6.3 NUCLEAR ENERGY

College Board Topics 6.6

Related Readings: Chapter 20

Learning Objectives and Essential Knowledge

ENDURING UNDERSTANDING

ENG-3

Humans use energy from a variety of sources, resulting in positive and negative consequences.

LEARNING OBJECTIVE

ENG-3.G

Describe the use of nuclear energy in power generation.

ESSENTIAL KNOWLEDGE

ENG-3.G.1

Nuclear power is generated through fission, where atoms of Uranium-235, which are stored in fuel rods, are split into smaller parts after being struck by a neutron. Nuclear fission releases a large amount of heat, which is used to generate steam, which powers a turbine and generates electricity.

ENG-3.G.2

Radioactivity occurs when the nucleus of a radioactive isotope loses energy by emitting radiation.

ENG-3.G.3

Uranium-235 remains radioactive for a long time, which leads to the problems associated with the disposal of nuclear waste.

ENG-3.G.4

Nuclear power generation is a nonrenewable energy source. Nuclear power is considered a cleaner energy source because it does not produce air pollutants, but it does release thermal pollution and hazardous solid waste.

LEARNING OBJECTIVE

ENG-3.H

Describe the effects of the use of nuclear energy on the environment.

ESSENTIAL KNOWLEDGE

ENG-3.H.1

Three Mile Island, Chernobyl, and Fukushima are three cases where accidents or natural disasters led to the release of radiation. These releases have had short- and long-term impacts on the environment.

ENG-3.H.2

A radioactive element's half-life can be used to calculate a variety of things, including the rate of decay and the radioactivity level at specific points in time.

SUGGESTED SKILL

Visual Representations

2.B

Explain relationships between different characteristics of environmental concepts, processes, or models represented visually:

- In theoretical contexts
- In applied contexts

Learning Objectives and Essential Knowledge

ENDURING UNDERSTANDING

ENG-3

Humans use energy from a variety of sources, resulting in positive and negative consequences.

LEARNING OBJECTIVE

ENG-3.I

Describe the effects of the use of biomass in power generation on the environment.

SUGGESTED SKILL

Environmental Solutions

7.B

Describe potential responses or approaches to environmental problems.

ESSENTIAL KNOWLEDGE

ENG-3.I.1

Burning of biomass produces heat for energy at a relatively low cost, but it also produces carbon dioxide, carbon monoxide, nitrogen oxides, particulates, and volatile organic compounds. The overharvesting of trees for fuel also causes deforestation.

ENG-3.I.2

Ethanol can be used as a substitute for gasoline. Burning ethanol does not introduce additional carbon into the atmosphere via combustion, but the energy return on energy investment for ethanol is low.

ENDURING UNDERSTANDING

ENG-3

Humans use energy from a variety of sources, resulting in positive and negative consequences.

LEARNING OBJECTIVE

ENG-3.L

Describe the use of hydroelectricity in power generation.

SUGGESTED SKILL

Environmental Solutions

7.F

Justify a proposed solution, by explaining potential advantages.

ENG-3.M

Describe the effects of the use of hydroelectricity in power generation on the environment.

ESSENTIAL KNOWLEDGE

ENG-3.L.1

Hydroelectric power can be generated in several ways. Dams built across rivers collect water in reservoirs. The moving water can be used to spin a turbine. Turbines can also be placed in small rivers, where the flowing water spins the turbine.

ENG-3.L.2

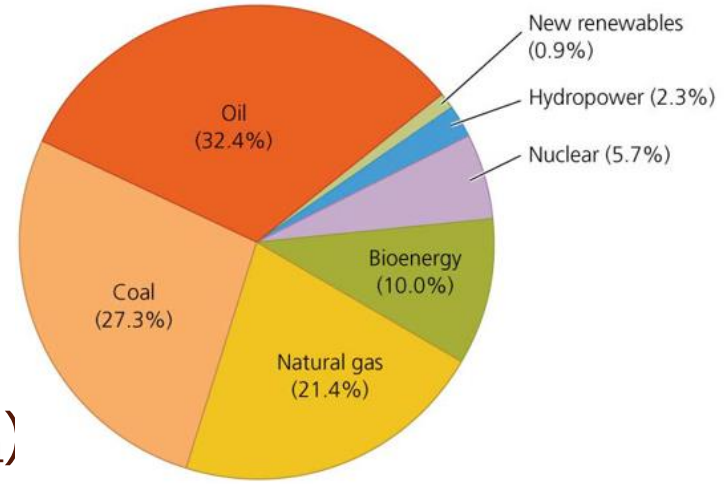
Tidal energy uses the energy produced by tidal flows to turn a turbine.

ENG-3.M.1

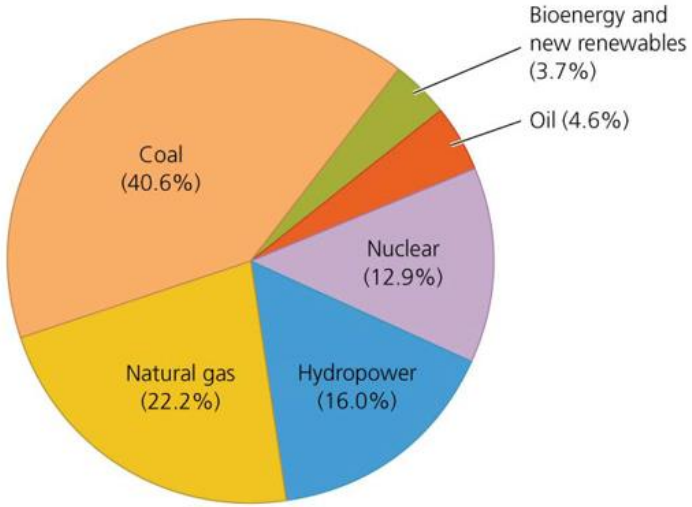
Hydroelectric power does not generate air pollution or waste, but construction of the power plants can be expensive, and there may be a loss of or change in habitats following the construction of dams.

Alternatives to Fossil Fuels

- Reserves of fossil fuels are limited and nonrenewable (on a human time scale)
- Combustion of fossil fuels are the leading cause of most forms of atmospheric pollution
  - SO_x, NO_x, VOC's, CO, PM, Greenhouse gases (CO_2, and CH_4)
- We have alternatives to fossil fuels.
  - Most are more expensive than fossil fuels, but that does not take into account ***external costs*** of the various energy sources.
  - Pricing of various energy sources is affected by the size of government subsidies.
  - Pricing of alternatives will drop as technology develops and we invest in increasing the necessary infrastructure.
- The most developed and commonly used alternatives to fossil fuels are nuclear, biomass, and hydroelectric



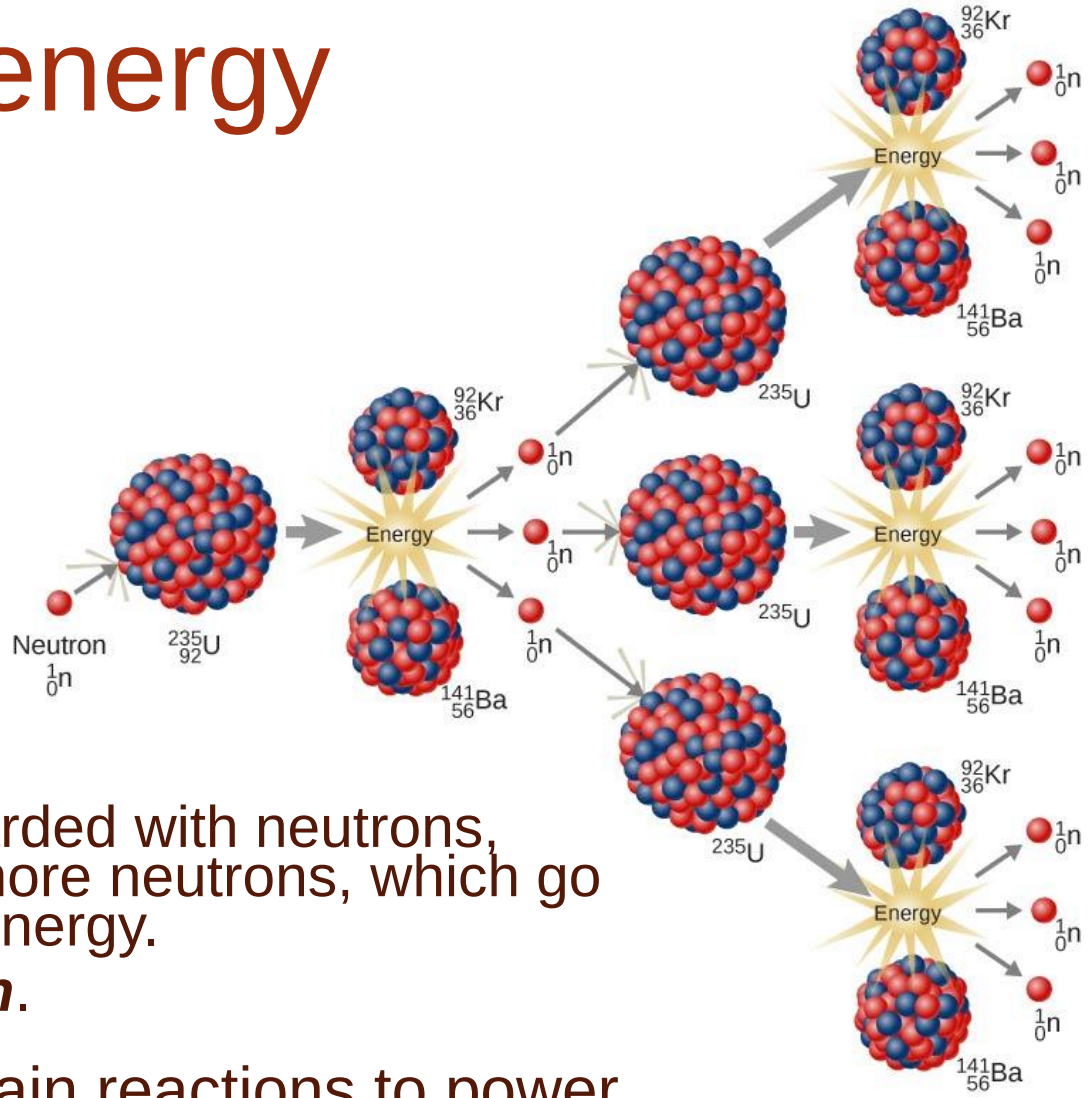
(a) World energy production, by source



(b) World electricity generation, by source

Fission releases nuclear energy

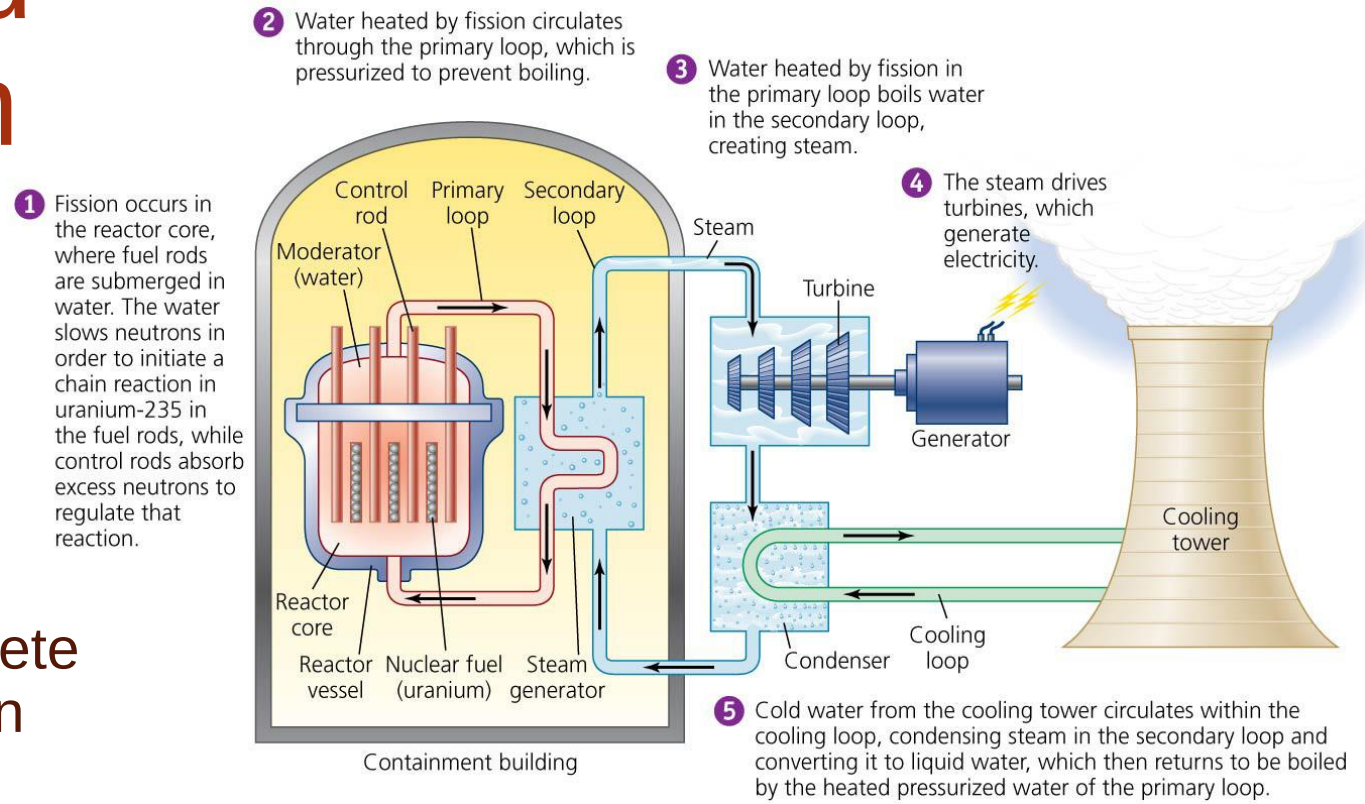
- ***Radioactivity*** refers to energy given off by the nucleus of radioactive isotopes.
  - The nuclei of ***radioactive isotopes*** are unstable and spontaneously split and emit high-energy radiation and subatomic particles as they decay into other isotopes/elements.
  - Eventually, radioactive isotopes will decay into more stable isotopes/elements.



- ***Nuclear Fission***
  - Nuclei of large radioactive elements are bombarded with neutrons, causing them to split and release energy and more neutrons, which go on to split additional nuclei, and release more energy.
  - This generates a self sustaining ***chain reaction***.
- Nuclear reactors initiate and control these chain reactions to power nuclear power plants which use the heat of the reaction to produce steam, which turns a turbine, to power a generator, and create electricity.

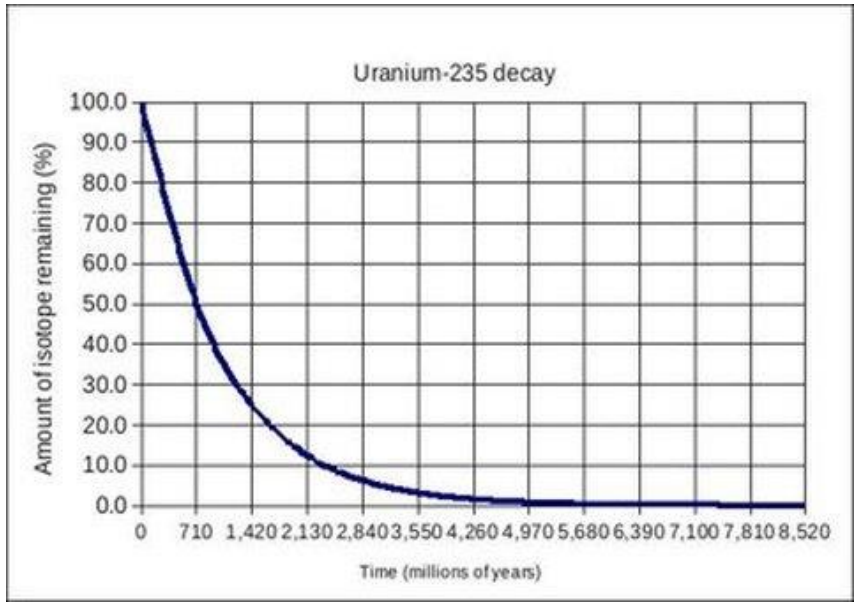
Nuclear reactors and electricity generation

- Fission takes place in the ***reactor core***.
  - The reactor core is housed in the ***reactor vessel***.
  - The reactor vessel, steam generator, and plumbing are located in a ***containment building***.
  - Containment buildings are thick concrete domes designed to contain radiation in the event of an accident.



- If not controlled the chain reaction will continue to build, generating increasing amounts of energy, in a runaway process of positive feedback that can lead to a reactor ***meltdown.***
  - ***Control rods*** are metallic alloys that absorb neutrons without experiencing fission.
  - Placed into the reactor core among water-bathed fuel rods.
  - Control rods can be moved in and out between fuel rods to control the rate of the chain reaction.

Nuclear Energy comes from process and enriched uranium ore



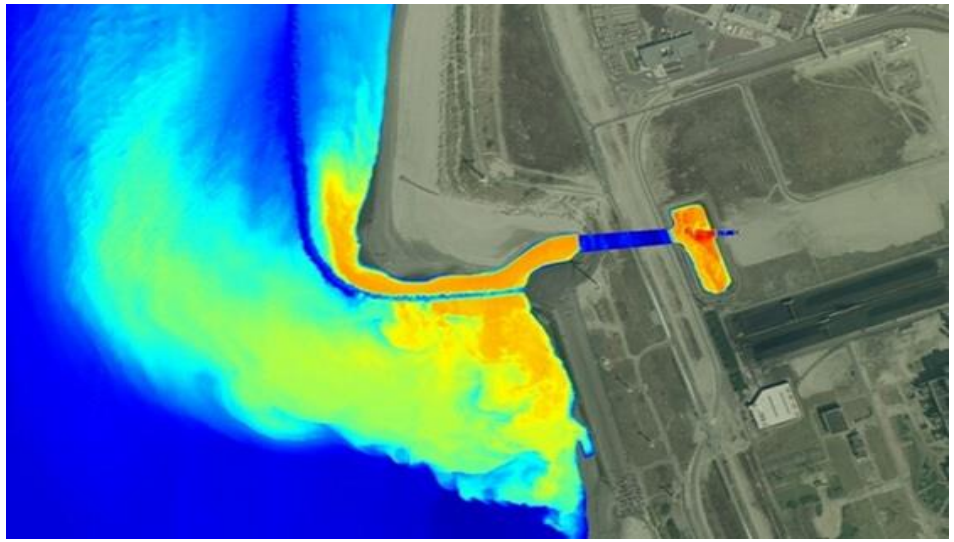
- Uranium ore contains several different ***isotopes*** of Uranium.
  - Over 99% of uranium occurs as uranium-238 (^{238}U)
  - ^{235}U, which is only 1% of total uranium, is needed in order to create sustainable chain reactions.
  - Uranium ore is ***enriched*** to 3% ^{235}U and formed into pellets (UO_2), which are incorporated into metallic tubes called ***fuel rods*** used in nuclear reactors.
- Uranium-235 will eventually decay into lead-207.
  - The rate of decay is determined by its ***half-life*****,** the time it takes for half of the atoms to decay.
  - $N_t = N_0(½)^{t/t(halflife)}$
  - ^{235}U has a half-life of 710 million years; other radioisotopes have different half-lives
- After several years in a reactor, fuel rods are depleted.
  - The uranium in the fuel rods no longer generates enough energy
  - Spent fuel rods can be reprocessed, but it is potentially dangerous and expensive, so they are disposed of as radioactive waste.

Benefits of nuclear power

- Nuclear power has minimal stack emissions compared to fossil fuels.
  - Water vapor is the only gas emitted by operation of nuclear power plants.
    - While technically a greenhouse gas, its residence time in the atmosphere is very short, limiting its warming potential.
  - Burning fossil fuels emits sulfur dioxide, nitrogen oxides, particulate matter, and carbon dioxide.
  - Nuclear power helps the United States avoid emitting 600 million metric tons of carbon each year.
- Nuclear power plants pose fewer human health risks from pollution.
- Huge amounts of energy from small amounts of uranium.
  - Minimizes damage from mining.
  - Although uranium is nonrenewable, reserves of uranium are much larger than those of fossil fuels.

Concerns over nuclear power

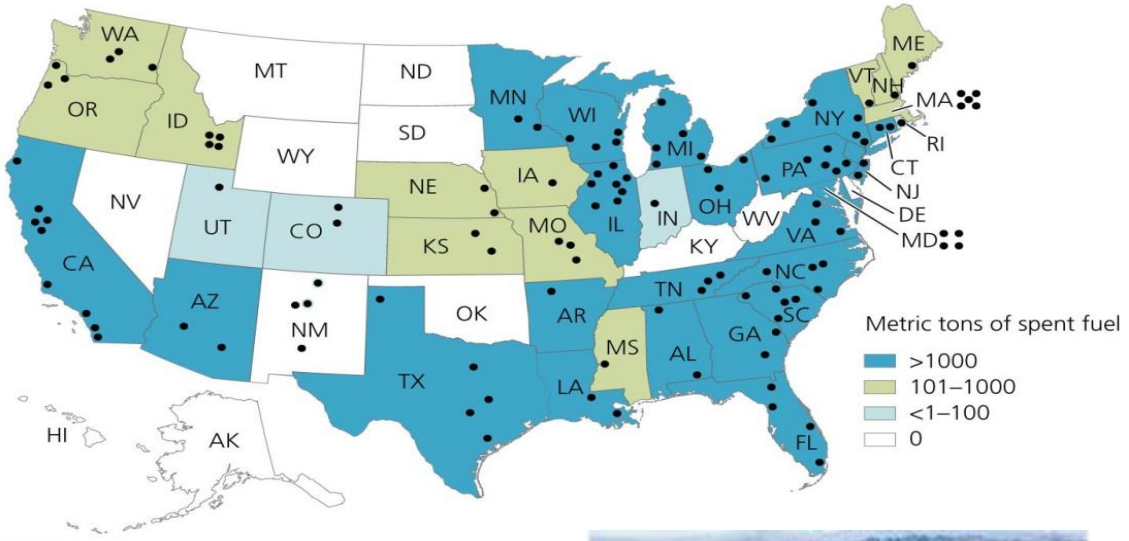
- Expensive and time consuming to build nuclear power plants. Even more expensive to decommission.
- Mine tailings and surface impoundments from uranium mining may increase environmental exposure to radiation.
- Nuclear power plants require huge amounts of water for moderating fission reactions, reactor cooling, steam generation, and cooling and condensing steam back to water.
- Thermal pollution when cooling water is discharged back to the environment.
- Spent fuel rods remain radioactive for hundreds of thousands of years and must be safely stored throughout this time period.
- Uranium and its decay products create security risks of nuclear proliferation and terrorism (dirty bombs).
- Fear of catastrophic accidents.

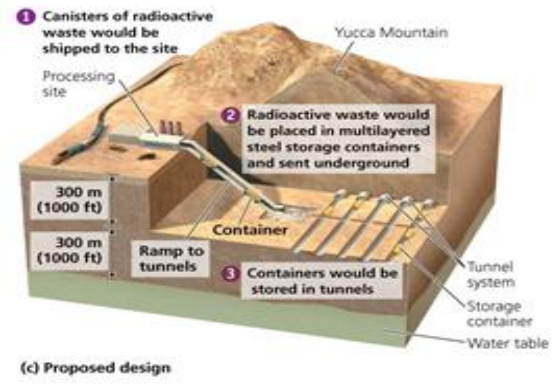


Waste disposal remains a challenge

- Waste is temporarily stored at power plants.
  - Spent rods are initially stored in water and then moved to dry storage in lead-lined drums inside concrete buildings.
  - Waste is currently held at 125 sites in 39 states.

- A secure centralized geologic storage site for high level nuclear waste has been proposed, but never completed.
  - ***Yucca Mountain, Nevada*** was initially chosen.
    - It was studied extensively, and $13 billion was spent on its development, before development was stopped.
    - Concern with a central location is shipments by rail and truck over thousands of miles could cause a high risk of accident or sabotage.
    - NIMBY



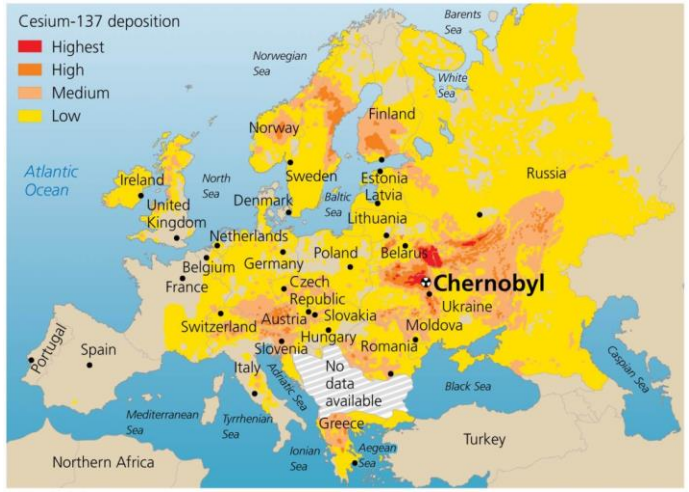


- **Yucca Mountain was chosen because:**
  - It is relatively remote with a low population density
  - It has minimal risk of earthquakes
  - Its dry climate and low water table reduce chances of groundwater contamination
  - It is on federal land so can be protected from sabotage.

Nuclear power poses a small risk of large accidents.

3 Mile Island

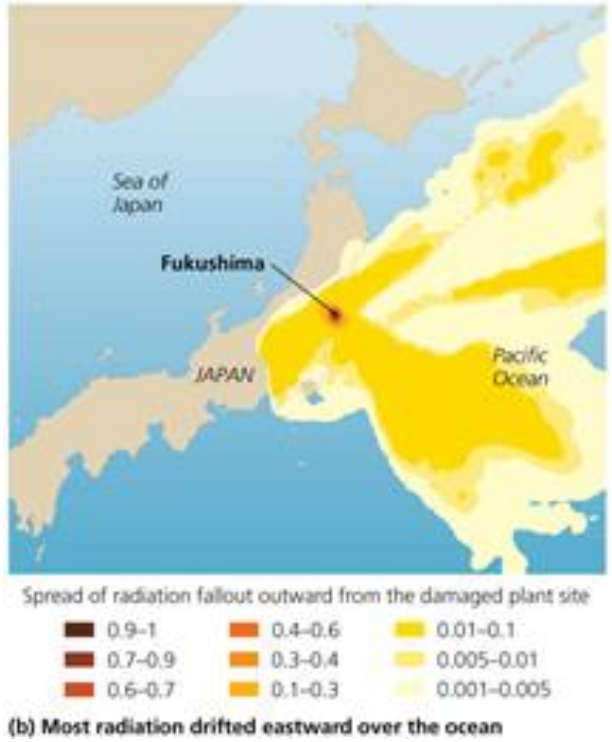
- The most serious accident in the United States was at the Three Mile Island Nuclear plant in Pennsylvania in 1979
  - A combination of human and mechanical errors caused coolant water to drain from the reactor causing a meltdown.
  - Half of one reactor core experienced meltdown, but most radiation was trapped in the containment building.



Chernobyl

- The most serious nuclear accident ever occurred during the1986 explosion at the Chernobyl plant in Ukraine
  - It was due to human error and unsafe design (no containment building)
  - For 10 days, radiation escaped while crews tried to put out the fire.
  - More than 100,000 residents were evacuated.
  - The landscape for 19 miles still remains contaminated with radiation.
  - The accident killed 31 people directly, thousands more became sick or developed cancer.
  - Radioactive fallout was carried over much of the Northern Hemisphere.

Nuclear power poses a small risk of large accidents.



Fukushima Daiichi

- A magnitude 9.0 earthquake struck Japan on March 11, 2011, sending a massive tsunami onshore.
  - At the power plant, the tsunami shut down the power and flooded the emergency generators.
  - Without electricity, the workers could not use the control rods to cool the uranium fuel.
- Three reactors experienced full meltdowns.
  - Radioactivity released was about one-tenth that of Chernobyl.
  - Most radiation drifted away from human population centers and into the Pacific Ocean, contaminating 150 mi^2 of ocean floor.
  - Thousands of residents were evacuated, and health effects from the event are uncertain.
  - Fuel rods in the remnants of reactors 1-3 continue to require cooling with 300 tons of water per day.
  - Used cooling water is contaminated with radiation and has been stored in tanks on site.
  - The plant operator expects to run out of storage in 2022, but fuel rods are expected to continue to generate energy until at least 2041.

Video Resources

- Nuclear Energy
  - https://www.youtube.com/watch?v=ZNla6s68AEE&feature=emb_logo