Nuclear power: heat from fission

A nuclear plant generates electricity using energy released from atomic nuclei. It uses many of the same steam-system components as a fossil-fuel plant, but a different source of heat.

1. SPLIT A NUCLEUS, NOT A CHEMICAL BOND

A uranium-235 nucleus can absorb a neutron and split into smaller nuclei, releasing energy and additional neutrons. Those neutrons can cause further fissions: a chain reaction. Fuel pellets containing uranium are held in metal fuel rods in the reactor core. Fission is not combustion: uranium is not burned with oxygen to release chemical energy.

2. FOLLOW THE ENERGY THROUGH THE PLANT

Reactor
Fission releases heat

→

Steam + turbine
Steam causes rotation

→

Generator
Produces electricity

Heat makes steam, which spins a turbine connected to a generator. A condenser turns the steam back into water for reuse. Cooling transfers unused heat to the surroundings; the generator does not convert all reactor heat into electricity.

3. CONTROL THE REACTION AND REMOVE HEAT

Control rods absorb neutrons to regulate the chain reaction. Coolant carries heat away from the core. These are different jobs: stopping the chain reaction does not immediately eliminate heat from radioactive decay, so cooling remains essential.

4. LOW DIRECT CARBON DOES NOT MEAN RENEWABLE

Uranium is a finite mineral resource, so nuclear power is nonrenewable. Fission produces no combustion CO_2, but mining, fuel processing and construction can cause emissions. Assess the full life cycle, not only the reactor.

Fission and power generation: US EIA, Nuclear Power Plants.
Fuel, decay heat and shielding: US NRC, Backgrounder on Radioactive Waste.
Operational emissions and life-cycle impacts: US EIA, Nuclear Power and the Environment.

Scope: College Board AP Environmental Science CED, Topic 6.6, pp. 125-126.

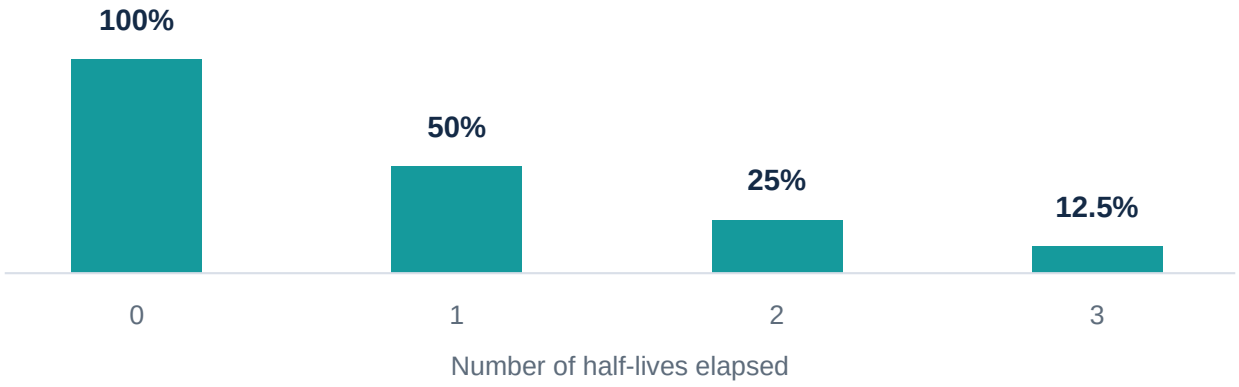
Half-life: halve what remains

Radioactivity is the emission of radiation as unstable nuclei transform or lose energy. Individual decay events are unpredictable, but a large population follows a predictable decay pattern.

1. DEFINE THE HALF-LIFE

A half-life is the time required for half the nuclei of a particular radioactive isotope in a sample to decay. Each equal time interval removes half of what remains, not half of the original amount. The parent isotope becomes decay products; the whole sample does not simply disappear.

2. EQUAL TIME INTERVALS, SMALLER AMOUNTS LOST



Bars show the percentage of original parent nuclei still undecayed.

3. WORKED EXAMPLE: A HYPOTHETICAL ISOTOPE

Start with 80 g of a parent isotope with a 10-year half-life. After 30 years, 3 half-lives have passed: 80 → 40 → 20 → 10 g remains undecayed.

Remaining amount = initial amount × $(1/2)^n$, where n = time / half-life.

4. RELATE AMOUNT TO ACTIVITY

For one isotope with no added material, its activity (decays per second) also halves each half-life. Mixed nuclear waste contains many isotopes, so it has no single half-life.

Meaning of radioactive decay: US NRC, Decay, Radioactive.
Half-life definition: US NRC glossary; chart and worked numbers are illustrative.
Different isotopes in spent fuel: US NRC, Backgrounder on Radioactive Waste.

Scope: College Board AP Environmental Science CED, Topic 6.6, pp. 125-126.

Benefits, waste and accident risks

Low combustion emissions are a major benefit, but they do not remove the need to manage radioactive materials, cooling water and severe accident risks.

1. WASTE AND WATER NEED DIFFERENT SAFEGUARDS

Spent fuel contains radioactive fission products and other long-lived isotopes; the hazard is not only leftover uranium-235. Pools cool and shield newly removed fuel; sufficiently cooled fuel can use dry casks. Safe isolation must prevent exposure and release. Separately, warmed cooling-water discharge can cause thermal pollution and harm aquatic life.

2. THREE CASES, DIFFERENT CAUSES AND CONSEQUENCES

Three Mile Island | USA, 1979

Equipment problems and operator errors caused loss of cooling and a partial core meltdown. Off-site radioactive releases were small; the NRC reports no detectable health effects. The accident led to major safety and training changes.

Chernobyl | Ukraine, 1986

A reactor test, unsafe operation and design weaknesses led to a power surge, explosions and fire. Large radioactive releases contaminated extensive areas, damaged nearby ecosystems and required evacuation and long-term restrictions.

Fukushima Daiichi | Japan, 2011

An earthquake and tsunami disrupted power and cooling. Cores overheated and melted; hydrogen explosions and radioactive releases followed. Land contamination, relocation and prolonged cleanup illustrate the consequences of losing cooling.

3. EXPLAIN THE RISK, NOT JUST THE LABEL

Contamination is unwanted radioactive material. Exposure depends on the isotope, amount, pathway and time; half-life alone does not determine safety. Cooling, containment, monitoring and secure waste management address different hazards.

Spent-fuel storage and environmental impacts: US EIA, Nuclear Power and the Environment.
Three Mile Island: US NRC accident backgrounder.
Chernobyl: US NRC accident backgrounder.
Fukushima: US NRC, Lessons Learned from Fukushima.

Scope: College Board AP Environmental Science CED, Topic 6.6, pp. 125-126.