases, includes three divisions:

Division 2.1: Flammable gas.

Division 2.2: Non-Flammable/Non-Poisonous Compressed Gas.

Division 2.3: Gas Poisonous by Inhalation.

- **Compressed gases:** Thousands of products are available that contain gases and mixtures of gases stored under pressure in cylinders. Three major groups of compressed gases are stored in cylinders:
- **Liquefied gases:** These gases exist inside the cylinder in a liquid-vapor equilibrium. They can become liquids at normal temperatures under pressure when inside cylinders.
- **Non-liquefied gases:** These gases do not become liquid when compressed at normal temperatures, even at very high pressures.
- **Dissolved gases:** These gases are chemically very unstable and can explode even at atmospheric pressure. They become stable in solution with an inert solvent (e.g., acetylene in acetone).

GASES AND VAPORS

Visual 8.5.14 (Continued)

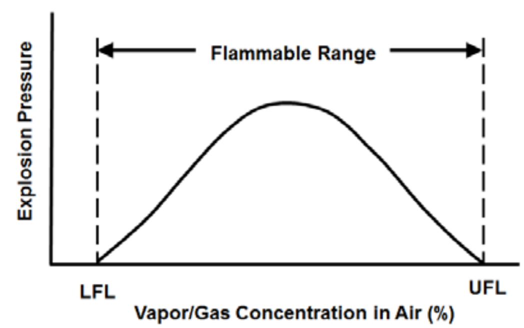
Gas pressure basics: It is helpful to understand a few basics about gas under pressure:

- **Pressure units:** The pressure of the gas in a cylinder is commonly given in units of kilopascals (kPa) or pounds per square inch gauge (psig).
- **Atmospheric pressure** is normally about 101.4 kPa (14.7 psi).
- **Gauge pressure** = Total gas pressure inside the cylinder minus atmospheric pressure.

GASES AND VAPORS

Visual 8.5.14 (Continued)

Hazards: Compressed Gases

Hazard Type	Description	Hazards
Pressure Hazards	All compressed gases are hazardous because of the high pressures inside the cylinders.	• **Leaks:** Gas can escape from open or leaking valves. • **Rocketing:** Damaged cylinders can become uncontrolled rockets (e.g., if an unsecured, uncapped cylinder is knocked over, the cylinder valve breaks and high-pressure gas escapes rapidly). • **Runaway reactions:** Poorly controlled release of compressed gas in chemical reaction systems can cause vessels to burst, create leaks in equipment or hoses, or produce runaway reactions.
Fire and Explosion Hazards	**Flammable gases:** A flammable gas is a material that is a gas at 68 °F (20 ºC) or below and 101.3 kPa of pressure (ambient temperature and pressure), i.e. the material has a boiling point of 68 °F at sea level and: • Is ignitable when in a mixture of 13% or less by volume with air, or • Has a flammability range with air of at least 12% regardless of the lower limit.	• **Fire and explosion:** A flammable gas can burn or explode when its concentration is within its lower flammable limit (LFL) and upper flammable limit (UFL). Outside this range, the gas is either too lean or too rich to burn. The flammable range of any gas is widened in the presence of oxidizing gases such as oxygen or chlorine and by higher temperatures or pressures.  • **Flash-back:** Many flammable compressed gases are heavier than air. If a cylinder leaks in a poorly ventilated area, these gases can settle and collect in low areas, and the gas trail can spread far from the cylinder. If the gas trail contacts an ignition source, the fire produced can flash back to the cylinder.

GASES AND VAPORS

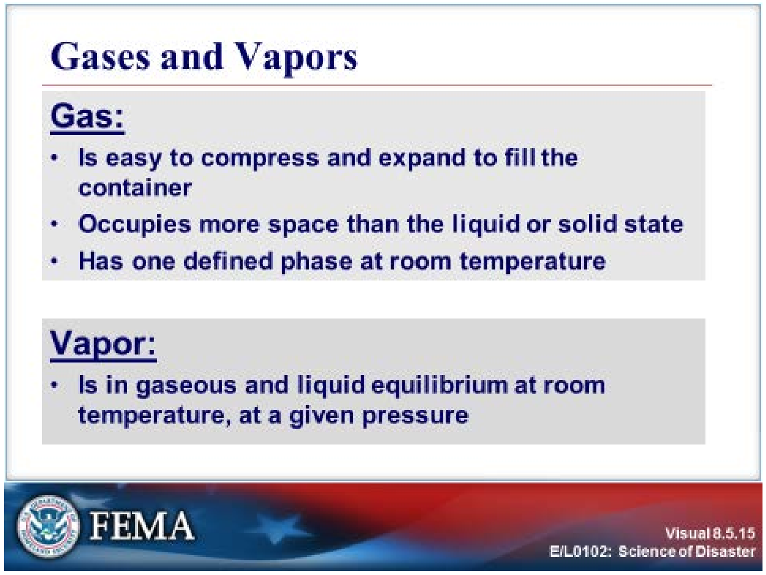
Visual 8.5.14 (Continued)

Hazards: Compressed Gases (Continued)

Hazard Type	Description	Hazards
Fire and Explosion Hazards (Continued)	**Oxidizing gases:** Oxidizing gases include any gases containing oxygen at higher than atmospheric concentrations (above 23-25%), nitrogen oxides, and halogen gases such as chlorine and fluorine.	• **Rapid, violent reactions:** Oxidizing gases can react rapidly and violently with combustible materials such as flammable gases, flammable and combustible liquids, oils, greases, many plastics and fabrics, finely divided metals, and other oxidizable compounds. • **Persistent fires:** Fires in atmospheres enriched with oxidizing gases burn much faster, can spread rapidly, and are very hard to extinguish.
	Dangerously reactive gases: Some pure compressed gases, such as acetylene and vinyl chloride, are chemically unstable. If exposed to slight temperature or pressure increases, or mechanical shock, they can readily undergo certain types of chemical reactions such as polymerization or decomposition.	• **Fire and explosion:** Chemical reactions may become violent, resulting in fire or explosion. Some dangerously reactive gases have other chemicals, called inhibitors, added to prevent these hazardous reactions.
Health Hazards	**Inert gases:** An inert gas is a gas that does not undergo chemical reactions (for example, oxidation) under a set of given conditions. The term *inert gas* is context-dependent because some gases can be made to react under certain conditions.	• **Oxygen displacement:** Inert gases can cause injury or death if they are present in sufficiently high concentrations. They can displace enough air to reduce oxygen levels. If oxygen levels are low enough, people entering the area can lose consciousness or die from asphyxiation. Low oxygen levels can particularly be a problem in poorly ventilated, confined spaces.
	Corrosive gases: Some compressed gases, such as ammonia, hydrogen chloride, chlorine, and methylamine, are corrosive.	• **Tissue destruction:** Corrosive gases can burn and destroy body tissues on contact.
	Toxic gases: Many compressed gases, such as chlorine, hydrogen sulfide, carbon monoxide, phosgene, and formaldehyde, are toxic or very toxic.	• **Varied health problems:** Toxic gases can cause various health problems depending on the specific gas, its concentration, the length of exposure, and the route of exposure. • **Burn-like injuries:** Contact between the skin or eye and liquefied gases in liquid form can freeze the tissue and result in a burn-like injury.

GASES AND VAPORS

Visual 8.5.15



Key Points

"Gas" and "vapor" may sound synonymous, but they do not refer to the same thing.

Gas: A gas has a single defined thermodynamic phase at room temperature. The molecules of a gas are in constant free motion past each other and can be compressed (also referred to as a compressible fluid). When no liquid or solid can form at the temperature of the gas, it is called a fixed gas.

Recall that in the phases of matter discussed earlier there is a "gas phase" that does not necessarily refer to a gas as a distinct element. Rather, it represents differences in interrelationships of molecules. A gas has its single gas particles vastly separated, making a gas invisible to the eye.

Vapor: A vapor is a mixture of two phases—gaseous and liquid—at room temperature. Vapor results from the two types of vaporization of a liquid—boiling and evaporation—causing the transition from liquid phase to gas phase. Evaporation occurs at the surface of the liquid when its temperature is below the boiling temperature at a given pressure. Boiling occurs below the surface of the liquid.

When a substance is at a temperature below its critical temperature, it is in a gas phase and therefore will be a vapor. A vapor can co-exist with its liquid or solid phase when they are in equilibrium state.

GASES AND VAPORS

Visual 8.5.16

Key Points

Dispersion of vapors is affected by several factors, summarized in the following table.

EXAMPLE:
Ammonia boils at -28.17^{O} F. If ammonia spills, there may be a second phase reaction, which can cause a cloud of ammonia to expand and move very quickly. Ammonia is lighter than air, and once it warms up, it tends to move up and way into the atmosphere.

GASES AND VAPORS

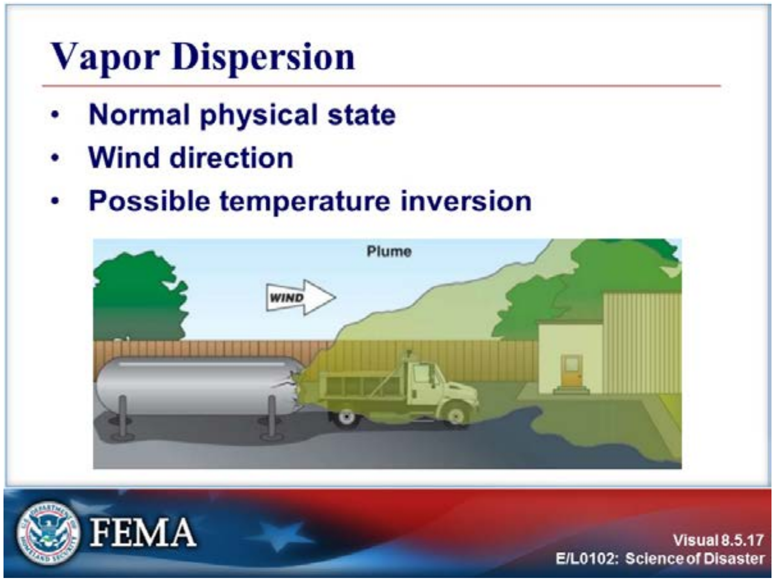
Visual 8.5.16 (Continued)

Factors That Affect Vapor Dispersion

Factor	Implications
Vapor pressure—The measurement of a particular liquid chemical's tendency to vaporize. Vapor pressure differs greatly among chemicals.	• Higher vapor pressure may disperse the chemical further. • Temperatures affect vaporization rate. • Amount of exposed surface affects vaporization rates.
Vapor density—The ratio of the density of a pure gas or vapor to the density of air. Vapor density differs at sea level vs. higher altitudes.	• Lighter density vapors float away. • Higher density vapors tend to sink.
Molecular weight—The sum of the weights of the atoms.	• Chemicals with heavier molecular weights will evaporate and float away more slowly. • Chemicals with heavier molecular weights are more likely to move along the ground rather than upward.
Atmospheric pressure—The weight of air. Atmospheric pressure differs at sea level vs. higher altitudes.	• Vapors at higher elevations travel farther than at sea level. • Gas or vapor entering the atmosphere will quickly adjust its volume; upon release, a tank of liquefied gas will expand.
Boiling point—The temperature at which a liquid boils and turns to vapor. Boiling point differs based on altitude.	• Heating liquids above their normal boiling points in sealed containers causes vapor pressures that may become very dangerously high. If pressure is not relieved, the container may burst or rupture. • If a spilled liquid is in an environment above its boiling point, it will rapidly boil and expand, and sometimes explode. • The lower the boiling point, the more likely the liquid will vaporize.

GASES AND VAPORS

Visual 8.5.17



Key Points

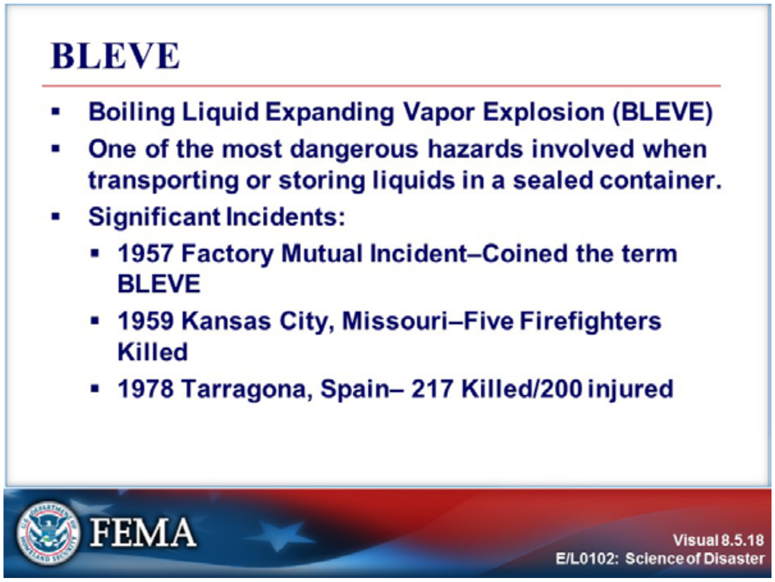
Other factors impacting vapor dispersion include:

- Normal physical state – The physical state or form of a material at normal temperature (68F)
- Wind direction – direction of the wind
- Possible temperature inversion: "An "inversion" occurs when a section of the atmosphere becomes warmer as the elevation increases. Inversion layers are a significant factor in the formation of smog in Los Angeles because they create stable atmospheric conditions. Inversions act to prevent mixing in the lower regions of the troposphere, so pollutants become trapped quite easily and contribute to the formation of smog." An inversion layer can trap gasses and vapors near the surface.

These concepts will impact you as an emergency manager. Understanding the above may impact your community and the response actions you may take.

BLEVE

Visual 8.5.18



Alt Text for Visual 8.5.18
BLEVE

- Boiling Liquid Expanding Vapor Explosion (BLEVE)
- One of the most dangerous hazards involved when transporting or storing liquids in a sealed container.
- Significant Incidents:
  - 1957 Factory Mutual Incident–Coined the term BLEVE
  - 1959 Kansas City, Missouri–Five Firefighters Killed
  - 1978 Tarragona, Spain– 217 Killed/200 injured

Key Points

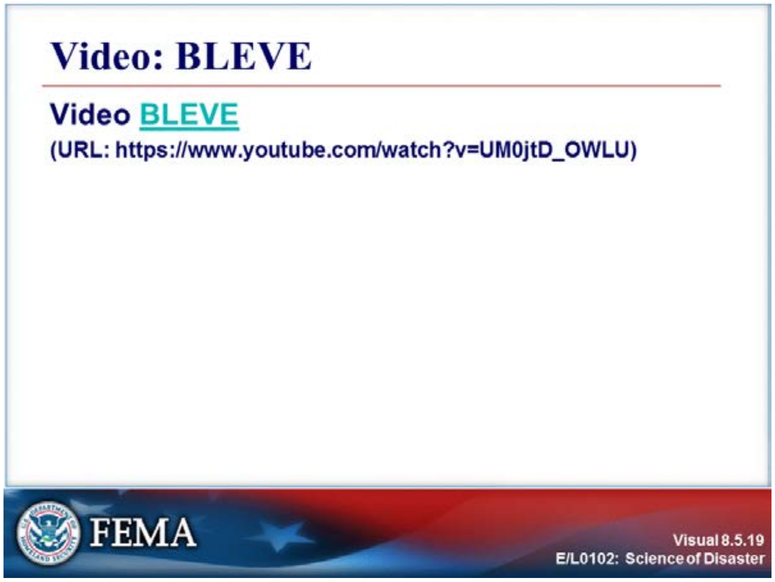
“BLEVE is an acronym that was first coined by three Factory Mutual (FM) researchers.

There are three characteristics of liquids which are relevant to the discussion of a BLEVE:

- If a liquid in a sealed container is boiled, the pressure inside the container increases. As the liquid changes to a gas it expands - this expansion in a vented container would cause the gas and liquid to take up more space. In a sealed container the gas and liquid are not able to take up more space and so the pressure rises. Pressurized vessels containing liquids can reach an equilibrium where the liquid stops boiling and the pressure stops rising. This occurs when no more heat is being added to the system (either because it has reached ambient temperature or has had a heat source removed).
- The boiling temperature of a liquid is dependent on pressure - high pressures will yield high boiling temperatures, and low pressures will yield low boiling temperatures. A common simple experiment is to place a cup of water in a vacuum chamber, and then reduce the pressure in the chamber until the water boils. By reducing the pressure, the water will boil even at room temperature. This works both ways - if the pressure is increased beyond normal atmospheric pressures, the boiling of hot water could be suppressed far beyond normal temperatures. The cooling system of a modern internal combustion engine is a real-world example.
- When a liquid boils it turns into a gas. The resulting gas takes up far more space than the liquid did.

BLEVE

Visual 8.5.19



Key Points

Introduction: This video is a training demonstration of BLEVE (Boiling Liquid Expanding Vapor Explosion)

Video Transcript:

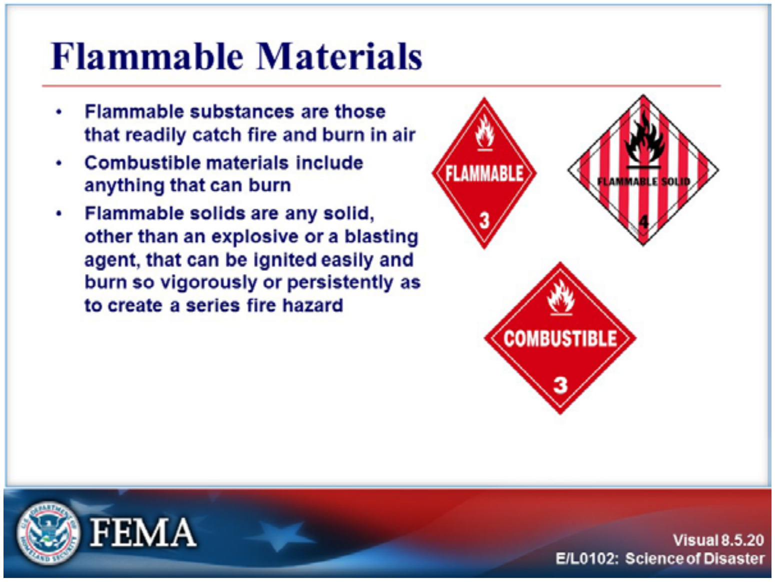
Narrator: When a tank is exposed to sustained heat, such as from a fire, the liquid within the tank is forced to boil or vaporize resulting in increased pressure in the tank. To prevent over stressing the tank the relief device activates, venting the excess pressure.

As pressure decreases in the tank the valve begins to close. With continued heating pressure again builds causing the relief valve to reopen. Where flames impinge on the tank below the liquid level, the liquid absorbs the heat allowing the tank metal to remain at a safe temperature. With continued relief valve operation, the liquid level drops exposing a greater area of the tank to the effects of heating. With the flames impinging on the vapor space of the tank, the temperature of the tank metal uncooled by liquid rises.

At some point due to the vapor pressure from within the tank metal begins to weaken, stretch, and eventually tear. As the tank comes apart large quantities of both liquid and vapor are released in a powerful explosion. The heat radiated is sufficient to ignite combustibles and cause burns great distances from the explosion. Tank sections containing rapidly igniting fuel can become flying missiles traveling great distances, causing secondary fires and other damage. It all happens quickly with little warning.

FLAMMABLES, COMBUSTIBLES, AND OXIDIZERS

Visual 8.5.20



Alt Text for Visual 8.5.20
Flammable Materials

- Flammable substances are those that readily catch fire and burn in air
- Combustible materials include anything that can burn
- Flammable solids are any solid, other than an explosive or a blasting agent, that can be ignited easily and burn so vigorously or persistently as to create a series fire hazard

Key Points

Before discussing the next hazard class (flammable and combustible liquids), let's consider a few concepts related to flammability, combustibility, and fire chemistry.

Flammable substances are materials that can easily catch fire under normal circumstances and with the help of minimal ignition source. Just a spark is sufficient. A good example of a flammable substance is propane. (What is considered "flammable" differs among organizations.)

Combustible materials include anything that can burn. More vigorous conditions are required for a combustible material to burn. A simple spark is definitely not enough. Paper and wood are good examples of combustible materials.

Hazard Class 4 consists of three divisions. U.S. DOT defines these divisions as follows:

- **Division 8.2, Flammable Solids**—Any solid material other than one classed as an explosive that, under conditions normally incident to transportation, is likely to cause fires through friction or retained heat from manufacturing or processing, or that can be ignited readily and, when ignited, burns so vigorously and persistently as to create a serious transportation hazard.
- **Division 4.2, Spontaneously Combustible**—A liquid or solid pyrophoric material that even in small amounts and without an external ignition source can ignite within 5 minutes after coming in contact with air, or a self-heating material that when in contact with air and without an energy supply is liable to self-heat.

FLAMMABLES, COMBUSTIBLES, AND OXIDIZERS

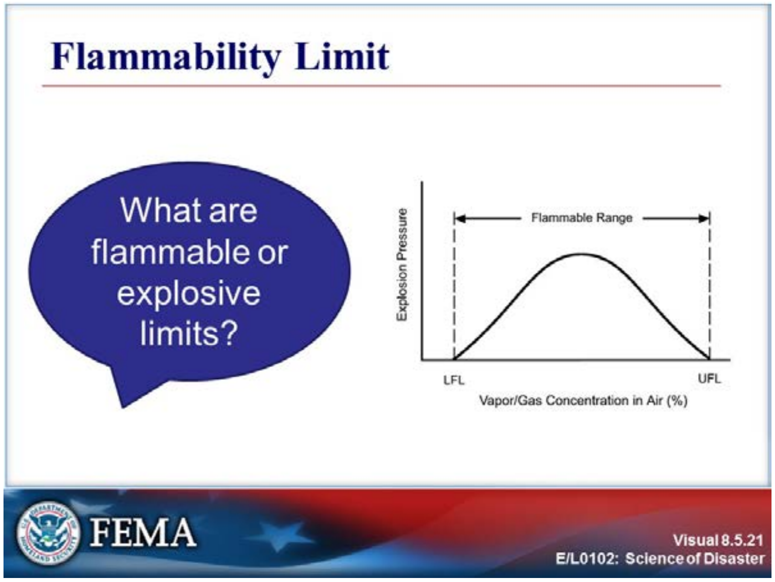
Visual 8.5.20 (continued)

- **Division 4.3, Dangerous When Wet**—A material that, by contact with water, is likely to become spontaneously flammable or to give off flammable or toxic gas at a rate greater than 1 liter per kilogram of the material per hour.

Examples of flammable solids include certain metallic hydrides, metallic sodium and potassium, oily fabrics, processed metals, matches, and nitrocellulose products.

FLAMMABILITY LIMIT

Visual 8.5.21

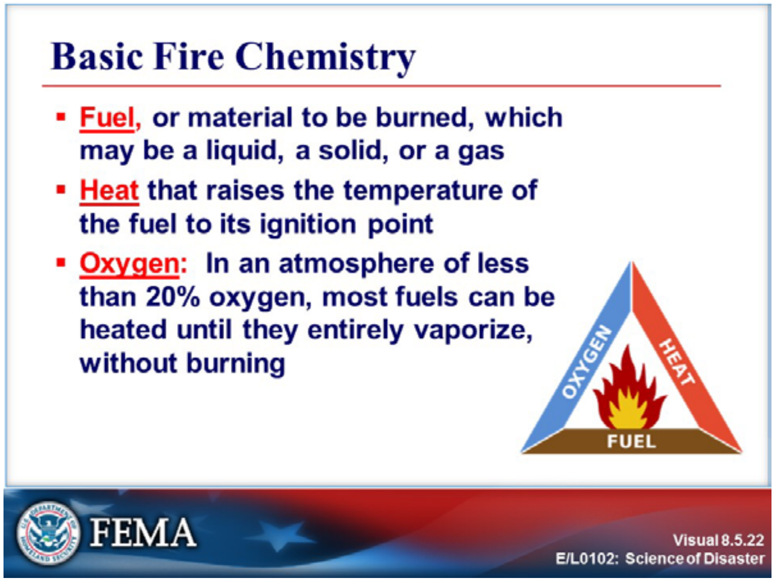


Key Points

<u>Discussion Question:</u> What are flammable or explosive limits?

FLAMMABLES, COMBUSTIBLES, AND OXIDIZERS

Visual 8.5.22



Alt Text fir Visual 8.5.22

Basic Fire Chemistry

- Fuel, or material to be burned, which may be a liquid, a solid, or a gas
- Heat that raises the temperature of the fuel to its ignition point
- Oxygen: In an atmosphere of less than 20% oxygen, most fuels can be heated until they entirely vaporize, without burning

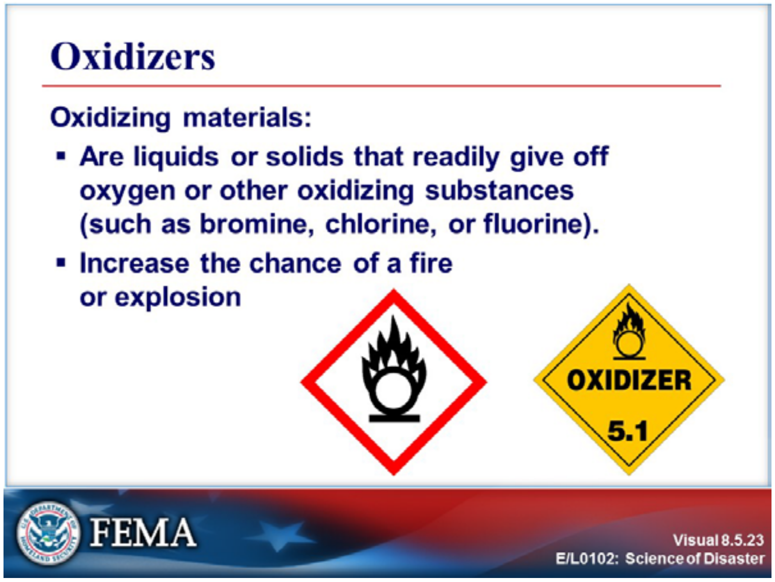
Key Points

Three elements are required to create a chemical exothermic reaction (fire): fuel, heat, and an oxidizing agent (usually oxygen). A fire naturally occurs when the elements are present and combined in the right mixture. If you take any one of these elements away and permanently interrupt the reaction, the fire goes out. Together these elements are called the fire triangle or combustion triangle.

- **Fuel:** Without fuel, a fire will stop. Fuel can be removed naturally (as when the fire has consumed all the burnable fuel) or manually, by mechanically or chemically removing the fuel from the fire. When fuel is removed, the fire stops because a lower concentration of fuel vapor in the flame leads to a decrease in energy release and a lower temperature. Removing the fuel thereby decreases the heat.
- **Heat:** Without sufficient heat, a fire cannot begin, and it cannot continue. Heat can be removed by the application of a substance that reduces the amount of heat available to the fire reaction.
- **Oxygen:** Without sufficient oxygen, a fire cannot begin, and it cannot continue. With decreased oxygen concentration, the combustion process slows.

FLAMMABLES, COMBUSTIBLES, AND OXIDIZERS

Visual 8.5.23



Key Points

Description: Hazard Class 5 includes two divisions: oxidizers and organic peroxides. Oxidizing materials are liquids or solids that readily give off oxygen or other oxidizing substances. They also include materials that react chemically to oxidize combustible materials. This means that oxygen combines chemically with the other material in a way that increases the chance of a fire or explosion. This reaction may be spontaneous at either room temperature or may occur under slight heating.

EXAMPLE:
Ammonium perchlorate is an oxidizing material with many uses in industry, construction, agriculture, and life support systems. Ammonium perchlorate:

- Can decompose at high temperatures forming toxic gases, such as chlorine, hydrogen chloride, and nitrogen oxides. Closed containers or tanks may rupture and explode if heated
- Does not burn but is a powerful oxidizer and explosive when mixed with combustible materials
- Is highly reactive, and impact or high temperatures can cause violent decomposition or explosion
- Can form shock-sensitive mixtures with finely powdered metals, metal oxides, strong reducing agents, sulfur, and phosphorus
- May cause eye irritation

FLAMMABLES, COMBUSTIBLES, AND OXIDIZERS

Visual 8.5.23 (Continued)

Examples: Common oxidizers are:

- Concentrated nitric acid.
- Compressed oxygen.
- Hydrogen peroxide.

There are other chemicals that are oxidizing materials. For example, liquid air has been involved in many explosions because of its oxidizing properties. Liquid air itself has about 30% oxygen, which makes it a powerful oxidant. However, when liquid air evaporates, it becomes richer in oxygen content as more volatile components evaporate slightly faster.

Impact of oxidizing materials: Oxidizing materials can:

- Speed up the development of a fire and make it more intense.
- Cause substances that do not normally burn readily in air to burn rapidly.
- Cause combustible materials to burn spontaneously without the presence of an obvious ignition source such as a spark or flame.

What happens when an oxidizing material comes in contact with a combustible substance largely depends on the chemical stability of the oxidizing material. The less stable an oxidizing material is, the greater the chance that it will react in a dangerous way.

The following table summarizes the hazards associated with oxidizing materials.

Hazards: Oxidizing Materials

Hazard Type	Hazards
Fire and Explosion Hazards	• **Oxygen supplier:** Oxidizing materials increase the chance of a severe fire or explosion because they provide plenty of oxygen to make a fire bigger and hotter. In fact, they can supply oxygen to a fire and support combustion even if there is no oxygen present in the air. • **Explosive mixtures:** Although most oxidizing materials do not burn themselves, they can produce very flammable or explosive mixtures when combined with combustible materials such as: o Organic materials (e.g., paper, wood, flammable and combustible liquids, greases, waxes, many plastics and textiles). o Finely divided metals. o Other oxidizable substances (e.g., hydrazine, hydrogen, sulphur, phosphorous, silicon, and ammonia). • **Incompatibilities:** Some oxidizing materials are also incompatible with noncombustible materials. These oxidizers can undergo dangerous reactions with water, inorganic acids, or even other oxidizing materials.
Health Hazards	• **Toxic/corrosive:** Oxidizing materials may be toxic or corrosive. • **Health issues:** Depending on the material, route of exposure, and dose, they could harm the body.

TOXIC AND INFECTIOUS SUBSTANCES

Visual 8.5.24

Alt Text for Visual 8.5.24

Toxic and Infectious Substances

- A toxic substance is a poisonous material, other than a gas, that is known to be so toxic to humans as to cause death, injury, or harm to human health
- An infectious substance is a material known or reasonably expected to contain a pathogen. (This will be covered in the next unit.)

Key Points

Hazard Class 6 includes:

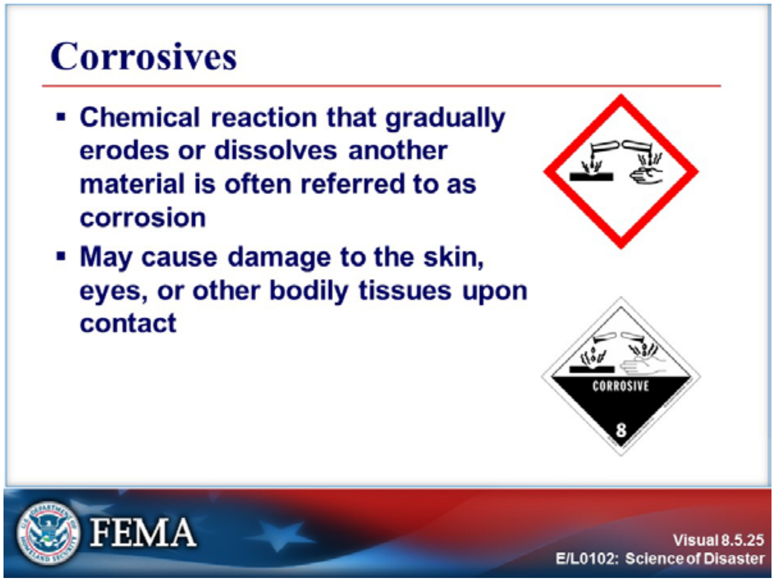
- Division 6.1: Poisonous or Toxic Substances.
- Division 6.2: Infectious Substances.

A **toxic substance** is a poisonous material, other than a gas, that is known to be so toxic to humans as to cause death, injury, or harm to human health if swallowed, inhaled, or brought into contact with skin.

An **infectious substance** is a material known or reasonably expected to contain a pathogen. Infectious substances will be covered in the next unit.

CORROSIVES

Visual 8.5.25



Key Points

Hazard Class 8 is Corrosives.

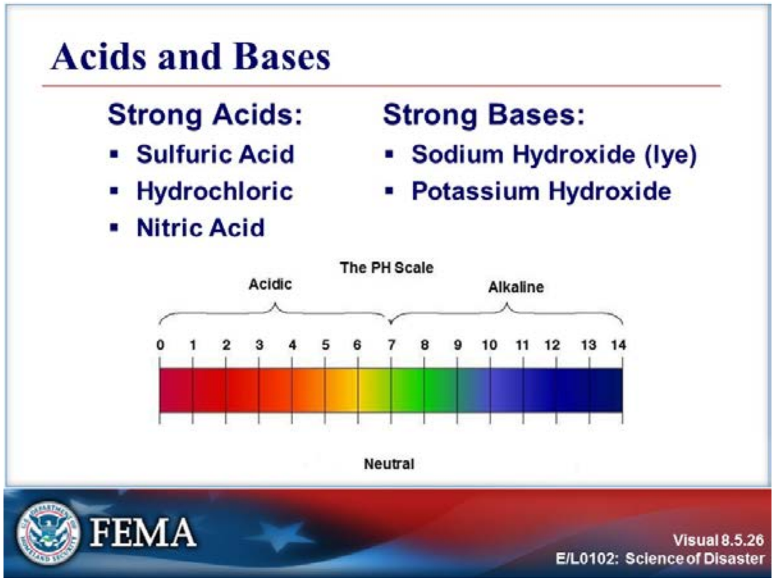
Corrosives are materials that can attack and chemically destroy another material, such as exposed body tissues or even metal.

They begin to cause damage as soon as they touch the skin, eyes, respiratory tract, digestive tract, or the metal.

Corrosives might be hazardous in other ways, too, depending on the particular corrosive material.

CORROSIVES

Visual 8.5.26



Key Points

Acids and bases: Most corrosives are either acids or bases (alkaline). The relative acidity or alkalinity of a substance is measured on the pH scale.

- An **acid** is a substance that donates hydrogen ions. When an acid is dissolved in water, the balance between hydrogen ions and hydroxyl ions is shifted, resulting in more hydrogen ions than hydroxyl ions in the solution. This kind of solution is acidic. Examples of strong acids include hydrochloric acid (HCL), hydrofluoric acid (HF), nitric acid (HNO3), and sulfuric acid (H2SO4).
- A **base** is a substance that accepts hydrogen ions. When a base is dissolved in water, the balance between hydrogen ions and hydroxyl ions shifts the opposite way. Because the base “soaks up” hydrogen ions, the result is a solution with more hydroxyl ions than hydrogen ions. This kind of solution is alkaline. Examples of strong bases include sodium hydroxide (NaOH) and potassium hydroxide (KOH).

Corrosiveness: The corrosiveness of an acid or base refers to how severely it damages surfaces upon contact, specifically living tissue. Strong acids and bases such as hydrofluoric acid and sodium hydroxide have a very high or very low pH and are extremely corrosive, requiring extensive precautions when handling because they eat through tissue and even bone. While acids and bases damage tissues in somewhat different ways (burning vs. emulsifying), the end result is often irreversible damage at the site of the injury.

CORROSIVES

Visual 8.5.26 (Continued)

pH scale: The pH scale ranges from 0 to 14 and is logarithmic, meaning that each numerical increase on the pH scale represents a tenfold increase in acids and base concentration relative to pure water measured at 7.0 pH. (For example, a 6.0 pH is 10 times more acidic than 7.0 pH; a 5.0 is 100 times more acidic than 7.0 pH.)

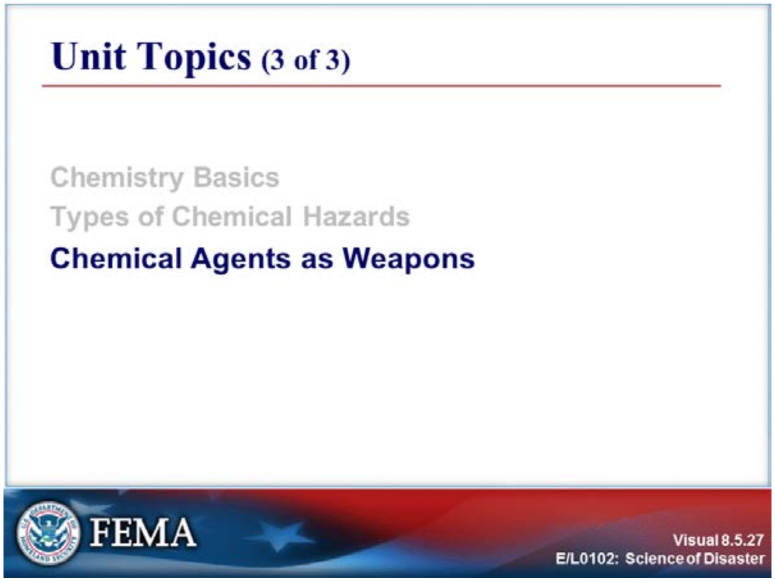
Distilled water is 7 (right in the middle of the scale). Acids are found between 0 and 7. Bases are from 7 to 14. Most of the liquids you find every day have a pH near 7. However, the pH of chemicals can reach both extremes.

Health effects of acids: Different corrosives can have different health effects on the human body.

- **Localized damage:** If splashed with a hydrochloric acid solution on 25 square inches (5 x 5) of skin, an immediate sensation of burning will take place and the tissue that was exposed will burn and decompose until the acid is flushed away or neutralized. While the exposed tissues will be damaged, there is no danger of the exposure going “systemic” (body-wide) and killing the person—although infection could be a problem later.
- **Systemic damage:** With systemic damage, the poison causes damage beyond the initial exposed area—for example by contaminating the blood or targeting one or more vital organs. If splashed with a 2% solution of hydrofluoric acid on 25 square inches of skin, the skin will not burn away as with other acids. Rather, the chemical will move to the bone and cause the bone to decompose. The effect will be systemic as the acid lowers the body’s calcium level, causing confusion, dizziness, and fainting. Besides the extreme pain of the bone being eaten away, without immediate medical attention, the victim will die.

CHEMICAL AGENTS AS WEAPONS

Visual 8.5.27



Key Points

We have taken a brief look at the science of chemical reactions and reviewed the various classes of chemical hazards. The next section of this unit will discuss the kinds of chemical agents that are most commonly used as weapons.

CHEMICAL AGENTS AS WEAPONS

Visual 8.5.28

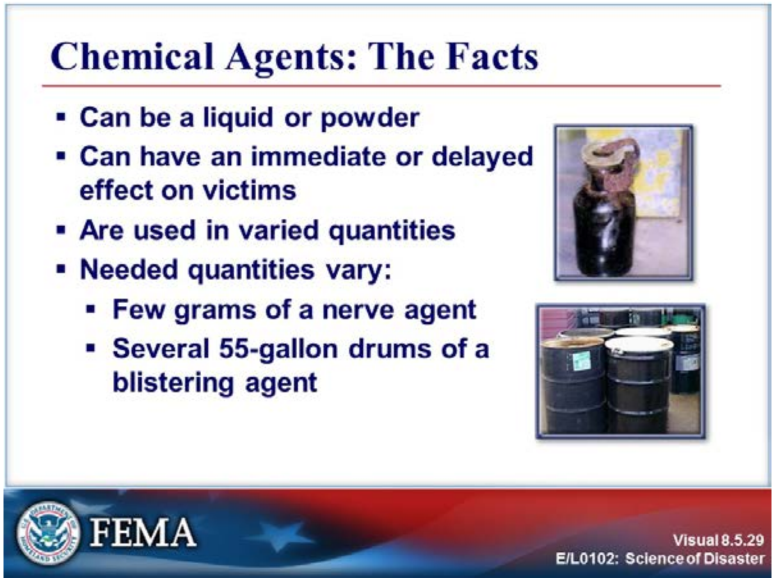
Key Points

What makes chemicals attractive as weapons of terror? Several factors make chemical agents advantageous as weapons:

- **Manufacture:** Chemical weapons are relatively safe and easy to manufacture, with little specialized knowledge or training.
- **Concealment:** Chemical weapons are easily concealed in domestic industry. Chemicals intended for a terrorist purpose look very similar to chemicals intended for industrial uses.
- **Precursors:** Precursors for chemical weapons are available. Ingredients for many chemical weapons are found in common products found in the home or garage, from cleaning products to pesticides. Moreover, a vast array of potentially harmful chemicals have legitimate uses in industry, research, medicine, and other fields, and can easily be obtained.
- **Handling and storage:** Chemical weapons are relatively safe to handle and store as long as basic guidelines are followed.
- **Mass casualties:** Chemical weapons are capable of causing mass casualties, especially when dispersed in aerosol or vapor form. Although many are extremely volatile and dissipate rapidly outdoors, large amounts are not needed indoors to have a deadly impact.
- **Survival:** Because chemical are not living organisms, many chemicals can survive dissemination and continue to cause damage over time.

CHEMICAL AGENTS AS WEAPONS

Visual 8.5.29



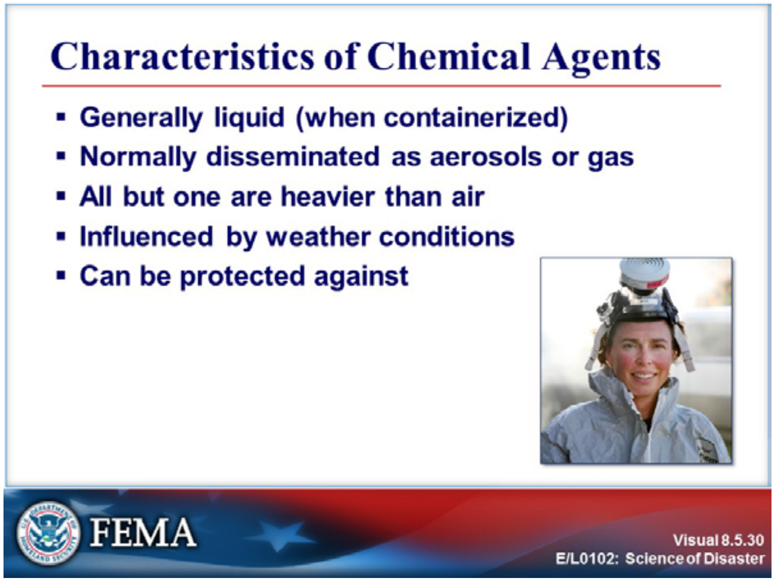
Key Points

Let's begin with a few basic facts about chemical agents.

- Chemical agents can be a liquid or a powder.
- They can have an immediate effect on victims (but some have a delayed effect and may not affect victims for 12 hours or more).
- Different chemical agents are used in varied quantities, from a few grams to gallons.
- The quantities needed vary. For example, nerve agents require only a few grams, whereas blister agents and blood agents require gallons to have a widespread effect.

CHEMICAL AGENTS AS WEAPONS

Visual 8.5.30



Key Points

In general, chemical agents:

- Are liquid when containerized (even though they are often referred to as gases). Some boil at low temperatures and become gases when exposed to the atmosphere.
- Are normally disseminated as aerosols or as gases, and thus will dissipate with time.
- Are influenced by weather conditions (temperature, wind speed, wind direction, humidity, and air stability).
- Can be protected against, treated, and decontaminated.

CHEMICAL AGENTS AS WEAPONS

Visual 8.5.31

Key Points

Chemical agents are classified as either (1) lethal agents, or (2) less than lethal agents, according to their intended use. Less than lethal agents, are agents that can kill you but aren't meant to.

Our focus is on lethal agents because of their greater potential for terrorist use. Less than lethal agents are not considered as primary terrorist threats, due primarily to their relatively short duration of effects and minimal toxicity.

Lethal agents are subdivided into:

- **Industrial materials** (choking agents and blood agents), which have various legitimate applications.
- **Military agents** (blister and nerve agents), which have little or no other purpose beyond their destructive nature.

CHEMICAL AGENTS AS WEAPONS

Visual 8.5.32

Alt Text for Visual 8.5.32
Chemical Agents

- Chemicals used by terrorists are manmade substances that are toxic to the human body.
    - Industrial Chemicals:
    - Large quantities for chemical processes
    - Easily available
- Common materials: chlorine/phosgene
- Military Agents:
    - Small quantity yields heavy casualties
    - Heavily regulated
    - Difficult, dangerous to produce
    - Common materials: nerve and blister agents

Book Reference: Chemical Agents

Key Points

Industrial chemicals are materials that have legitimate industrial uses but are also used or considered as chemical warfare agents. For example, chlorine/phosgene, hydrogen cyanide, cyanogen, and chloride are four chemical agents commonly used in the sanitation, plastics, and pesticide industries that are known to have been used as chemical warfare agents.

Industrial chemicals exist in large quantities for use in chemical processes and are therefore easily available. Common materials include chlorine and phosgene.

These agents are respiratory agents and can be protected against by effective respiratory protection, although skin contact with concentrated material may cause chemical burns. They are all exceedingly volatile and dissipate rapidly outdoors.

CHEMICAL AGENTS AS WEAPONS

Visual 8.5.32

Military agents were solely designed for battle field use. However, these agents appeal to terrorists because a small amount can cause a large number of casualties. These agents are not easy to obtain due to regulations on the material needed to produce them. They are also very dangerous and difficult to produce. Common military agents are nerve and blister agents that were strictly developed as military weapon as weapons of mass destruction (WMD).

The following tables summarize key facts about industrial and military chemical agents.

CHEMICAL AGENTS AS WEAPONS

Visual 8.5.32 (Continued)

Chemical Agents—Industrial Materials

Common Name/Symbol	**Chlorine (Cl)**	**Phosgene (CG)**	**Hydrogen Cyanide (AC)**	**Cyanogen Chloride (CK)**
Military Class	Choking agent		Blood agent	
Industrial Use	Purification	Plastics	Electroplating, dyes	
Odor	Bleach	Mown hay	Bitter almonds	
Symptoms	Coughing Choking Tightness in chest		Gasping for air Red eyes, lips, skin	
Hazard	Inhalation/skin			
First Aid	Aeration		Aeration, cyanide kit	
Decontamination	Aeration			

Chemical Agents—Military Blister Agents

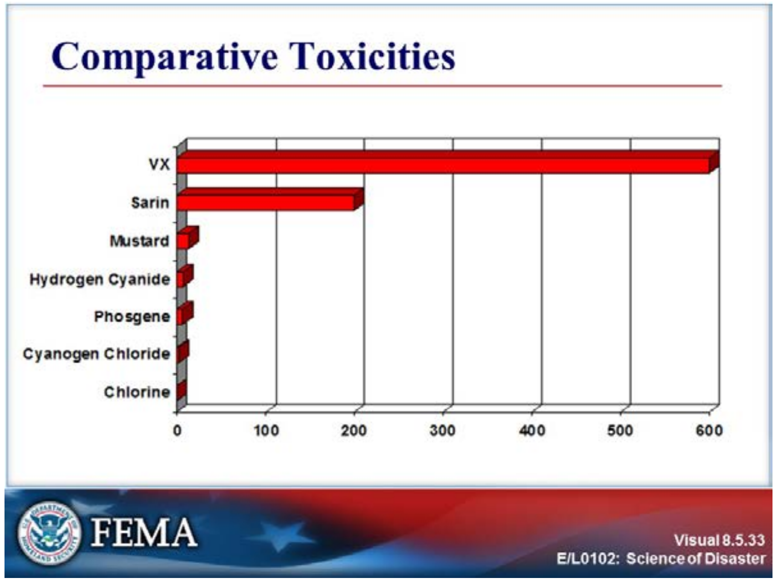
Common Name/Symbol	**Sulfur Mustard (HD)**	**Nitrogen Mustard (HN-3)**	**Lewisite (L)**	**Phosgene Oxime (CX)**
Military Class	Mustards		Arsenical	Nettle agent
Odor	Garlic	Fishy	Geraniums	Irritating
Appearance	Oily, yellow-brown	Oily, clear	White solid	**Colorless crystalline solid or yellowish-brown liquid**
Symptoms	Eyes: Burning, gritty Skin: Delayed blisters Lungs: Raspy cough, severe damage		Skin: Immediate Lungs: Searing	pain, delayed blisters pain, severe damage
Protection	Respiratory and skin			
First Aid	Decontaminate			

Chemical Agents—Military Nerve Agents

Series	**G-Series**	**V-Series**
Common Name/Symbol	Tabun (GA), Sarin (GB), Soman (GD	V-Agents: VX, Vx
Odor	Fruity	Sulfur
Symptoms	Pinpointing of pupils Vomiting/diarrhea Difficulty breathing	Salivation Twitching Convulsions
Protection	Respiratory and skin	
Self/First Aid	Atropine + 2-PAM Chloride	
Decontamination	Removal; flush with water	

TOXIC AND INFECTIOUS SUBSTANCES

Visual 8.5.33



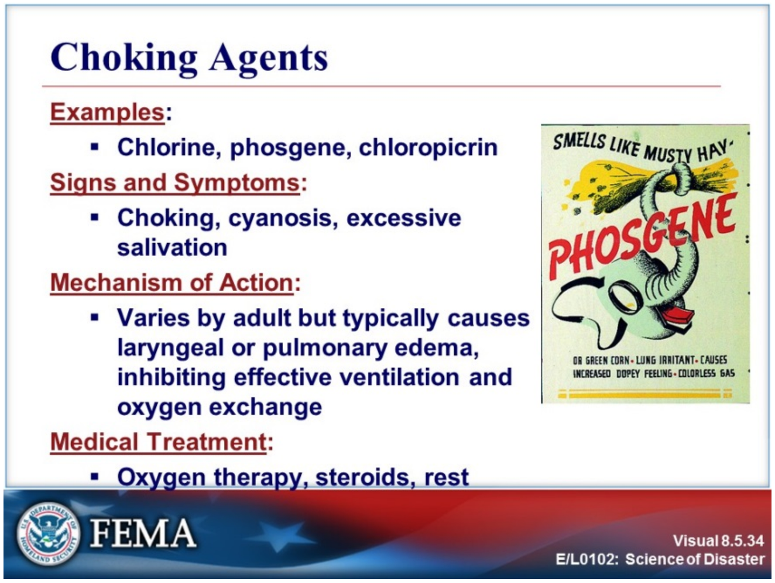
Key Points

The visual shows a graphic comparison of the approximate lethalities of several chemical agents that will be discussed later in this unit. They are based relative to chlorine in terms of **inhalation toxicity.**

For **skin toxicity,** 10 milligrams of VX equals 1 to 2 grams of mustard or sarin. Less than a pinhead of mustard is required to achieve a small blister, less than a pinhead of VX can be lethal.

CHOKING AGENTS

Visual 8.5.34



Alt Text for Visual 8.5.34
Choking Agents
Examples:
- Chlorine, phosgene, chloropicrin

Signs and Symptoms:
- Choking, cyanosis, excessive salivation

Mechanism of Action:
- Varies by adult but typically causes laryngeal or pulmonary edema, inhibiting effective ventilation and oxygen exchange

Medical Treatment:
- Oxygen therapy, steroids, rest

Key Points

Choking agents are the most basic of the chemical weapons. They act by inhibiting the pulmonary system's ability to effectively ventilate or transfer oxygen across the pulmonary membrane in the lungs.

The exact mechanism varies with each choking agent, however most all cause edema (fluid buildup) in the tissue around the larynx or within the lungs. The best treatment for victims is to remove them from the environment and provide them supplemental high concentration oxygen. Corticosteroids have been shown to be effective in reducing inflammation of the tissue and aid in returning to normal air exchange. However, most treatments are supportive in nature.

BLOOD AGENTS

Visual 8.5.35

Alt Text for Visual 8.5.35
Blood Agents
<u>Examples</u>:
- Cyanide (CN), cyanogen chloride (CNCL)

<u>Signs and Symptoms</u>:
- Air hunger, tachycardia, seizures

<u>Mechanism of Action</u>:
- Prevents aerobic metabolism at the tissue level causing cellular hypoxia and profound lactic acidosis

<u>Medical Treatment</u>:
- Hyperbaric treatment, cyanide antidote kit (amyl nitrate and sodium nitrate)

Key Points

Blood agents have been used in warfare as early as World War I. Discovered by Swedish chemist Cheele in 1782, cyanide has been used in a number of terrorist and criminal acts including the cyanide laced drinks used by Jim Jones' People's Temple in Guyana in 1978, the sarin attacks on the Tokyo subway in 1995, and it is purported there was cyanide laced with the explosives used at the first World Trade Center attack in 1993.

Cyanide acts at the cellular level to inhibit the body's ability to transport oxygen. Thus, the body switches to anaerobic metabolism to produce the necessary energy. The anaerobic metabolism produces lactic acid throughout the body thereby causing seizures, cardiac dysrhythmias, cyanosis, and eventually death. The body literally chokes to death at the cellular level. Medical treatment involves removing the victim from the environment, providing high concentration atmospheric oxygen through the use of a hyperbaric chamber, and in some cases, the use of Amyl Nitrate and Sodium Nitrate may be used to assist in the excretion of excess cyanide in the body.

BLISTER AGENTS

Visual 8.5.36

Alt Text for Visual 8.5.36
Blister Agents
Examples:
- Mustard, Lewisite, Phosgene

Signs and Symptoms:
- Dermal blisters, photophobia, respiratory distress, GI distress

Mechanism of Action:
- Varies based on agent. Many cause irritation of exposed tissues, fluid and electrolyte imbalances, edema, and leukocytosis

Medical Treatment:
- No known treatment. Supportive care is indicated

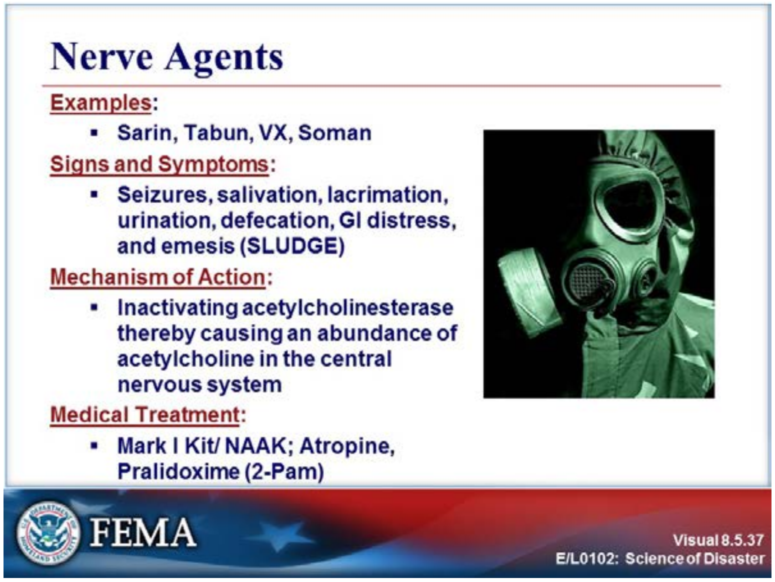
Key Points

Blister agents are best known for their classic blistering of the skin. However, blister agents have a variety of impacts beyond the dermal layer that cause significant complications. For example, Mustard acts at a cellular level to inhibit glycolysis (the ability of a cell to create energy). Additionally, the blistering causes massive fluid shifts and electrolyte imbalances within the body. In turn this can cause significant or fatal symptoms including respiratory distress and cardiac dysrhythmias.

Finally, high-doses of blister agents have been shown to cause leukocytosis (death of white blood cells) thereby leaving victims vulnerable to opportunistic infections for days or even weeks after exposure.

NERVE AGENTS

Visual 8.5.37



Alt Text for Visual 8.5.37
Nerve Agents
Examples:
- Sarin, Tabun, VX, Soman

Signs and Symptoms:
- Seizures, salivation, lacrimation, urination, defecation, GI distress, and emesis (SLUDGE)

Mechanism of Action:
- Inactivating acetylcholinesterase thereby causing an abundance of acetylcholine in the central nervous system

Medical Treatment:
- Mark I Kit/ NAAK; Atropine, Pralidoxime (2-Pam)

Key Points

Originally intended to be developed as an insecticide, the first nerve agents were developed between World Wars One and Two. The vast majority of nerve agents are classified as organophosphorus chemicals. You may hear the terms nerve agent poisoning or organophosphate poisoning as interchangeable. The latter is usually heard when referring to patients exposed to insecticides or pesticides in a civilian context. Nerve agents work by inhibiting the reuptake of the achetocholine (ACH) in the central nervous system. Because ACH acts as a neurotransmitter for muscle contractions, an abundance of ACH causes global overstimulation of the muscles causing systemic contractions (seizures). Additionally, nerve agents overstimulate the parasympathetic nervous system causing pupil dilatation and loss of bladder and gastrointestinal control.

NERVE AGENTS

Visual 8.5.37

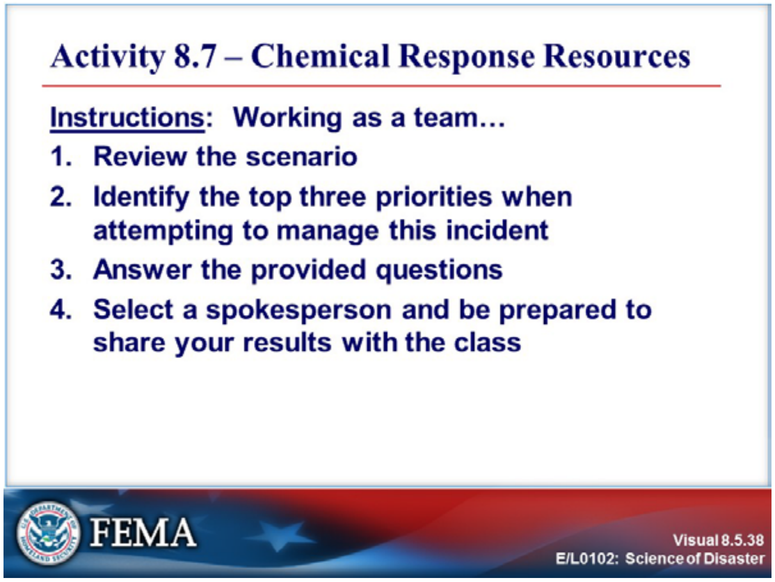
First responders are often taught the pneumonic SLUDGE to identify nerve or organophosphate poisoning:

- Salivation
- Lacrimation
- Urination
- Defecation
- Gastrointestinal Distress
- Emesis.

The most effective treatment is a combination of Atropine and Pralidoxime (2-Pam) also packaged together by the military as a Mark I kit with auto-injectors (exactly like an epinephrine pen). The atropine works manly to reduce bronchospasms in the lungs, re-enabling effective respiration. However, Pralidoxime is needed to help with the reduction of muscle contractions/seizure activity.

ACTIVITY 8.7 – CHEMICAL RESPONSE RESOURCES

Visual 8.5.38



Key Points

Instructions: Working as a team…

1. Review the scenario.
2. Identify the top 3 priorities when attempting to manage this incident.
3. Answer the provided questions.
4. Select a spokesperson, and be prepared to share your results with the class.

Scenario:
At approximately 3am two freight trains collided with each other in your community. One of the freight trains was carrying chlorine gas, sodium hydroxide, and cresol. One of the rail cars has ruptured, releasing about 60 tons of chlorine gas. The immediate community is a mix of industrial production and residential.

ACTIVITY 8.7 – CHEMICAL RESPONSE RESOURCES

Visual 8.5.38 (Continued)

Activity 8.7 Worksheet

1. As an emergency management professional, identify your top three priorities when attempting to manage this incident.

2. What are the impacts of chlorine gas to the surrounding community?

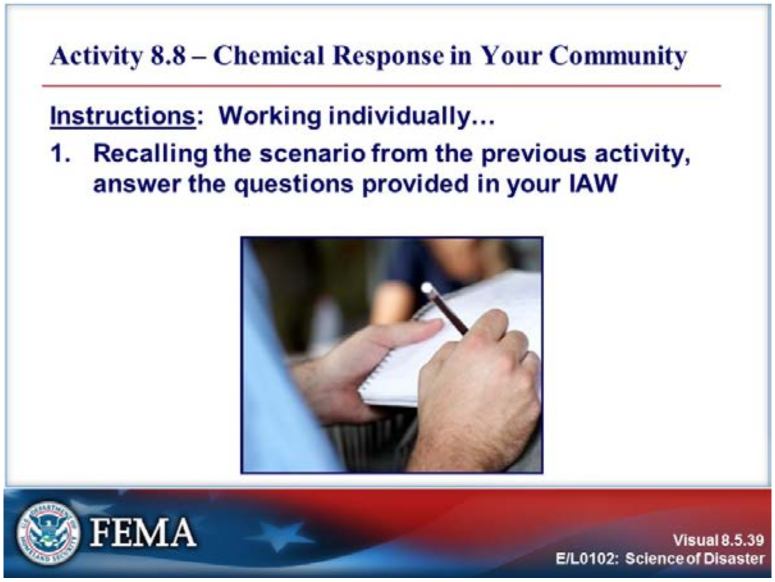
3. What are the health impacts?

4. What is the impact to your first responders?

5. How did you find this information?

ACTIVITY 8.8 – CHEMICAL RESPONSE IN YOUR COMMUNITY

Visual 8.5.39



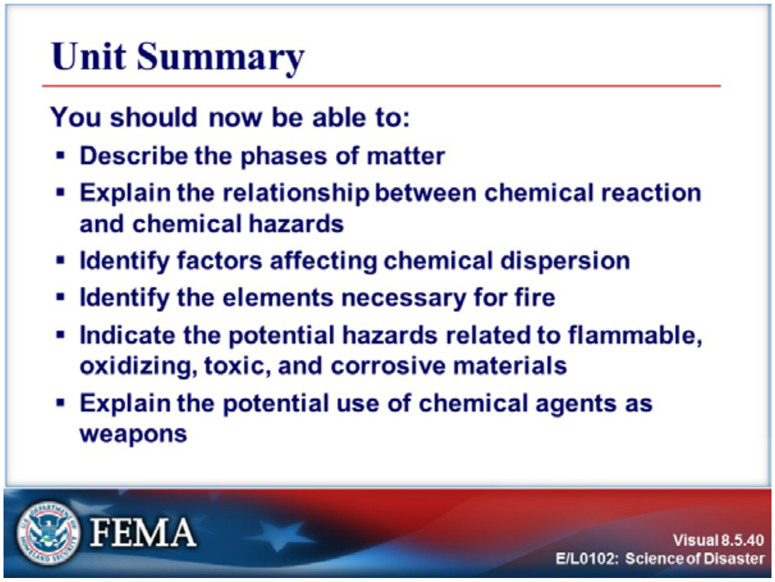
Key Points

<u>Instructions</u>: Working individually…

1. Recalling the scenario from the previous activity, answer the questions provided in your IAW.

UNIT SUMMARY

Visual 8.5.40



Alt Text for Visual 8.5.40
Unit Summary
You should now be able to:

- Describe the phases of matter
- Explain the relationship between chemical reaction and chemical hazards
- Identify factors affecting chemical dispersion
- Identify the elements necessary for fire
- Indicate the potential hazards related to flammable, oxidizing, toxic, and corrosive materials
- Explain the potential use of chemical agents as weapons

Key Points

Do you have any questions about the material covered in this unit?

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MODULE 9. COURSE SUMMARY

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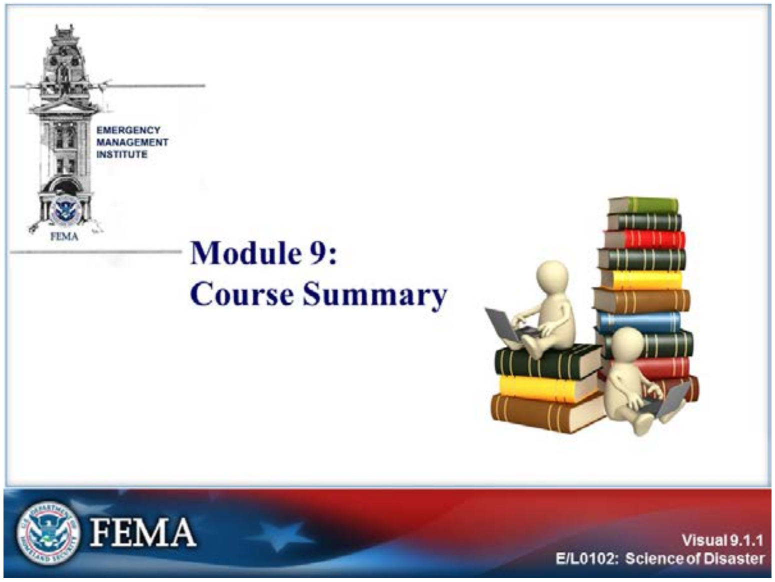
INTRODUCTION

Visual 9.1.1



Key Points

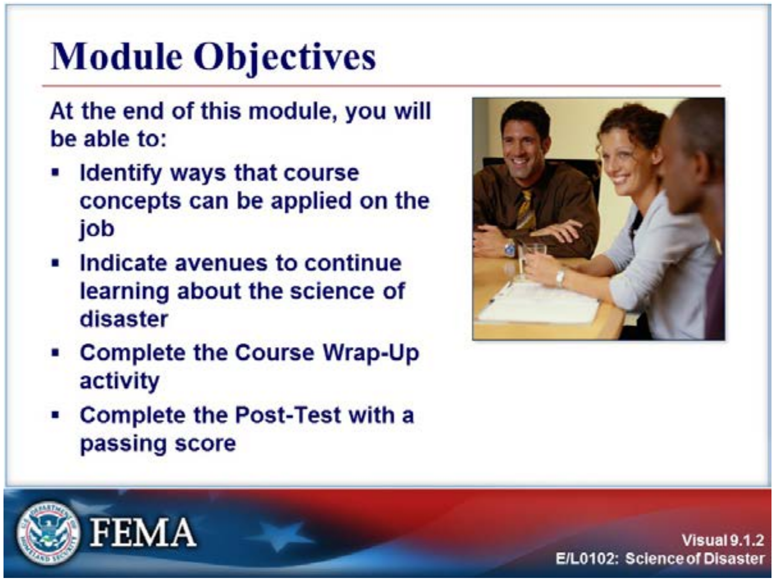
This module provides an opportunity to review key concepts covered in the training and to consider their practical applications.

A suggested time plan for this module is shown below.

Topic	Time
Introduction and Course Summary	5 minutes
Activity 9.1 – Course Wrap-Up	10 minutes
Post-Test	45 minutes
Feedback and Graduation	10 minutes
Total Time	**1 hour 10 minutes**

INTRODUCTION

Visual 9.1.2



Key Points

Review the module objectives as shown on the visual.

SUMMARY

Visual 9.1.3

Key Points

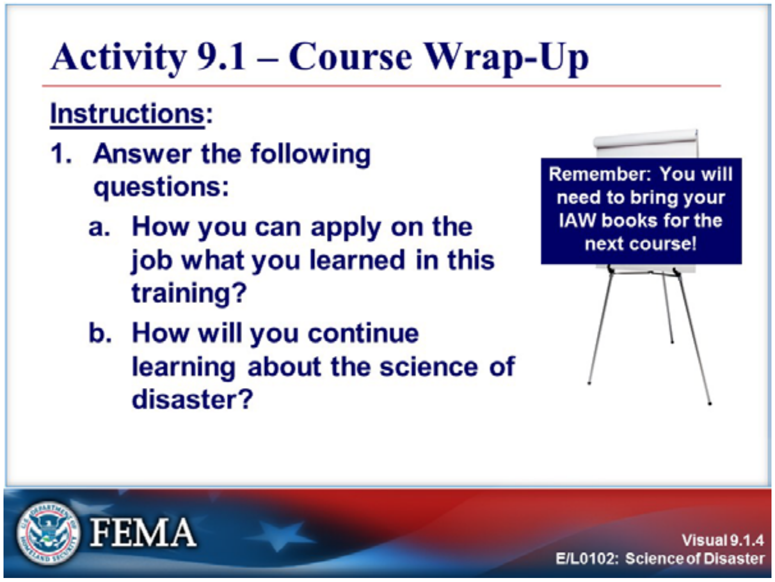
This course introduced you to scientific concepts and principles in several key areas related to natural and human-caused disasters. The course focused on common and emerging threats that provide a basis for understanding the science of disaster.

The course was organized as follows:

- **Module 1: Introduction to Science of Disaster**
- **Module 2: Storms**
  - Unit 1: Atmospheric Science Overview
  - Unit 2: Hurricanes
  - Unit 3: Convective Storms
  - Unit 4: Other Hazardous Weather
- **Module 3: Floods**
- **Module 4: Extreme Heat, Droughts, and Wildfires**
- **Module 5: Landslides and Sinkholes**
- **Module 6: Earthquakes and Tsunamis**
  - Unit 1: Earthquakes
  - Unit 2: Tsunamis
- **Module 7: Volcanoes**
- **Module 8: Human-Induced**
  - Unit 1: Science of Human-Induced Disasters
  - Unit 2: Chemical
  - Unit 3: Biological
  - Unit 4: Explosives
  - Unit 5: Radiation
- **Module 9: Course Summary**

ACTIVITY 9.1 – COURSE WRAP-UP

Visual 9.1.4



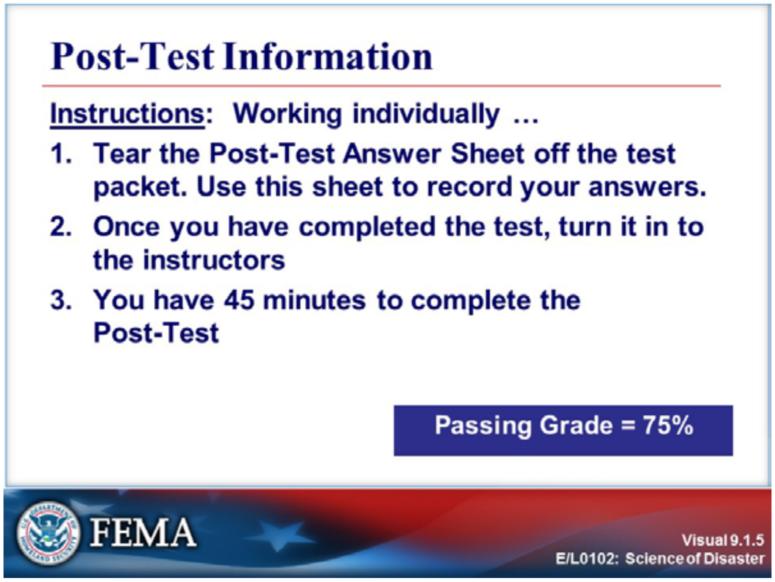
Key Points

Instructions:

1. Answer the following questions:
   - How you can apply on the job what you learned in this training?
   - How you will continue learning about the science of disaster?

POST-TEST

Visual 9.1.5



KEY POINTS

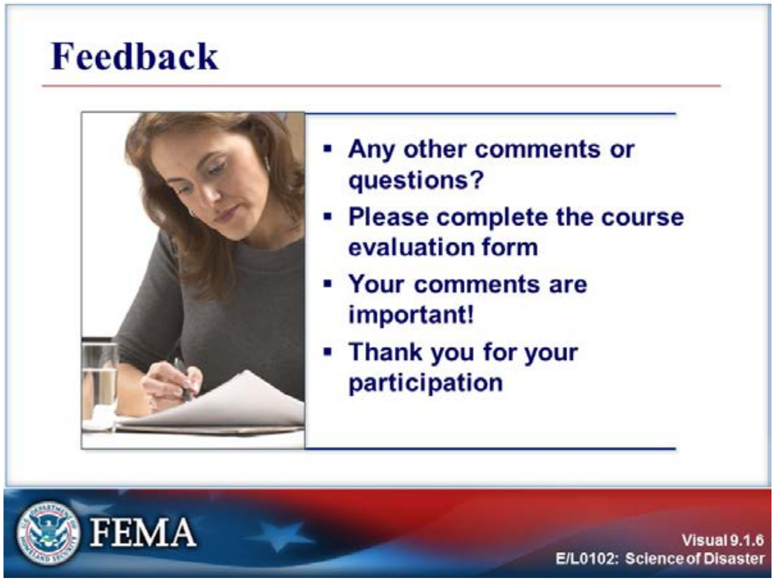
Instructions:

1. Tear the Post-Test Answer Sheet off of the test packet. Use this sheet to record your answers.
2. Once you have completed the test, turn it in to the instructors.
3. You have 45 minutes to complete the Post-Test.

You must have a score of 75% on the Post-Test to pass.

FEEDBACK AND GRADUATION

Visual 9.1.6



Key Points

Congratulations! You have completed the course Science of Disaster. Thank you for your participation and for your contributions to the discussions.

We value your input. Please provide your feedback on the course evaluation form.

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