

How Nuclear Power Works

by [Marshall Brain](#) and [Robert Lamb](#)

Introduction to How Nuclear Power Works

The nuclear power plant stands on the border between humanity's greatest hopes and its deepest fears for the future.

On one hand, atomic energy offers a [clean energy](#) alternative that frees us from the shackles of fossil fuel dependence. On the other, 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, viewers around the world became well acquainted with this reality as 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](#)].



Photo by DigitalGlobe via [Getty Images](#)

Satellite view of the Fukushima-Daiichi nuclear power plant on March 16, 2011, after an 8.9 magnitude earthquake and tsunami set in motion a chain of disastrous events at the facility. See more [pictures of the aftermath of Japan's earthquake and Tsunami](#).

As of March 1, 2011, there were 443 operating nuclear power reactors spread across the planet in 47 different countries [source: [WNA](#)]. In 2009 alone, atomic energy accounted for 14 percent of the world's electrical production. Break that down to the individual country and the percentage skyrockets as high as 76.2 percent for Lithuania and 75.2 for France [source: [NEI](#)]. In the United States, 104 nuclear power plants supply 20 percent of the [electricity](#) overall, with some states benefiting more than others.

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

What About Plutonium?

Uranium-235 isn't the only possible fuel for a power plant. Another fissionable material is plutonium-239. **Plutonium-239** is created by bombarding U-238 with neutrons, a common occurrence in a nuclear 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.

While older plants burn fossil fuels, nuclear 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.

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. See [How Nuclear Radiation Works](#) for complete details.

The animation to the right 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 kilograms) of uranium. So many, in fact, that a pound of highly enriched uranium as used to power a nuclear submarine is equal to about a million gallons of gasoline.

The splitting of an atom releases an incredible amount of 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.

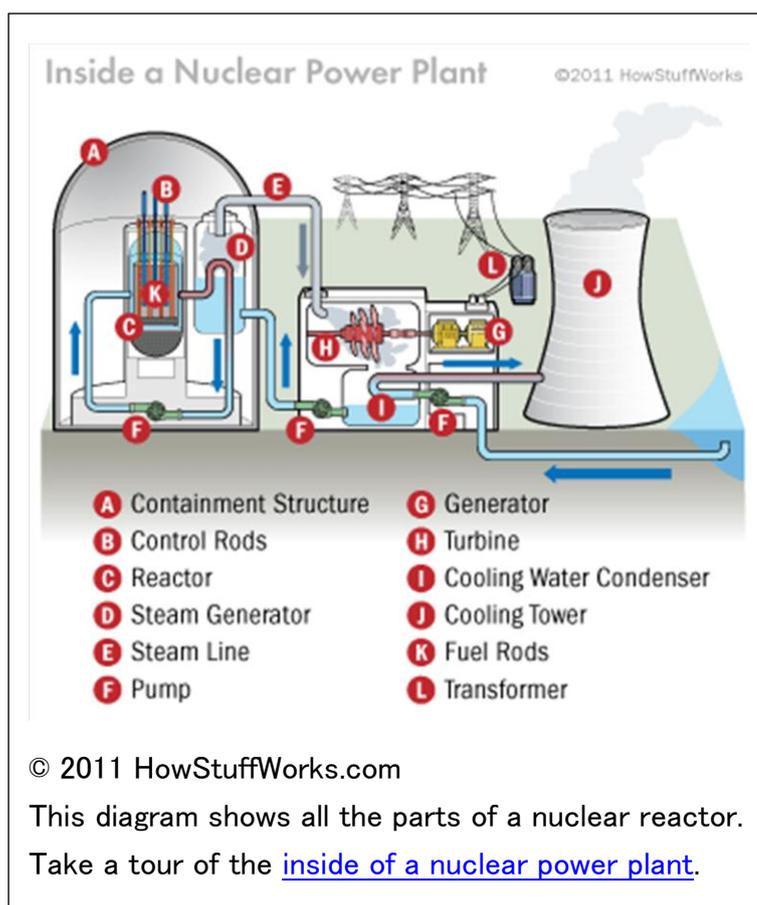
But for all of this to work, scientists have to first enrich a sample of uranium so that it contains 2 to 3 percent more U-235. Three-percent enrichment is sufficient for nuclear power plants, but weapons-grade uranium is composed of at least 90 percent U-235.

Stick with us. We'll head inside the power plant and investigate the reactor next.

Inside a Nuclear Power Plant

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.

Enriched uranium typically is formed into 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.

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. To learn more about the properties involved, read [How Steam Technology Works](#).

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.

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 outside 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

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



Martin Rose/Getty Images Entertainment/[Getty Images](#)
As you can tell by looking at this photograph of Germany's Brokdorf nuclear plant, concrete plays an important role in containing radioactive materials.

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.

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. 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.

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

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.

According to the Nuclear Energy Institute, the power produced by the world's nuclear plants would normally produce 2 billion metric



Sergei Supinsky /AFP/[Getty Images](#)

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

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 [source: [Hvistendahl](#)]. Plus, all this comes with a far lighter fuel requirement. Nuclear fission produces roughly a million times more energy per unit weight than fossil fuel alternatives [source: [Helman](#)].

And then there are the negatives. 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 potentially deadly.

On average, a nuclear power plant annually generates 20 metric tons of used nuclear fuel, classified as **high-level radioactive waste**. When you take into account every nuclear plant on [Earth](#), the combined total climbs to roughly 2,000 metric tons a year [source: [NEI](#)]. All of this waste emits [radiation](#) and heat, meaning that it will eventually corrode any container that holds it. It can also prove lethal to nearby life forms. As if this weren't bad enough, nuclear power plants produce a great deal of **low-level radioactive waste** in the form of radiated parts and equipment.

Over time, spent nuclear fuel decays to safe radioactive levels, but this process takes tens of thousands of years. Even low-level radioactive waste requires centuries to reach acceptable levels. Currently, the nuclear industry lets waste cool for years before mixing it with glass and storing it in massive cooled, concrete structures. This waste has to be maintained, monitored and guarded to prevent the materials from falling into the wrong hands. All of these services and added materials cost [money](#) -- on top of the high costs required to build a plant.

Nuclear Catastrophe and Reactor Shutdown

Remember, at the heart of every nuclear reactor is a controlled environment of radioactivity and induced fission. When this



Paula Bronstein/[Getty Images](#)

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.

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 of radioactive material into the surrounding area, contaminating millions of acres of forest. The disaster forced the evacuation of at least 30,000 people, and eventually caused thousands to die from cancer and other illnesses [source: [History Channel](#)].

Chernobyl was poorly designed and improperly operated. The plant required constant human attention to keep the reactor from malfunctioning. Meanwhile, modern plants require constant supervision to keep from shutting down. Yet even a well-designed nuclear power plant is susceptible to natural disaster.

On Friday, March 11, 2011, [Japan](#) suffered the largest [earthquake](#) in modern history. A programmed response at the country's Fukushima-Daiichi nuclear facility immediately descended all of the reactor's control rods, shutting down all fission reactions within ten 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 and that 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.

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. You can read more about exactly what happened in [How Japan's Nuclear Crisis Works](#).