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How Nuclear Power Works

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An aerial photograph view of the Hinkley Point B Nuclear Powerstation on Aug. 8, 2017 in Bridgewater, England. DAVID GODDARD/GETTY IMAGES

To some, nuclear energy offers a clean energy alternative that frees us from the shackles of fossil fuel dependence. To others, it summons images of disaster: quake-ruptured Japanese power plants belching radioactive steam, the dead zone surrounding Chernobyl's concrete sarcophagus.

But what happens inside a nuclear power plant to bring such marvel and misery into being? Imagine following a volt of electricity back through the wall socket, all the way through miles of power lines to the nuclear reactor that generated it. You'd encounter the generator that produces the spark and the turbine that turns it. Next, you'd find the jet of steam that turns the turbine and finally the radioactive uranium bundle that heats water into steam. Welcome to the nuclear reactor core.

The water in the reactor also serves as a coolant for the radioactive material, preventing it from overheating and melting down. In March 2011, TV viewers around the world learned what happens when the cooling system suffers a catastrophic failure. Japanese citizens fled by the tens of thousands from the area surrounding the Fukushima-Daiichi nuclear facility after the most powerful earthquake on record and the ensuing tsunami inflicted serious damage on the plant and several of its reactor units. Among other events, water drained from the reactor core, which in turn made it impossible to control core temperatures. This resulted in overheating and a partial nuclear meltdown [source: NPR].

As of April 2018, there are about 450 nuclear power reactors in operation in 50 countries, and they provide about 11 percent of the world's electricity, according to the World Nuclear Association. In the U.S. alone, there are 99 reactors in 61 commercially operating nuclear power plants within 30 U.S. states, including Tennessee's Watts Bar Unit 2, a 1,150 megawatt-capacity reactor that began commercial operation in October 2016 [source: EIA].

Nuclear energy supplies 20 percent of U.S. electricity needs, less than the 31.7 percent that comes from natural gas and the 30.1 percent from coal, and only slightly more than the 17.1 percent provided by renewables such as hydropower, wind and solar [source: EIA]. But some countries depend on the atom more heavily. France, for example, gets 72 percent of its electricity from nuclear plants, and Sweden gets about 40 percent from them, according to a report from April 2018 [source: World-Nuclear.org].

In this article, we'll look at just how a nuclear reactor functions inside a power plant, as well as the atomic reaction that releases all that crucial heat.

Nuclear Fission: The Heart of the Reactor

Despite all the cosmic energy that the word "nuclear" invokes, power plants that depend on atomic energy don't operate that differently from a typical coal-burning power plant. Both heat water into pressurized steam, which drives a turbine generator. The key difference between the two plants is the method of heating the water [source: Mnsu.edu].

While coal-powered plants burn fossil fuels, nuclear-powered plants depend on the heat that occurs during **nuclear fission**, when one atom splits into two and releases energy. Nuclear fission happens naturally every day. **Uranium**, for example, constantly undergoes spontaneous fission at a very slow rate. This is why the element emits radiation, and why it's a natural choice for the **induced fission** that nuclear power plants require [source: World-nuclear.org].

Uranium is a common element on Earth and has existed since the planet formed. While there are several varieties of uranium, **uranium-235** (U-235) is the one most important to the production of both nuclear power and nuclear bombs.

U-235 decays naturally by alpha radiation: It throws off an alpha particle, or two neutrons and two protons bound together. It's also one of the few elements that can undergo induced fission. Fire a free neutron into a U-235 nucleus and the nucleus will absorb the neutron, become unstable and split immediately.

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The animation above shows a uranium-235 nucleus with a neutron approaching from the top. As soon as the nucleus captures the neutron, it splits into two lighter atoms and throws off two or three new neutrons (the number of ejected neutrons depends on how the U-235 atom splits). The process of capturing the neutron and splitting happens very quickly.

The decay of a single U-235 atom releases approximately 200 MeV (million electron volts). That may not seem like much, but there are lots of uranium atoms in a pound (0.45 kilogram) of uranium [source: World-nuclear.org]

The splitting of an atom releases heat and **gamma radiation**, or radiation made of high-energy photons. The two atoms that result from the fission later release **beta radiation** (superfast electrons) and gamma radiation of their own, too [source: World-nuclear.org].

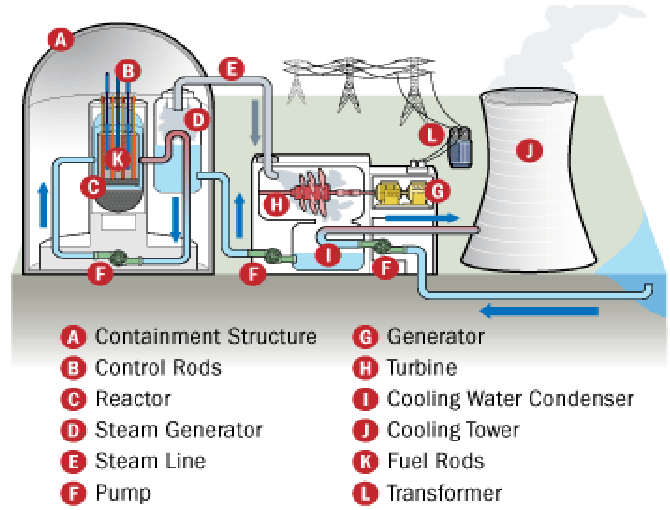
But for all of this to work, scientists have to first enrich a sample of uranium so that it contains 2 to 3 percent more U-235 [source: World-nuclear.org]. Three percent enrichment is sufficient for nuclear power plants, but weapons-grade uranium is composed of at least 90 percent U-235. The process of enriching uranium is done via a centrifuge after a gas has been created from the uranium. The force of the centrifuge separates the U-235 atoms from the U-238 atoms. At first, there is only a slight increase in the concentration of U-235 atoms, so the process has to be repeated several times in the centrifuge to increase the enrichment. Making weapons-grade uranium is very difficult and expensive, which is one reason so few countries have nuclear weapons. But these barriers are not insurmountable [source: Zielinski].

WHAT ABOUT PLUTONIUM?

Uranium-235 isn't the only possible fuel for a power plant. Another fissionable material, **Plutonium-239** is created by bombarding U-238 with neutrons [source: World-nuclear.org].

Inside a Nuclear Power Plant

This diagram shows all the parts of a nuclear reactor.



In order to turn nuclear fission into electrical energy, nuclear power plant operators have to control the energy given off by the enriched uranium and allow it to heat water into steam. That steam then drives turbines to generate electricity [source: NEI].

Enriched uranium typically is formed into 1-inch-long (2.5-centimeter-long) pellets, each with approximately the same diameter as a dime. Next, the pellets are arranged into long **rods**, and the rods are collected together into **bundles**. The bundles are submerged in water inside a pressure vessel. The water acts as a coolant. Left to its own devices, the uranium would eventually overheat and melt.

To prevent overheating, **control rods** made of a material that absorbs neutrons are inserted into the uranium bundle using a mechanism that can raise or lower them. Raising and lowering the control rods allow operators to control the rate of the nuclear reaction. When an operator wants the uranium core to produce more heat, the control rods are lifted out of the uranium bundle (thus absorbing fewer neutrons). To reduce heat, they are lowered into the uranium bundle. The rods can also be lowered completely into the uranium bundle to shut the reactor down in the event of an accident or to change the fuel [sources: Nosowitz, World-nuclear.org].

The uranium bundle acts as an extremely high-energy source of heat. It heats the water and turns it to steam. The steam drives a turbine, which spins a generator to produce power. Humans have been harnessing the expansion of water into steam for hundreds of years.

In some nuclear power plants, the steam from the reactor goes through a secondary, intermediate heat exchanger to convert another loop of water to steam, which drives the turbine. The advantage to this design is that the radioactive water/steam never contacts the turbine. Also, in some reactors, the coolant fluid in contact with the reactor core is gas (carbon dioxide) or liquid metal (sodium, potassium); these types of reactors allow the core to be operated at higher temperatures [source: World-nuclear.org]

Given all the radioactive elements inside a nuclear power plant, it shouldn't come as a surprise that there's a little more to a plant's exterior than you'd find at a coal power plant. In the next section, we'll explore the various protective barriers between you and the atomic heart of the plant.

Outside a Nuclear Power Plant

As you can tell by looking at this photograph of Germany's Brokdorf nuclear plant, concrete plays an important role in containing radioactive materials.

MARTIN ROSE/GETTY IMAGES ENTERTAINMENT/GETTY IMAGES

Once you get past the reactor itself, there's very little difference between a nuclear power plant and a coal-fired or oil-fired power plant, except for the source of the heat used to create steam. But as that source can emit harmful levels of radiation, extra precautions are required.

A concrete liner typically houses the reactor's pressure vessel and acts as a radiation shield. That liner, in turn, is housed within a much larger steel containment vessel. This vessel contains the reactor core, as well as the equipment plant workers use to refuel and maintain the reactor. The steel containment vessel serves as a barrier to prevent leakage of any radioactive gases or fluids from the plant [source: Nuclear-power.net].

An outer concrete building serves as the final layer, protecting the steel containment vessel. This concrete structure is designed to be strong enough to survive the kind of massive damage that might result from earthquakes or a crashing jet airliner [source: Wald].

These secondary containment structures are necessary to prevent the escape of radiation/radioactive steam in the event of an accident. The absence of secondary containment structures in Russian nuclear power plants allowed radioactive material to escape in Chernobyl [source: Salisbury].

Workers in the control room at the nuclear power plant can monitor the nuclear reactor and take action if something goes wrong. Nuclear facilities also typically feature security perimeters and added personnel to help protect sensitive materials.

As you probably know, nuclear power has its share of critics, as well as its supporters. On the next page, we'll take a quick look at some of the pros and cons of splitting an atom to keep everyone's TVs and toasters running.

Pros and Cons of Nuclear Power

This storage facility near the site of the Chernobyl Nuclear Power Plant currently houses nuclear waste.

SERGEI SUPINSKY /AFP/GETTY IMAGES

What's nuclear power's biggest advantage? It doesn't depend on fossil fuels and isn't affected by fluctuating oil and gas prices. Coal and natural gas power plants emit carbon dioxide into the atmosphere, which contributes to climate change. With nuclear power plants, CO2 emissions are minimal, though uranium mining, construction of reactors, transportation of fuel and other parts of nuclear energy do generate greenhouse gases [source: Lenzen].

According to the Nuclear Energy Institute, the power produced by the world's nuclear plants would normally generate 2.2 billion tons (2 billion metric tons) of CO2 per year if they depended on fossil fuels. In fact, a properly functioning nuclear power plant actually releases less radioactivity into the atmosphere than a coal-fired power plant. That's because when coal is burned for electricity, fly ash (which contains very concentrated amounts of uranium and thorium) is released. This fly ash has 100 times more radioactivity than the radioactivity released by a nuclear power plant producing the same amount of energy [source: Hvistendahl]. Plus, nuclear energy comes with a far lighter fuel requirement. Nuclear fission produces roughly a million times more energy per unit weight than fossil fuel [source: Helman].

But there are many negatives as well. Historically, mining and purifying uranium hasn't been a very clean process. Even transporting nuclear fuel to and from plants poses a contamination risk. And once the fuel is spent, you can't just throw it in the city dump. It's still radioactive and exposure to this waste can cause radiation sickness, cancer or even death, depending on how much radiation you absorb [source: Rettner]. According to the U.S. Government Accountability Office, the U.S. has accumulated 88,185 tons (80,000 metric tons) of nuclear waste generated by power plants, most of which was still stored at company sites, as the federal government struggles to come up with a better solution.

And as if this weren't bad enough, nuclear power plants produce a great deal of **low-level radioactive waste** in the form of shoe covers, wiping rags, equipment and other materials [source: NRC].

Nuclear Catastrophe and Reactor Shutdown

A glimpse of the aftermath from the largest earthquake in history and the ensuing tsunami that tore Japan apart and led to its nuclear catastrophe.

PAULA BRONSTEIN/GETTY IMAGES

Remember, at the heart of every nuclear reactor is a controlled environment of radioactivity and induced fission. When this environment spins out of control, the results can be catastrophic.

For many years, the Chernobyl disaster stood as a prime worst-case example of nuclear malfunction. In 1986, the Ukrainian nuclear reactor exploded, spewing 50 tons (45 metric tons) of radioactive material into the surrounding area, contaminating millions of acres of forest. The disaster forced relocation of 150,000 people, and eventually caused thousands to die from cancer and other illnesses [source: History.com].

Chernobyl was poorly designed and improperly operated. The plant required constant human attention to keep the reactor from malfunctioning. Yet even a well-designed nuclear power plant is susceptible to natural disaster.

On Friday, March 11, 2011, Japan experienced the largest earthquake in modern history. A programmed response at the country's Fukushima-Daiichi nuclear facility immediately descended on all of the reactor's control rods, shutting down all fission reactions within 10 minutes. Unfortunately, however, you can't shut down all radioactivity with the flip of a switch.

As we explored on the previous page, nuclear waste continues to generate heat years after its initial run in a power plant. Similarly, within the first few hours after a nuclear reactor shuts down, it continues to generate heat from the decay process.

The March 2011, quake manifested a deadly tsunami, which destroyed the backup diesel generators that powered the water coolant pumps the facility had turned to after it couldn't get power from Japan's grid. These pumps circulate water through the reactor to remove decay heat. Uncirculated, both the water temperature and water pressure inside the reactor continued to rise. Furthermore, the reactor radiation began to split the water into oxygen and volatile hydrogen. The resulting hydrogen explosions breached the reactor building's steel containment panels [source: World-Nuclear.org].

Simply put, the Fukushima-Daiichi facility had many countermeasures in place to shut down operations in the event of severe seismic activity. They just didn't count on losing power to their coolant pumps.

Plants such as Japan's Fukushima-Daiichi facility, Russia's Chernobyl and the United States' Three Mile Island remain a black eye for the nuclear power industry, often overshadowing some of the environmental advantages the technology has to offer.

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