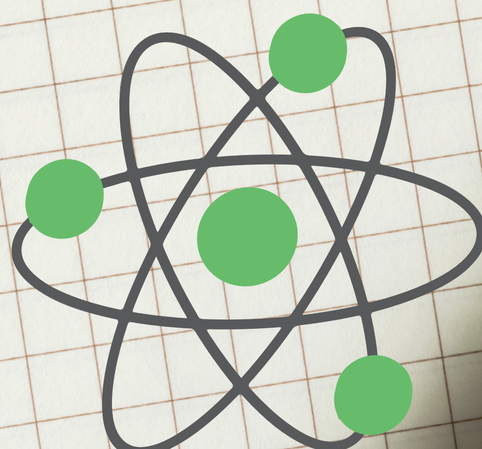
The Quick Read Nuclear Energy Guide

21 Easy-to-Understand Q & As

No prior nuclear knowledge needed!

A companion resource to the upcoming Chain Reaction novel



By Shawn M. Connors

Founder of the Atomic Garage Movement

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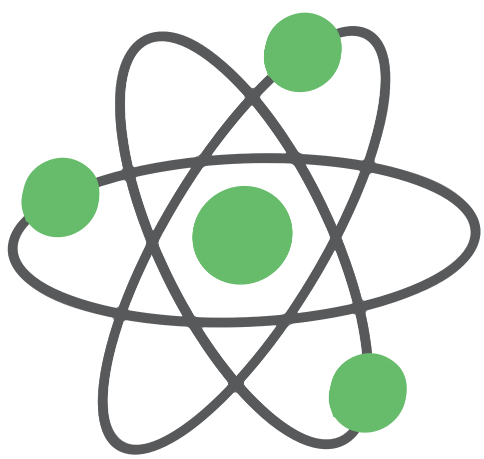

By Shawn M. Connors

Designed by Jennifer Cronin
Edited by Jennifer Cronin

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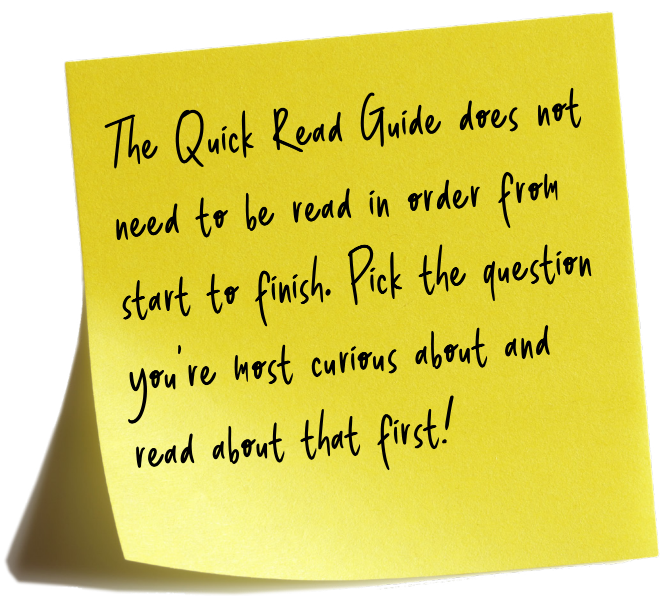


Introduction

This guide is a non-fiction companion for the fictional novel *Chain Reaction*. You don't need to read *Chain Reaction* to get the full benefit of this guide. More information about *Chain Reaction* is located at the end of this introduction.

Writing a novel about nuclear energy in a way that both high-level scientists and non-scientists can equally enjoy was a big challenge. During the research for the novel, it quickly became apparent the volume of information about nuclear energy's history and technology could not be covered in one's lifetime. As a result of that realization, we wrote down 21 questions about the topic we thought needed to be answered as basically as possible.

The project of answering those 21 questions took on a level of importance that couldn't be ignored. My editor, Jen Cronin, and I decided to pause the work on the novel and answer the 21 questions in the form of a non-fiction guide that would offer us quick access information when writing the book. As we worked through the questions, it became obvious the information would serve anyone who wanted to know more about subject. The guide takes about 50 minutes to read through cover-to-cover. It's loaded with links if you want to know more about each area covered.

The novel, *Chain Reaction*, is not nearly as technical as this guide, but the information here is the scientific basis for the novel. You'll notice one of the characters in *Chain Reaction*, Bob James, a retired nuclear room operator (reactor driver) gets credit for writing this guide when it appears in the novel. That is a nod to the balance between reality and fiction that drives the *Chain Reaction* story.
This guide is also available for free as a PDF download on our website, AtomicGarageMovement.com or in Kindle format on Amazon.com. Part of limiting the scope of this work was accomplished by focusing on current and near future nuclear technology. Some of nuclear energy's extensive history is included to put the present situation into context.

Marie Curie, born in 1867, winner of two Nobel Prizes in the field of science and a pioneer in researching radioactivity, said it best:

"Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less."

— Marie Curie

About *Chain Reaction* — a story about power in the age of climate change

The year is 2027. Amy Austin, a 19-year-old science polymath faces off with Josh Manning, an Academy Award Winning actor and world-renowned environmentalist, in a debate over the fate of an old nuclear power plant located in Amy's hometown of Algonquin, Michigan. The locals refer to the plant as The Rock. The live debate gets heated and goes beyond the fate of one nuclear plant. The battle of wits converges on a single question: What is the vision of an ideal future for the Earth? Amy and Josh's answers to that question aren't that contradictory. They ring true. When all the news is dark, pessimistic, and apocalyptic, it's the first time in a long time anyone has captured the imaginations and hearts of the public.

We soon learn Amy is working on her own advanced micro nuclear reactor — a device that is 30 years ahead of current technology. The debate combined with the incredible safety and capability of Amy's reactor triggers a series of events, a Chain Reaction, that ripples throughout the world. As an ecoterrorist group manipulated by powerful global players moves against Amy, there is no going back. It's now or never in what is a breathtaking and dangerous race to save the planet.

1. What exactly is nuclear energy?

Quick Answer

- Nuclear energy is a source of power held via a bond inside the nucleus of an atom. The power is released when the atom splits.
- A nuclear reactor uses uranium as fuel just as you use food as fuel. Both are condensed forms of energy from a star. The uranium's energy was collected from distant supernovas. Your energy was originally collected from our sun (also a star) by edible plants.
- A uranium atom is split in a nuclear reactor and creates heat. That heat is used to superheat water and then produce steam that turns a turbine that powers a generator that produces electricity.
- As the uranium atom splits, it expels two more neutrons that hit two more uranium atoms causing them to split, and so on. This is called a chain reaction.
- The first human-caused chain reaction took place in Chicago, Illinois in 1942.
- The release of energy from a chain reaction creates enormous heat that we use to superheat pressurized water, turn that water into steam, and then power a turbine that makes electricity.

"Energy cannot be created or destroyed, it can only be changed."

— Hermann Von Helmholtz,
German Physicist, 1847

More Details

Our sun or distant stars (other suns) are the source of all energy. Energy never really is spent, it just changes forms. When you walk, you burn the energy stored in calories you've consumed. Your physiology is your reactor. As you tap that power source, the energy is changed into kinetic energy as you walk. Heat is a byproduct of burning energy. You get sweaty when you exercise. Sweat is your body's cooling tower. The heat you produce when burning calories is scattered into the atmosphere and recycles itself in that sea of gasses. And you produce waste. That waste also scatters heat and keeps some energy as it changes forms. The calories that fuel you were collected from the sun's energy and condensed by plants, or even more condensed by animals eating plants. You then consume the plants or the animals (or animal products) to get at a more condensed form of calories.

> I didn't realize that!
>
> ***A nuclear reactor uses uranium as fuel just as you use food as fuel. Both are condensed forms of energy from a star. The uranium's energy was collected from distant supernovas. Your energy was originally collected from our sun (also a star) by edible plants.***

Nuclear fuels originally got their energy from ancient, distant supernovas

Uranium contains highly condensed amounts of energy. It came from supernovas (dying suns) between 6.5 billion years to 200 million years ago. Uranium is a million times denser than coal. The neutrons and protons in uranium are the tiny particles in the nucleus that make up each atom of uranium. Those neutrons and protons are bonded together by the energy released by those ancient supernovas. The uranium was spewed off into space and eventually melded into the crust of our forming planet, Earth.

The first time an atom was observed splitting

In 1938, radiochemist Otto Hahn, Lise Meitner, and Fritz Straussman, working in a Berlin, Germany lab, discovered that a uranium atom split when bombarded by a neutron. When we split a uranium atom, a tiny amount of those ancient supernovas power is released.

The first chain reaction

When the second atom of uranium splits, it shoots off two more neutrons that cause two atoms of uranium to split, and so on. By putting the kind of uranium atoms that split closer together (enriched uranium), we can control trillions of them splitting at nearly the same time, which is called a chain reaction. The first controlled chain reaction was demonstrated on December 2, 1942, during the Manhattan Project led by Italian-born Enrico Fermi. The name of the crude but elegant reactor was called Chicago Pile- 1 (CP-1). CP-1 was the first nuclear reactor. The release of energy from a chain reaction creates enormous heat that we use to superheat pressurized water, turn that water into steam, and then power a turbine that makes electricity. The concept is the same as it has been since steam engines became the dominant power source in the late 19th century.

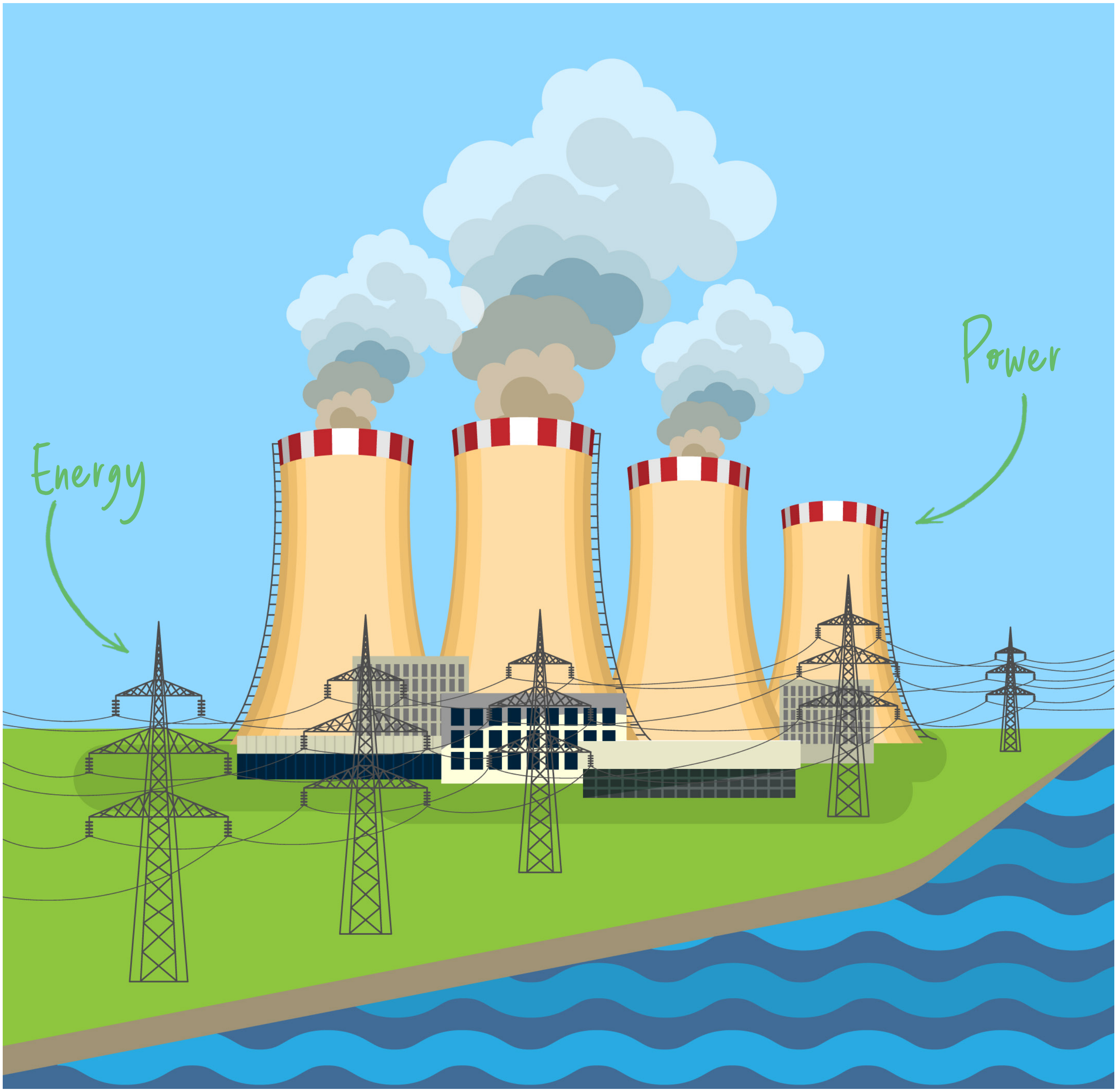
2. Is there a difference between nuclear power and nuclear energy?

Quick Answer

» Power is what is produced by a nuclear reactor, and energy is what is transmitted and consumed.

More Details

Most people use both terms interchangeably. But they are different. Think of a weightlifter. Power is how strong the weightlifter is (power is measured in watts). Energy is how long the weightlifter can keep lifting the weight (energy is measured watt-hours). A nuclear reactor produces power and transmits usable energy through the grid (wires and transformers that distribute energy).



3. What is the difference between fission and fusion?

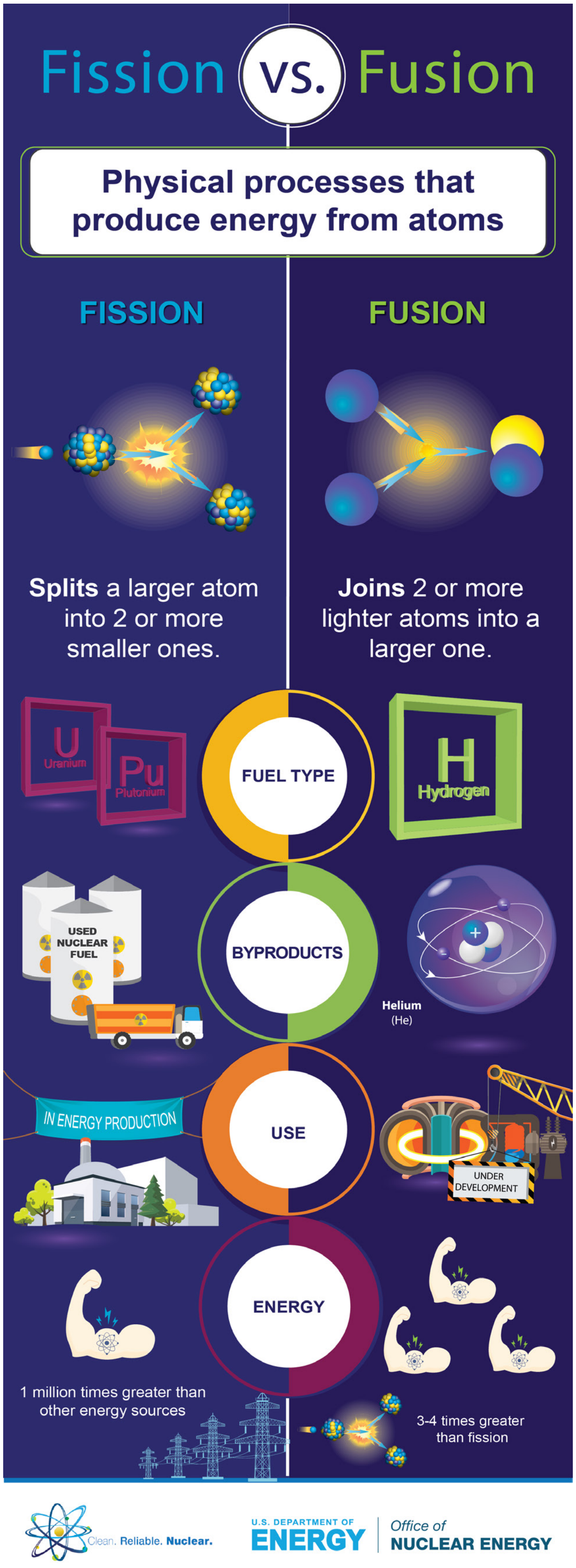
Quick Answer

I. Fission

» Fission splits an atom, and energy is released.

II. Fusion

» Fusion jams two atoms together, and energy is released.
» Scientists (including a couple young ones) have successfully created fusion reactions. But it took more energy to create the heat than the energy produced.
» Eight countries are working on or testing fusion reactors. The progress being reported is encouraging.
» Fusion energy operates with low-dose radiation and leaves no radioactive waste behind. It does not emit greenhouse gasses. And its fuel supply (mostly molecules that make up water and air) are inexhaustible.
» Several promising fusion reactors are being built and tested around the world.
» Eventually, fusion will be the world's primary, if not only, source of energy.
» Fusion could be the technology that makes energy inexpensive, clean, and abundant all over the world.



More Details

Fission splits the nucleus in a heavy atom (uranium or plutonium), and energy is released when the ancient bonds between the neutrons and protons separate. Fission is the physics that has been powering all nuclear reactors for the last 70 years. Fusion, as the word implies, fuses together two atoms, and energy is released. Just the opposite of fission.

How fusion works

Our sun is a nuclear fusion reactor. Our sun's immense gravity and intense heat jam together two different, light nuclei of hydrogen to form a single heavier nucleus of helium. The new nucleus of helium weighs more than the combined weight of the previous two hydrogen nuclei. So, to balance itself, it throws off neutrons in the form of gamma rays. That releasing of the extra weight unlocks the stored energy in those previous two hydrogen nuclei. The gravity and heat on the sun are enough to keep a fusion reaction going.

Note: Our sun only has 5 billion years of fuel left.

Why it's hard to jam together two nuclei

The single proton in a hydrogen nucleus is positive, so it repels the single positive proton in the opposing hydrogen nucleus, like trying to push the same poles of two magnets together.

On Earth, we try to create enough force (using magnets) and heat (using plasma) to jam the atoms of Deuterium - Tritium together to create a fusion reaction. The ideal temperature for the plasma is 100 million degrees C (180 million degrees F). Fusion has been successfully achieved on Earth, but so far, we spend more energy making it than it produces.

The equation for measuring the energy in versus energy out is called Net Energy Gain (NEG). The answer is expressed as Q = X. So, Q > (greater) than 1 means the fusion reactor is producing more energy than it's using. The ITER Tokamak reactor team in France hopes to achieve Q = 10 or more. That means it would take 50 MW in to create 500 MW out, a factor of 10. There have been brief glimpses (measured in seconds or fractions of seconds) of achieving surplus energy from fusion reactions.

No greenhouse gasses or radiation

Fusion energy operates with low-dose radiation and leaves no radioactive waste behind. It does not emit greenhouse gasses. And its fuel supply, mostly molecules that make up water and air, are inexhaustible. It also produces more energy per unit of atomic weight, making it more efficient than fission.

Young fusion scientists

In 2008, a 14-year-old named Taylor Wilson built a nuclear fusion reactor in his garage. It took more energy to make the reaction happen than it produced. But it was a successful fusion reaction. In 2018, Jackson Oswalt, at the age of 12, accomplished the same feat, becoming the youngest person to do so.

Promising fusion tests

There are several fusion test reactors around the world, including the large International Thermonuclear Experimental Reactor (ITER Project) in southern France with seven countries participating. In early 2022, China's test fusion reactor, the Experimental Advanced Superconducting Tokamak (EAST), also called Artificial Sun, achieved a fusion reaction for 17 minutes. Large fusion nuclear reactors are called Tokamak Reactors. They were first conceptualized by Soviet physicists in 1950, followed by the first working Tokamak reactor, the T-1, built in 1958. These devices use powerful magnets and superheated plasma in creating the fusion reaction, although scientists are also working on other fusion reactor designs much smaller than the Tokamaks, using new applications with magnets. If scientists can achieve a sustained fusion reaction (maybe even in short bursts) that puts out more energy than it took to create it, we'll have a game changer available.

In addition to the international coalition working on the ITER project, the United States, Russia, China, United Kingdom, Spain, Germany, France, and Japan are working on their own fusion reactors — the UK's Tokamak Energy, ST-40 and Mega Amp Spherical Tokamak (MAST), the Joint European Torus (JET), and Japan's Stellarators. The United States hopes to build a prototype nuclear fusion plant starting in 2035. And US companies like Lockheed Martin are committing significant resources to developing scalable fusion reactors. Several institutions and people around the world are working on fusion power.

Fusion's potential

If the governments of the world were behaving, there is no reason every person on Earth could not have access to abundant fusion-based energy in the form of electricity. No country experiences prosperity without an abundant source of energy. Without getting into an entire fusion manifesto, the challenges are still daunting. If humanity can survive another 50 to 100 years, fusion will eventually power the world. It would be nice to be surprised by a breakthrough fusion reactor in the shorter term. Some scientists think it could happen. You never know.

Note: The remainder of this guide is about the current and near future of nuclear energy, which is fission.

4. Did the hit comedy *The Simpsons* and its depiction of the fictional Springfield Nuclear Power Plant have an element of truth in it?

Quick Answer

- There is an element of truth in satire, or it would not have worked. The producers effectively lampooned and exaggerated lapses in the nuclear industry's training, communications, and ownership structures, most of which were exhibited during and after the 1979 Three Mile Island Accident.
- *The Simpsons* first appeared on television in 1989. It's the longest running series in history (now in its 33rd season and 715th episode) and appeals to a wide spectrum of the population. Merchandise sales related to the Simpsons is a multi-billion-dollar industry.
- The show revolves around Homer Simpson, an employee at the local Springfield Nuclear Power Plant, with a clear antinuclear message.
- But the funniest scenes depicting the daily operation of the fictional nuclear plant are not only inaccurate, they're non-existent in the real-life operation of a nuclear power plant.
- The Simpsons have become a trusted source of information to the viewing public, and the show has influenced the public's negative perception of nuclear energy. Popular culture has played a key role in the actual implementation of nuclear-energy agendas and will continue to do so.

More Details

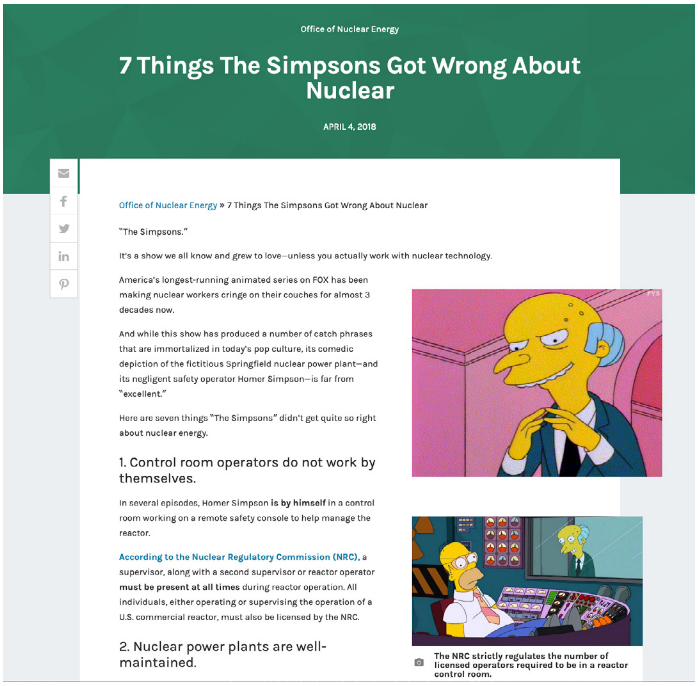
At the Simpsons' fictional Springfield Nuclear Power Plant, the emergency exit doors were painted on. Homer and another employee dumped liquid nuclear waste into a kids' playground until the kids became bald, so they started dumping it in the park. Radioactive plutonium was used as paper weights. The fish downstream from the plant grew three eyes. As a potential meltdown occurs, Homer just starts pressing buttons in the control room; meltdowns are averted by pure luck. Homer wears a radiation protection suit. His son, Bart, plays an arcade game called "Nuke." Their comic book hero is Radioactive Man. Radioactive Man's sidekick is Fallout Boy. And the family visited the Sha-Boom Ka-Boom Diner. When it's pointed out that Homer, who is alone in the control room, only has a high-school degree and is totally incompetent, the characters decide, "It's best not to think about it." There's a painting in Homer's home of the Springfield Nuclear Plant's cooling towers, and those towers are in many background scenes.

An element of truth

The truth is that nuclear power plants are extremely safe because the operators insist on a culture of safety and exercise constant vigilance. But prior to the Three Mile Island accident in 1979, the nuclear industry had grown complacent. Human error, which caused the accident, was followed by confusing messages, which resulted in public panic. A lot of the comic material in the Simpsons pegs to the post-accident reports from Three Mile Island. For example, the training was inadequate, the controls were in the wrong places, and the plant owners were dangerously overconfident. We're fortunate no injuries or death resulted from that accident. But even that "luck" is satirized in the Simpsons.

The US Government responded to *The Simpsons*

In 2018, the US Department of Energy put out a release titled, *7 Things The Simpsons Got Wrong About Nuclear Energy*. Almost as hilarious as the actual show, the official statement wraps up by making an offer, "We will, however, be more than willing to provide feedback to Homer when the (fictional Springfield) power plant is ready to submit an application to the NRC for their license renewal for the next 30 years!" I think Homer will find reality is stranger than fiction when he files that application.


Office of Nuclear Energy

7 Things The Simpsons Got Wrong About Nuclear

APRIL 4, 2018

Office of Nuclear Energy » 7 Things The Simpsons Got Wrong About Nuclear

"The Simpsons."

It's a show we all know and grew to love—unless you actually work with nuclear technology.

America's longest-running animated series on FOX has been making nuclear workers cringe on their couches for almost 3 decades now.

And while this show has produced a number of catch phrases that are immortalized in today's pop culture, its comedic depiction of the fictitious Springfield nuclear power plant—and its negligent safety operator Homer Simpson—is far from "excellent."

Here are seven things "The Simpsons" didn't get quite so right about nuclear energy.

1. Control room operators do not work by themselves.

In several episodes, Homer Simpson **is by himself** in a control room working on a remote safety console to help manage the reactor.

According to the Nuclear Regulatory Commission (NRC), a supervisor, along with a second supervisor or reactor operator **must be present at all times** during reactor operation. All individuals, either operating or supervising the operation of a U.S. commercial reactor, must also be licensed by the NRC.

2. Nuclear power plants are well-maintained.

The NRC strictly regulates the number of licensed operators required to be in a reactor control room.

Myths versus reality

Here are a few myth busters depicted in the Simpsons about nuclear power:

- Nuclear “waste” is solid, not a liquid green color. Although, “waste” will be molten in many future reactors.
- Nuclear “waste” is safely shielded from the outside environment.
- Waste is stored in 125-ton stainless steel-lined dry casks, not barrels.
- An entire shift of engineers is in a control room.
- A nuclear plant emits less radiation than when standing in downtown Denver, by the US Capitol Building, near a coal plant, or your marble kitchen countertop.
- A lot of very smart people work at nuclear power plants, making them one of the safest workplaces in the country.
- Radioactive plutonium pieces are not used as paperweights. Although, I do have a piece of low radioactive Bismuth serving as a paperweight on my desk.

> I didn't realize that!
>
> ***A nuclear plant emits less radiation than when standing in downtown Denver, by the US Capitol Building, near a coal plant, or your marble kitchen countertop.***

Note: You can imagine where the producers of the Simpsons got some of their material. Nuclear energy folklore says, “A modern nuclear power station could be operated by one man and a dog. The man would be there to feed the dog, and the dog would be there to bite the man if he touched any of the controls.”

The Simpsons filled a vacuum

According to Megan M Ruxton in a paper called, “The Simpsons and Nuclear Power: How Television’s Atomic Family Has Impacted Public Attitudes on Nuclear Power” for Academia.edu, although experts can factually explain why nuclear energy is safe, some highly educated people (non-experts) don’t believe them. That gap exists because of strong common beliefs (e.g., environmentalism) and values (e.g., use the sun and wind for energy) held by the highly educated. If you have a smart friend who, when talking about nuclear energy, might say something like, “Oh, let me tell you. You don't want to be downwind from one of those things when it has a meltdown. That radiation is nasty stuff,” you’re understandably going to trust your friend’s opinion and pass that opinion on to others as your own, unless you embark on a deeper dive into the literature.

The Simpsons are successful because the show is hilarious. Also, according to Ruxton, “The Simpsons influences public opinion by reflecting the attitudes held by its viewers.” Time has passed since the last nuclear accident (Fukushima Daiichi, 2010), and with the emergence of an apocalyptic climate change narrative entering the public consciousness, attitudes may now be trending more in favor of nuclear energy. Maybe the Simpsons’ producers will soon turn their satiric light on fossil fuels.

5. What is nuclear fuel?

Quick Answer

- The three nuclear fuels are uranium, plutonium, and thorium.
- Before nuclear fuel is placed inside a reactor, it's called the "front end" of the nuclear fuel cycle.
- Nuclear fuels are forms of condensed energy from ancient supernovas. Their energy is stored in metals rather than decayed plants and animals. That's why nuclear fuels are not considered fossil fuels.
- Uranium needs to be enriched (a higher concentration of a certain kind of uranium) before use in most nuclear reactors.
- HALEU (High Assay Low Enriched Uranium) is more enriched than used in today's reactors and will be the primary fuel of new reactors.
- Only traces of plutonium exist in nature. The plutonium used in nuclear reactors is a byproduct of uranium-238 exposed to a nuclear chain reaction inside the reactor core.
- Thorium is fertile, meaning it can't fission in the form it comes out of the ground. It is transmuted (series of changes) into uranium-233 when exposed inside a nuclear reactor. Once it turns into uranium-233, it then can be used to start or maintain a chain reaction.

More Details

Front-end nuclear fuel cycle

Nuclear fuel from the point it's mined to the time it's placed into the nuclear reactor is called the front end of the nuclear fuel cycle. Uranium and thorium have millions of times more energy stored in them than wood, coal, oil, or gas. One golf ball size of thorium could provide one high-energy human all the energy they need for their entire life.

Nuclear fuels are elements. An element is a substance made of only one kind of atom. All the known elements are listed on the periodic table. Nuclear fuel used today is mostly uranium. About a third of the operating nuclear plants use plutonium as fuel. And thorium is the third element that can be used as nuclear fuel. Let's focus on uranium first.

a. Uranium: Most uranium, at the time it's mined, is uranium-238. Nuclear reactors need uranium-235 to create a chain reaction. Less than 1 percent of mined uranium is 235 (.07). Those numbers (238 & 235) are the atomic mass, which is the number of neutrons + the number protons in the atom's nucleus. The different numbers are different isotopes, which means they are part of the same element, but have a different number of neutrons. This information is on the periodic table.

Note: To have a basic understanding of nuclear energy, it isn't necessary to know the atomic weight of various elements. Just understand that when those atomic weight numbers change (e.g., uranium 235 into plutonium 239), the fuel inside the reactor is changing and presenting different problems and opportunities. If you keep learning about nuclear energy, you'll come to understand the relevance the periodic table plays in physics.

b. Uranium-235: The most common nuclear fuel.

To be usable as a nuclear fuel (in most of the currently active nuclear reactors), uranium must be enriched so we have uranium-235 making up more of the mix. It must be enriched so 3 to 5 percent of it is uranium-235. We can enrich uranium in a few ways. It's a complex straining process involving gasification and centrifugal force (or even lasers). Some uranium-238 separates out during enrichment, leaving more uranium-235, which is what works in a nuclear reactor.

c. HALEU: This means High Assay Low Enriched Uranium (pronounced like, "Hey, Lou."). You'll hear this acronym more often. HALEU means the uranium is enriched more than 5 percent and often up to 20 percent to facilitate faster chain reactions in the new reactors now being tested.

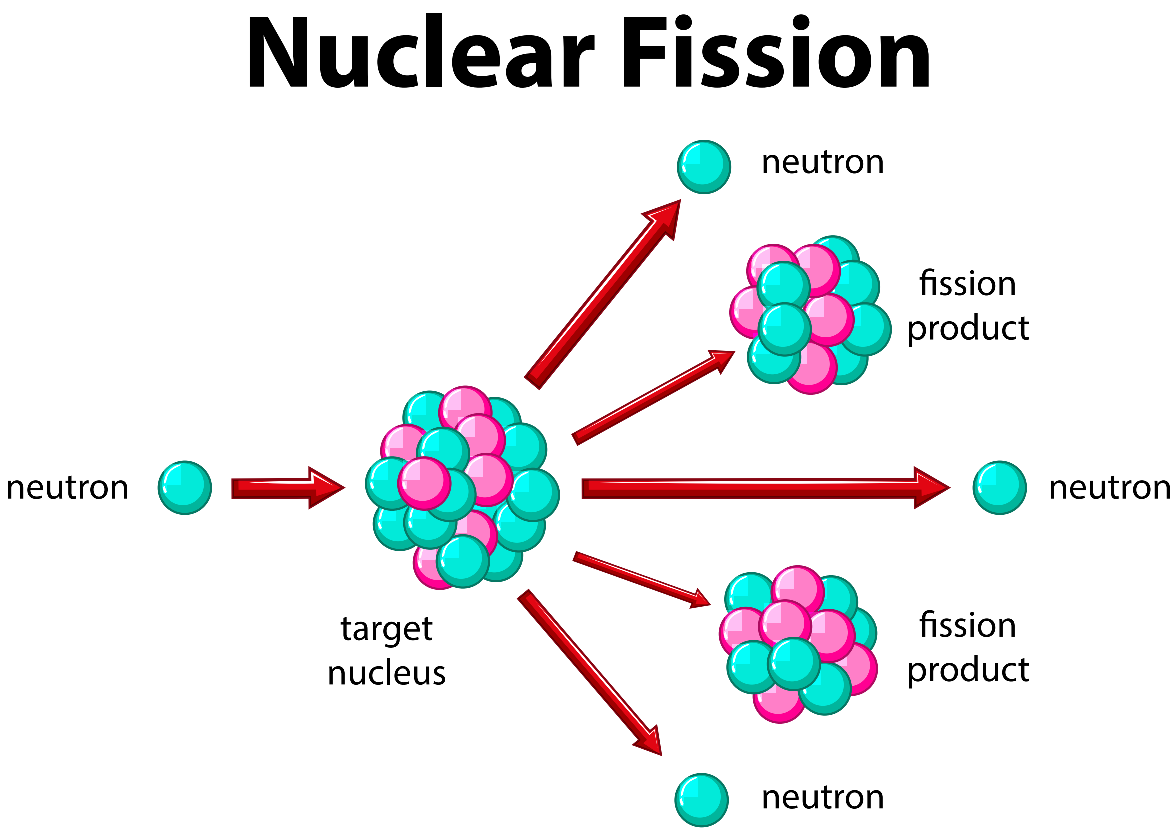
d. Plutonium-239: One element produced (as a byproduct) from uranium-235 being used in certain kinds of nuclear reactors is plutonium. Even though plutonium rarely occurs in nature, it can be collected as some uranium in an active reactor transmutes (changes) into plutonium-239. Just one kilogram (2.2 pounds) of Plutonium-239 can create 8 million kilowatt hours of electricity when used in a commercial reactor. That's enough to power about 530 high-energy, stand-alone homes.

> I didn't realize that!
>
> ***Just one kilogram (2.2 pounds) of Plutonium-239 can create 8 million kilowatt hours of electricity when used in a commercial reactor. That's enough to power about 530 high-energy, stand-alone homes.***

e. Plutonium-238: This form of plutonium has been used in more than two dozen NASA space missions during the last 50 years. This type of plutonium is not useful for producing fissionable power in a nuclear reactor or for a weapon. It is very stable, and its decay radiation produces heat that is chemically turned into electricity. When you see space probes, surface vehicles, and eventually life support systems on other planets, plutonium-238 will most likely be the power source.

f. Thorium is the third element that can be considered a nuclear fuel. Although still theoretical, it's possible that thorium could be the primary future nuclear fuel. It's abundant all over Earth, three times more abundant than uranium. Thorium transmutes (changes) into different elements when put inside an active reactor (radiated). It ultimately changes into uranium-233.

g. Uranium-233: Uranium-235 and plutonium-239 are what we refer to as fissile. That means we can split their atoms with a neutron and start a fission chain reaction, which is referred to as "going critical." But thorium is known as fertile (its nucleus can't be split in a fission reaction). When a thorium atom absorbs a uranium neutron inside an active reactor, it doesn't split but it transmutes into different isotopes. In its final stage, much of it becomes Uranium-233. Uranium-233 is fissile, and like uranium-235, it will split and can be used to create or maintain a chain reaction. Thorium is not likely to be used in traditional nuclear reactors, although it has been successfully tested in them as a potential nuclear fuel. It's best used in a Molten Salt Reactor (MSR). More about MSRs later. The best metaphor is to think of thorium (fertile) as a log, and uranium (or plutonium) as its kindling (fissile).



6. How does a nuclear reactor work?

Quick Answer

» A fission chain reaction takes place in the fuel assembly, the core inside the reactor containment vessel.
» One megawatt equals power to about 500 high-energy US homes.
» A moderator slows the speed of the chain reaction so it can be sustained. That chain reaction creates heat used to make steam.
» The thermodynamics inside a nuclear reactor make it self-regulating.
» Steam turbines and generators are primarily the same in nuclear, coal, and natural gas plants.

More Details

There are many types of nuclear reactors. For this part of the guide, I'll explain how the reactor works inside of a Pressurized Water Reactor (PWR). PWRs represent about 75 percent of the approximately 450 active nuclear reactors in existence.

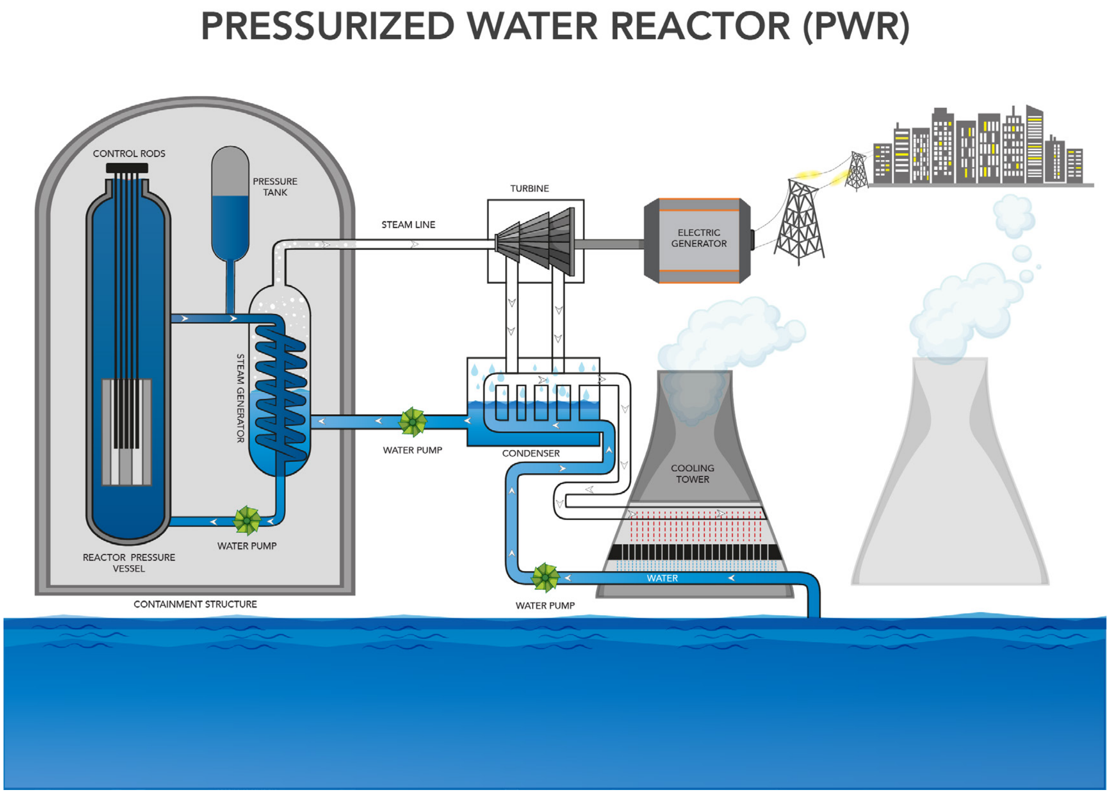


Image courtesy of the U.S. Department of Energy Office of Nuclear Energy

It's just a fancy steam engine

Water boils at 100 degrees C (212 degrees F) at sea level. But if the water is highly pressurized, it can be heated beyond 100 C without boiling. Think of a household pressure cooker, only on a bigger scale. This results in much more powerful steam generation as it's depressurized, which means the reactor will be able to generate a lot of power.

Two circuits

There are two circuits in a PWR. In the first or primary circuit, the water flows around the reactor core, between the fuel rods and is hyper-heated to 325 degrees C (617 degrees F). That water is moderating the chain reaction so there is some radioactivity in it. The second circuit of water comes in from the outside, and the heat (but not the water) inside the reactor is exchanged with the second circuit.

After the water from the second circuit picks up the heat inside the reactor, it heads back out in what is known as the hot leg. It travels to a steam generator where some pressure is relieved, and steam is produced. The electrical generation takes place, then the steam is condensed back into water at a temperature of 290 degrees C (about 550 degrees F). That cooled water is just 35 degrees C cooler (95 degrees F) than it was on the hot leg. Then it's sent back through the second circuit via what is known as the cold leg.

Heat exchange

Imagine you were extremely hot and slipped into a tub of circulating water to "cool off." What is really happening is you're transferring heat from your hotter body (the first circuit) to the cooler water around you (the second circuit). The water doesn't have to be freezing cold, just somewhat lower than your body temperature to pick up the heat.

Big water pipes

The water in the second circuit is traveling through pipes 7 meters in diameter (about 23 feet). Nearly 22 tons of water run through the reactor core every second. A four-loop PWR will have four secondary circuits going to four turbines and their partner generators. That means a single four-loop reactor can send out power from four stations in four different directions.

There's also a need for fresh water to enter the first and second circuits as water evaporates. The steam coming off a nuclear reactor cooling tower is an observable sight of non-radioactive heat coming off a nuclear reactor.

Fuel assemblies

The reactor core contains the fuel assemblies. These can vary in configuration, but a typical PWR fuel assembly is made of thousands of uranium dioxide (UO2) pellets (about the size and shape of a pencil eraser) that are slid on top of each other inside fuel rods. The fuel rods are made of a zircaloy cladding (an alloy of zirconium), which can withstand the radiation, boron (used as an additional moderator), and the high heat. About 400 pellets in each fuel rod are pressed down upon by a spring at the top of the rod. Each uranium pellet will be responsible for 5 trillion fissions per second.

Inside the core

The rods are spaced just 3mm (a little over 1/10th of an inch) apart so water can flow through them. There are 264 individual rods and 25 guide tubes for stability in an assembly that is a 17 X 17 (289 hole) grid. Guide straps are also used to stabilize the assembly. The assembly is transported by an overhead crane that uses powerful magnets to lift and lower the assembly into place. One fuel assembly weighs about 1,300 pounds. A 1,100-megawatt reactor will contain more than 157 fuel assemblies, made up of 45,000 fuel rods and 15 million fuel pellets. Each assembly contains enough energy for four years of operation at full power. One pellet of uranium has the same energy as one ton of coal.

1,000 megawatts = Power for 500,000 homes (conservative estimate)

An average US household uses about 10,000 kilowatt-hours (kWh) of electricity each year. If you use this average, then 1 megawatt (1 million watts) = power to 1,000 homes. But more people are moving to the Sun Belt. As more people depend on air conditioning, keep smart phones on, and charge their electric vehicles, that average seems backward looking. There can be a 60-percent swing in energy uses from homes in the north and homes in the south. So, I use a thumbnail guesstimate of 1 megawatt = energy for 500 homes. Thus, a nuclear plant putting out 1,000 megawatts = power to 500,000 homes. I think that number is more realistic.

Moderators

Remember, it's neutrons being released from splitting uranium atoms that causes the chain reaction. One thing that nuclear engineers (reactor drivers) do to keep the chain reaction going is counterintuitive. They slow down the reaction. They do that by using moderators, which slow neutrons. Water is a good moderator. For example, the hydrogen atom in water slows down a neutron, like when billiard balls hit each other. That gives neutrons a better chance of colliding with another uranium atom's nucleus.

Self-regulating reactivity

One interesting feature about all kinds of nuclear reactors is that they self-regulate. When water (or any substance) cools, its molecules get closer together (molecules are made of atoms). When water heats up, just the opposite happens, the molecules get farther apart (creating a void). So, when the coolant (water) in a nuclear reactor gets hotter, its molecules get farther apart, which makes it harder for a neutron to reach a nearby atom to split. Thus, the reaction automatically slows down (negative reactivity). As the water cools, the molecules get closer together so neutrons find more nearby targets to hit. Thus, the reaction speeds up (positive reactivity). Now imagine the fissions per second staying the same. When the power in an operating nuclear reactor is neither going up or down (zero reactivity) the fissions per second are matched to the power produced. Reactors run very close to zero reactivity with any changes usually under 1 percent. It's like cruise control in your car. The power generated matches the desired speed.

Turbines, generators, and electrical grid

Once the hot water in the hot leg is somewhat depressurized in the steam generator, that steam (which is mechanical energy now) hits the fan blades of a turbine, and the turbine turns the main generator's alternators (via a large shaft). Then electrical energy is produced and transmitted to the grid.

Note: The nuclear reactor is the source of the heat in the plant. In a fossil-fuel power plant, burning coal, natural gas, or biofuels (like wood chips) create the heat. But once the heat is used to make steam, all power plants are alike. Therefore, the fossil-fuel workforce is highly trained, and experienced. They can adapt to a coal plant being changed into a natural gas plant or nuclear plant with proper training in a relatively short time. It's all familiar to them. The re-training time to operate a wind turbine or solar farm and its infrastructure would take longer.

7. What if something goes wrong at a nuclear power plant?

Quick Answer

» The chain reaction in the nuclear reactor is quickly shut down in what is known as a SCRAM or a TRIP. This can be accomplished by a computer or a human engineer.
» Water keeps circulating through the reactor core to keep it cool.
» Numerous events (big and small) can trigger a SCRAM. And although not welcome, they happen enough that the engineers manage them according to safety standards established over decades.
» A Nuclear Regulatory Agency (NRC) Resident is onsite or nearby, and all SCRAMS must be promptly reported to the NRC.

More Details

The SCRAM

A SCRAM or a TRIP is an event that shuts down the chain reaction in a nuclear reactor. The control rods (made of various materials that absorb neutrons) are lowered into the fuel assemblies, and boron may be added directly to the water flowing around the reactor core. Boron, which also absorbs neutrons, is sometimes referred to as "poison." But the word poison in this case means it stops the chain reaction. Once the neutron absorbers are in the reactor the chain reaction shuts down immediately.

In a fast-acting emergency such as a fire or earthquake, the computer system would handle this job within a couple seconds, while also making many other adjustments faster than humans could intervene. Once the chain reaction is shut down, the engineers can evaluate the situation and determine next steps.

A SCRAM is like a circuit breaker tripping in your house and cutting off the power. Later, you can determine what went wrong, and if you can safely turn the power back on.

I didn't realize that!

A SCRAM is like a circuit breaker tripping in your house and cutting off the power. Later, you can determine what went wrong, and if you can safely turn the power back on.

The nuclear reactor keeps getting cooled

The reactor core must continue to be cooled by a flow of water even after the chain reaction has ended. The nuclear fuel remains hot because it is decaying, thus it is highly radioactive. Two of the three big nuclear accidents (covered later in this guide) occurred because water (coolant) was cut off from circulating through the reactor core after the chain reaction was shut down. Thus, the uranium fuel melted down.

Reasons for a SCRAM

A nuclear plant can SCRAM for numerous reasons. A natural or human-caused disaster, or an unexplained variance in the operating parameters of the nuclear plant would be reasons for a SCRAM. For example, if a valve or a pump leaks radioactive water or gas into the containment area, a sensor would pick up that anomaly and the computer or an operator may shut down the chain reaction.

SCRAMS are rare occurrences, but they are not unusual. Faulty sensors can also cause a SCRAM. If you were in a control room during a SCRAM, it would get your attention, but it would not rattle the operators. The hundreds of sensors throughout a nuclear plant are extremely sensitive. A resident representative of the Nuclear Regulatory Commission (NRC) is always onsite or nearby to evaluate the situation. All anomalies that require intervention at a nuclear plant must be promptly reported to the Nuclear Regulatory Commission (NRC).

Note: There are a couple of colorful legends about where the name SCRAM came from. The one that rings true is at the time the first fission chain reaction was about to be tested at Chicago Pile-1 in 1942. An engineer on the project, Bill Wilson, was installing a big red button. If there was an emergency, it would signal the "suicide squad" to dump a liquid cadmium solution on the reaction to stop it. When somebody asked what the big red knob was for, Wilson replied, "You'd push it if you had a problem." To which the person asked, "Then what?" Wilson reportedly said, "Then you scram out of here."

8. How is a nuclear reactor refueled and how often?

Quick Answer

- A new fuel cell inside a reactor lasts for about five years.
- Every 18 months to two years, the nuclear reactor is shut down, and about a third of the older fuel cells are removed and replaced with fresh ones.
- Used nuclear fuel is cooled in pools of circulating water for about five years. Then moved to dry cask storage units.
- Fuel in (not that radioactive) / fuel out (very radioactive).
- Technology and experience have made handling used nuclear fuel a safe process. It requires training and vigilance, like an airline pilot landing a large airliner or a harbor pilot bringing a large ship into port.

More Details

Moving the big fuel assemblies

About one-third (about 65) of the fuel assemblies (cells) inside a nuclear reactor are replaced every 18 months to two years. These fuel cells are always moved under water. There's about 200,000 gallons in the 40-foot plus stainless-steel reactor cavity. Remember: Water is an excellent moderator; and in a PWR, boron is also added to the water in the reactor cavity when changing fuel assemblies. Boron absorbs neutrons coming from the decay heat that are in the water, thus offering another level of safety to the work crews. The 150-ton reactor head is removed, and then the fuel assembly is removed.

The cooling pool is nearby and connects to the reactor cavity via a tunnel with a conveyor belt inside it. A hoist lifts the fuel assembly out and a tilt machine sets it on its side for the short ride to the cooling pool. The cooling pool is also 40-feet deep, and the bottom 14 feet has storage racks to hold the spent fuel assemblies upright, under water. Water keeps circulating through the cooling pool to keep the fuel assemblies from overheating.

If you fall into a nuclear fuel cooling pool

If you ever fall into a nuclear fuel cooling pool (called ponds in Great Britain), don't panic. Just stay on the surface. It's about 30 degree C (86 degrees F). And if you don't swim down near the spent fuel, you will be safe because the water is an effective shield. If you were walking on the bridge over the top of a cooling pool, you would receive no radiation from that spent fuel even though you could see it less than 50 feet away.

Dry cask storage

The used fuel stays in the cooling pool for about five years before being transported into dry storage casks. The used fuel is transported into the casks under water in the cooling pool. Then the cask is drained, thus its name of dry cask. Most dry casks sit on pads that cost $1 million each outside the nuclear plant. Commercial US nuclear power plants do not have access to a permanent repository for their nuclear waste. For now, that waste sits in a secure area near each nuclear plant. We'll cover dry storage casks more in the question about nuclear waste.

Fuel in versus fuel out

Uranium, both in the ground and enriched, is not dangerously radioactive before it is put into an active nuclear reactor (radiated). Nuclear plant workers take safety precautions with inbound nuclear fuel because it does emit low-level radiation. But the fuel in that stage is low risk. This is why you hear a lot about "nuclear waste" but not about how the nuclear fuel gets transported and moved around before it goes into a reactor.

When used uranium fuel comes out of the reactor, a portion of it is highly radioactive because it's decaying faster after being radiated. That decay makes the used fuel very hot, and it takes thousands of years before it's not radioactive. The used nuclear fuel is also dense, so it doesn't take up much space. If it's properly shielded, as it has been for 60 years, it poses almost no risk to the public. And it can be recycled and used in nuclear reactors again, or its decay heat could be used in various industrial applications.

Safety is the issue, not the fuel

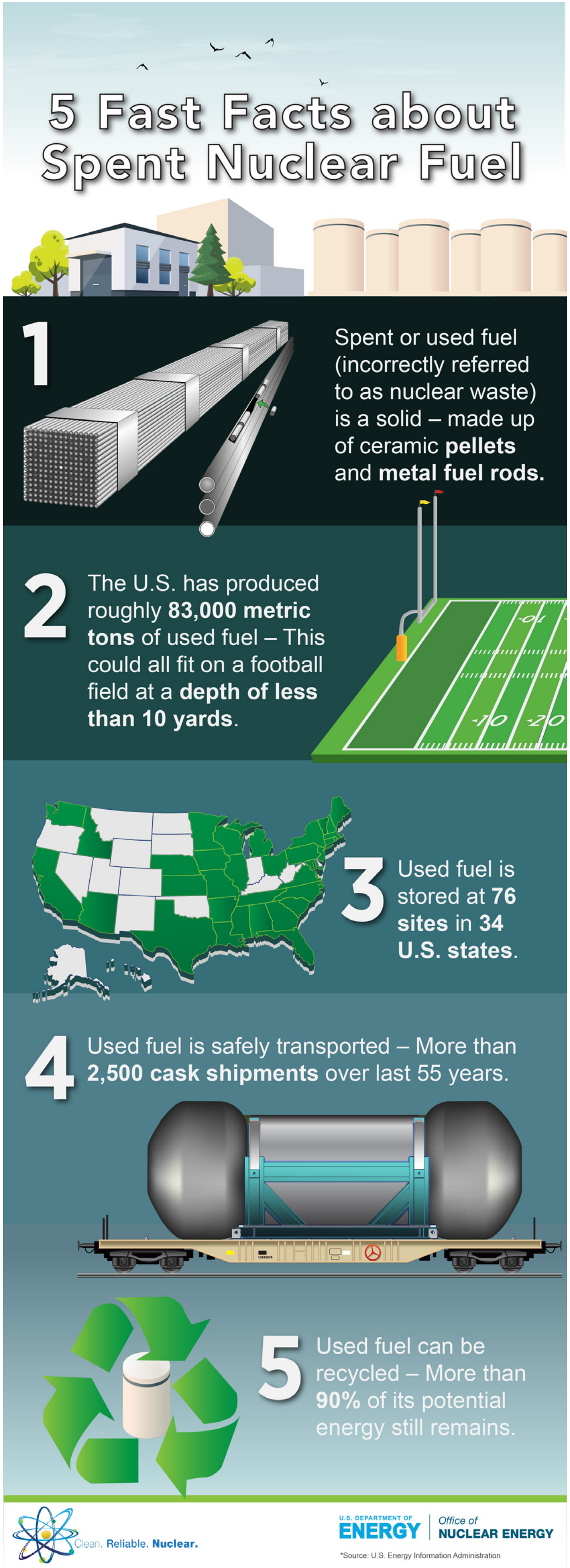
Nobody would advise someone to fill the backseat of their SUV with gas instead of putting the gas in their tank. The fuel itself is not a danger if taken within the context of how it is used and shielded from the environment.

It's not unusual to hear antinuclear advocates mention the total weight of nuclear waste in the US (about 95,000 tons), although all of it could be stacked on a football field about 10 yards high, which they never mention. Or they'll mention the temperature of the decaying used fuel residing in cooling pools or dry cask storage (570 degrees C / 1058 degrees F). The metals around that fuel are cooler (400 degrees C / 752 degrees F). They'll suggest a fission reaction will start up inside those and we'll have multiple meltdowns. The fuel is constantly cooling, not heating up. And the physics make a chain reaction from occurring in used fuel storage an almost impossible occurrence.

Perspective

Let's use the same tactic to advocate against fossil-fuel cars to make the point. The fuel in the combustion chamber of these dangerous cars is 2,800 degrees C / 4,500 degrees F. The walls of these combustion chambers, and heaven help us if they ever fail, are as high as 245 degrees C / 475 degrees F. And if that's not bad enough in itself, they must cart around about 120 pounds of highly flammable, explosive, and toxic fuel. About 190,000 of these controversial engines burst into flames every year in highway accidents. Then these pro-car nincompoops sit there with straight faces and claim it's okay to strap your kid into one of these bombs and cruise around. Do they think we're out of our minds?

We all make benefit-to-risk calculations and then follow through. In most cases, we hop in that car and drive somewhere.



9. Are there different types of nuclear reactors?

Quick Answer

- Yes, as in all technology like cars, planes, ships, and space vehicles, there are many models.
- The nuclear energy community categorizes all nuclear reactors into four separate generations of nulcear reactors, with I being oldest, II and III being the present reactors, and IV being the future.
- Almost all current operating nuclear reactors are Generation II. A few newer reactors now are Generation III (improvements on Generation II reactors).
- Pressurized Water Reactors (PWRs), Boiling Water Reactors (BWRs), and CANDU Heavy Water reactors represent the three reactors that supply almost all the nuclear energy to the world.
- Generation IV reactors are a different technology paradigm than previous generations and require new production, operation, and regulatory structures that should be to the world's benefit.

More Details

Anyone who has visited a museum related to the history of transportation like cars, trains, ships, planes, and space vehicles has observed the many different contraptions that have been invented over time. Nuclear energy is the same. Entire books and libraries are filled with the stories, drawings, test results, and actual artifacts of the past. People dedicate their entire professional careers studying these histories.

For purposes of this guide, we're going to embrace the present and near future of nuclear energy and use history only when it adds context to that discussion.

The four generations of nuclear reactors

There are four (or 4.5) generations (sometimes referred to as phases) of nuclear reactors:

- Generation I: Early prototype reactors, 1950s and 1960s
- Generation II: Commercial power reactors (current active reactors)
- Generation III: Advanced light water reactors (newer active water-based reactors)
- Generation III+: Evolutionary designs, improved economics
- Generation IV: highly economical, enhanced safety, minimal waste, proliferation resistant.

About 90 percent of the world's nuclear reactors use water as a moderator, coolant, and heat exchange. Boiling Water Reactors (BWRs) are the second most popular reactor in the world behind Pressurized Water Reactors (PWRs), which I used as the example for the question: How does a nuclear reactor work? And we'll also cover CANDU Heavy water reactors, which represent a smaller percentage of the world's power generation. In the last part of this guide, we'll cover Generation IV Reactors.

Boiling Water Reactors

Boiling Water Reactors (BWRs) are another type of reactor used around the world. According to Science Direct.com, "There are 75 BWRs in operation including four advanced BWRs in Japan." They differ from Pressurized Water Reactors (PWRs) in that they are simpler in design. The water boils right inside the reactor vessel and turns to steam at the top; there is no secondary loop where the heat is exchanged. Since the steam forms at the top of the reactor, the control rods in a boiling reactor are inserted at the bottom.

BWRs = Less Pressure, Fewer Parts

Boiling water reactors are also more standardized because they're built by one compnay, General Electric, after originally being developed at the Argonne National Laboratory. Because there is no second circuit, BWRs require fewer moving parts, pumps, heat exchangers, and equipment than a PWR. A BWR operates at about half the pressure of a PWR (1,040 psi versus. 2,300 psi). However, their reactor is larger than a PWR because it's designed differently and performs more functions.

There is some radioactivity in the turbines of a BWR after the reaction is shut down. This is because the water that flows around the core is turned directly into steam. However, once the reaction stops, the radioactivity quickly dissipates.

Why radioactive water in a BWR is a manageable risk

BWRs have less radioactive shielding from the environment than a PWR, primarily because they don't use a second circuit. However, the water flowing inside the reactor is cleaned of radiation and other fission particles on each pass through the reactor via the Reactor Water Cleanup System (RWCU), which maintains a high reactor water quality that includes keeping the circulating water as free from radiation as possible.

Also, the uranium pellets (like in a PWR) are loaded into waterproof zirconium cladded tubes which make up the fuel cells. The water inside a BWR reactor is picking up some radioactivity but not as much as one may think on first seeing its design. The PWR, because it has a second circuit not exposed to the core, has been more popular than the BWR.

CANDUs are heavy water reactors

Heavy Water Reactors, also known as CANDU (Canadian Deuterium Uranium) reactors, use heavy water instead of light water. Fifteen percent of all Canada's energy comes from these reactors. According to the World Nuclear Association, "Today, there are 34 Candu power reactors in seven countries, as well as 13 'Candu derivative' reactors in India, with more being built. Export sales of 12 Candu units have been made to South Korea (4), Romania (2), India (2), Pakistan (1), Argentina (1) and China (2), along with the engineering expertise to build and operate them."

- The deuterium in heavy water has one extra neutron than hydrogen in light water. Thus, an extra neutron from splitting one uranium atom is freed to hit another uranium atom. That makes CANDU more fuel efficient and cheaper to operate than a PWR or BWR that uses light water.
- Unlike in a PWR or a BWR, the uranium in a CANDU can be used in its natural state without being enriched.
- It is a fast reactor and therefore does not use moderators like PWRs do. This means it can "breed fuel." And because the newly made fuel is inside the reactor, it can be refueled while operating at full power, without the need to shut it down. The newly formed bred fuel, plutonium-239, represents half the power a CANDU reactor produces.
- The CANDU reactor operates at lower pressures than PWRs and BWRs, which means the reactor vessel and other parts can be built less expensively. And a CANDU can burn various fuels including thorium, plutonium, and the nuclear waste sitting in dry storage casks (after being processed).
- These reactors were made in Canada starting in the late 1950s to produce commercial electrical power. Canada shared the technology with India (with US involvement and help). But in violating the agreement between Canada and the US with India, the Indian government used the plutonium-239 produced by the CANDU reactor to build India's first nuclear bomb and tested it in 1974. It was called the Smiling Buddha.

Note: During WWII, Germany produced heavy water in occupied Norway, at the Vemork hydroelectric power plant. The Allies were concerned Germany might use the heavy water to produce the first nuclear bomb. Physicists understood the potential power of fission that could be used to make a bomb before WWII began. In early 1942, a special British operation failed to destroy the Vemork power plant. A year later, a team of Norwegian Commandos successfully destroyed it. The movie *The Heroes of Telemark*, released in the United States in January 1966, is a story about Vemork's destruction.

10. Why are nuclear plants so big and expensive to build?

Quick Answer

- In the 1960s, power company executives believed an "efficiency of scale" could be realized with larger nuclear plants. And their egos caused a competition of sorts between them to build nuclear plants bigger and faster.
- Wind and solar are heavily subsidized and distort market prices for energy.
- Overregulation also contributes to today's cost overruns. But the real culprit is poor construction management practices.
- France standardized construction of nuclear plants in the 1970s, establishing a model for the industry.
- The United States adopted the Pressurized Water Reactor (PWR) for commercial purposes, which the US Navy committed to in the 1950s.
- Even with all the mismanagement and politics, the big expensive nuclear plants have been a net benefit to the world.

More Details

In the 1960s, power company executives concluded that bigger was better. They believed they could increase the size of a nuclear plant and bring down their average per megawatt construction costs. This is called an "efficiency of scale." It was a popular management mantra in the 1960s and, not surprisingly, it was used in the new area of nuclear energy. Unfortunately, big egos were involved in nuclear plants buildouts, and a competition of sorts developed among power company executives.

Grew too big and too fast

During a four-year period in the 1960s, power company executives ramped up the size of reactors from 200 megawatts (power for 100,000 high-energy US homes) to 1,200 megawatts (power for 600,000 high-energy US homes). This rush to build larger plants resulted in complexity, lack of standardization, regulatory confusion, and skyrocketing construction cost overruns.

Each new nuclear power plant built is more or less customized for the owner. Imagine that each time Boeing built a jumbo jet each copy was significantly different from the other copies, and you get the idea of why nuclear plants are so expensive to build.

Generation II & III nuclear reactors are huge in scale

The scale is huge. A person standing by a 480-ton nuclear reactor pressure vessel (RPV) as it's being delivered to a nuclear plant looks like a small doll. The RPV will draw 5 megawatts to operate with its cooling pump weighing about 55 tons. The steam generators are each 65 feet tall, and almost 15 feet wide. The PWR containment domes protect the outside environment from any potential release of radioactive steam coming from inside the containment area. The containment structure can be 140 feet in diameter and 226 feet high, and about 2.5 feet thick at the top, with cooling towers being 550 feet tall. These large structures require huge amounts of upfront capital costs and sometimes take longer than two decades to build.

What if the powers that be had decided in the 1960s to stay at 200 megawatts, standardize the designs, and build the plants close to end users? With a perspective of 60 years, 10 years of nuclear-energy study, and from the comfort of my La-Z-Boy, I'd say they screwed up.

Subsidies distort the market

I believe the era of building big Generation II & III reactors is now behind us in the US. But many "energy experts" and antinuclear activists will say, "Nuclear energy is just too expensive compared to the alternatives." The problem is no current value is calculated for nuclear power's high efficiency, 24/7 baseline, carbon-free power. Instead, we fail to subsidize a nuclear reactor, then shut it down, and then replace it with a natural gas plant that produces tons of greenhouse gasses, which experts plan on removing from the atmosphere at almost any costs to taxpayers and electric consumers.

Wind and solar are politically popular right now. As a result, solar gets 250 times more federal subsidies than nuclear. In 2018, wind and solar got $9.8 billion, fossil fuels got $3.2 billion, and nuclear got $100 million. Yet nuclear energy produces about 20 percent of the country's energy, representing over half of its carbon-free energy. In 2021, the $1.2 trillion infrastructure bill was signed into law. That bill included $6 billion for the Department of Energy "to extend the life of the country's existing nuclear plants." Climate change and the world's growing thirst for energy are giving nuclear power generation a second look.

Note: According to the General Accounting Office, it cost $1 billion to $2 billion to design and certify a new type of nuclear reactor and $75 million of that are NRC fees for design certification.

Overregulation has played a role in increasing costs

PWRs have four levels of shielding between the nuclear reactor core and the outside environment (zirconium cladding tubes, reactor casing, containment area, and the containment dome). According to Colin Tucker in the book, *How To Drive A Nuclear Reactor*, PWRs also have as much as four levels of redundancy (quadruplicated) for many key pieces of equipment like pumps, valves, pipework, power supplies, etc. A typical PWR has 200,000 parts and assemblies. That means a lot of safety checks, inspections, and extra maintenance.

The only new reactor projects underway in the US are unit #3 and unit #4 (Generation III+), started in 2013 and being built by Georgia Power and Southern Nuclear at Plant Vogtle. They are AP-1000 Westinghouse PWR reactors. The original budget was $14 billion. Unit #3 was supposed to be done in 2016, and unit #4 in 2017. At the beginning of 2022, the cost is now $27 billion, and the reactors won't be operational until the end of 2022 for Unit #3, and 2023 for unit #4.

Note: As pointed out by Jeff Barry, a top science writer for Quora, China is building numerous AP-1000 nuclear power plants. One plant with two of those reactors is already up and producing electricity. It is the Sanmen Nuclear Power Station. The price for those two reactors — which are essentially identical to Georgia Power's Plant Vogtle — is $6.12 billion USD (versus $27 billion for Vogtle in the US). That is a 4-to-1 ratio for the same thing.

Why China has a price advantage over the US for the same reactor

In a representative Democracy like the United States, our strength is the freedom of our fellow citizens to innovate, collaborate, experiment, and produce. When we're working like that, guided by reasonable regulations, we excel at innovation, and the public supports the work. However, dissenting voices carry weight in our system of government, as it should be. Sometimes, those opposed to nuclear power, for example, achieve tremendous influence on the course of events. Right now, we're at a disadvantage because our nuclear energy community has not been able to produce to their full potential. Eventually, the technology and the math determine the long-range path of the energy source. Once common sense is demanded by the public, supported by the facts that emerge from the historical arc of the technology, the US has demonstrated throughout history that we can lead and support the world in energy innovation.

The Chinese Communist Government (CCG) is a one-party communist dictatorship. The citizens' duty is to carry out the government mandate. Right now, China's central command process has an advantage in nuclear energy development because they can systematically test concepts and standardize processes across all disciplines regardless of dissenting opinions.

The world would welcome US leadership in nuclear energy

Our long experience with nuclear energy and our excellent safety record over six decades are attractive to any country wanting to work with the US in nuclear-energy development. Never underestimate the power of a free society to solve big problems quickly once the creative spirits of its citizens are unshackled. The more freedom a society has, the cleaner their economies are.

If you believe climate change and/or energy poverty are critical issues, then all the countries of the world will need to have access to clean abundant energy in the very near future. China will be a huge provider of nuclear energy to themselves and the world whether the US is or not. But the world really needs the US in the game.

Note: China is planning to build 150 new nuclear reactors in the next 15 years at a cost of $440 billion. They will surpass the United States in nuclear-energy production by 2030 at the present rate.

The 4 things that could lower costs (actually, there are 5 now)

According to an MIT study, the four areas that could dramatically lower the construction costs of a new nuclear plant are:

1. **Standardization.** France is a good example of that strategy put into practice.
2. **Seismic Isolation.** These features should be built into the standard designs, instead of evaluated later in the project's timeline.
3. **Advanced Concrete.** Less likely to have flaws like cracking and becoming brittle from neutron exposure.
4. **Modular.** Ability to build parts and assemblies in factories.

I'll add one more of my own, No. 5. As an average student, I am honored to enhance an MIT study.

5. **Reform Risk Analysis at NRC.** The risk of an occurrence should be based on probability, and a risk-to-benefit ratio should be determined before a regulation is adopted. The Nuclear Regulatory Commission needs to be reformed.

Note: [NuScale, a Generation IV test reactor, took over six years] to have its first application accepted, and it was 12,000 pages long. NuScale will leave a lower bar to competitive entry behind it because it will have taken the risk of applying for new nuclear technology first. This is an inherent penalty to first-mover innovation and needs to be corrected. Nobody wants to go first.

Also, in 2022, the NRC denied Oklo Power (a micro nuclear reactor innovator) an application to build a 1.5 MW micro test reactor, called Aurora, at Idaho National Labs, although the NRC approved of the design in 2020. The NRC claimed "significant information gaps" in its description of Aurora's potential accidents as well as its classification of safety systems and components. Not knowing the details, it's common for applicants to have to respond to very low probability event scenarios and explain how they would keep the reactors safe in those unlikely situations. The potential scenarios should be probable, not just various situations someone can dream up. Hopefully, Oklo will soon be able to proceed.

France standardized nuclear energy

After the oil crisis of 1973, France came up with a then-controversial plan (Messmer Plan) to standardize its nuclear fuel cycle and power plant construction. The slogan at the time was, "In France, we do not have oil, but we have ideas." By 1984, France started building standardized nuclear power plants. Now, about 70 percent of France's power comes from nuclear energy. As the industry transitions into building smaller reactors called Small Modular Reactors (SMRs), they will be built at factories and assembled on site. Thus, France has positively demonstrated how standardization can be accomplished as part of a nuclear-energy strategy.

What if we amortized the cost over the life of the nuclear plant?

Most current and future nuclear plants could have a useful life of 80 to 100 years with appropriate upgrades. When amortized over this long timeframe, numerous attractive financial products could be produced as investment vehicles. This is referred to as the Levelized Cost of Electricity (LCOE), which is the total cost to build and operate a power plant over its lifetime/total electrical output dispatched from the plant. Even with a long-life expectancy, investors must also be assured that the antinuclear advocates, along with their political allies, cannot shut down a nuclear plant for arbitrary reasons when it still has years of useful energy production ahead of it.

Some nuclear plants have been shut down as they were ready to go into service

Many investors and owners have gone bankrupt during the construction of nuclear plants. This happens when investors and owners run out of money, and state governments deny state subsidies and consumer rate increases where the plants are being built. Occasionally, federal subsidies come into play. Once a nuclear plant's construction goes over budget and over schedule, the whole business gets complicated.

Even at the stage when nuclear plants were nearly completed and ready to go online, they were shut down. More than 310 US nuclear plants

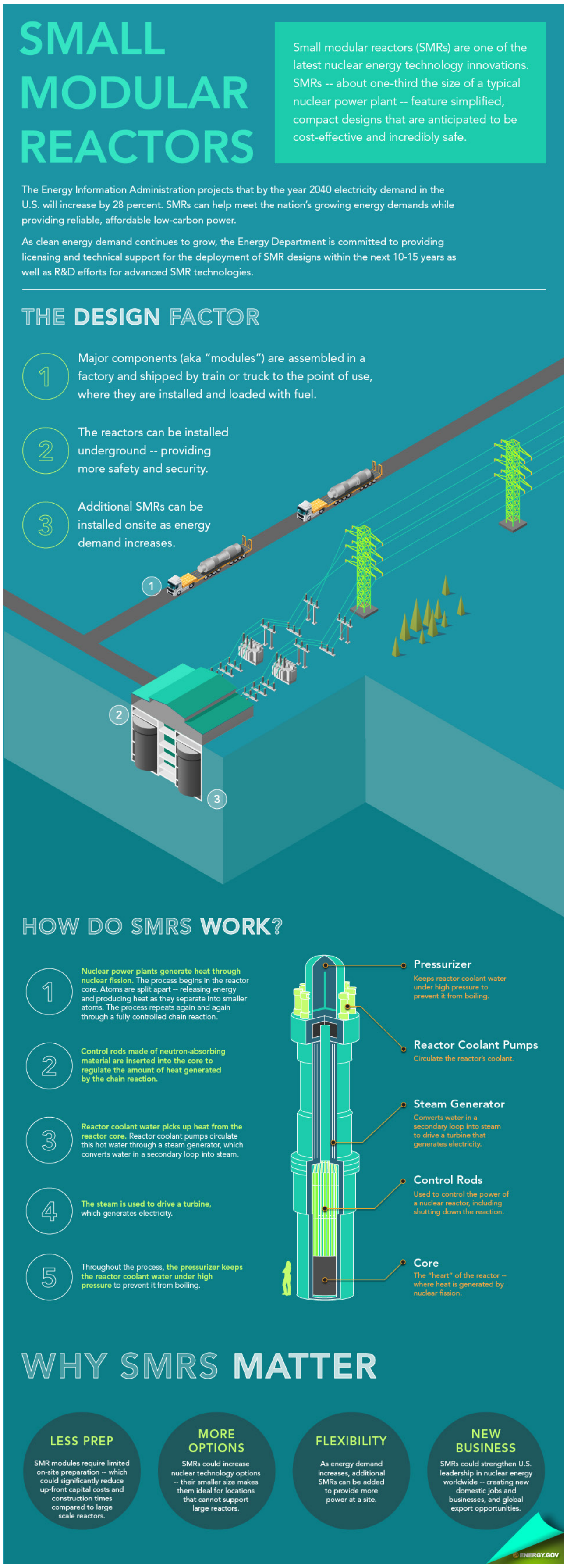


Image courtesy of the U.S. Department of Energy Office of Nuclear Energy have been canceled during planning or construction since the 1970s. The nearly 2,000 megawatt (powers 1 million high-energy US homes) Zimmer Nuclear Plant in Ohio, with three reactors planned, is alphabetically the last on the list. The first reactor was shut down as it was ready to go online after 12 years of construction (1972 to 1984) and being 90 percent completed. The plans for the remaining two reactors were also canceled in 1984. The site was turned into a coal plant.

The Shoreham Nuclear Power Plant located in East Shoreham, New York, was completed in 1984 at a cost of $6 billion. Opposition to the plant was strong because of the 1979 Three Mile Island accident (which we will cover in this guide). The Shoreham plant was completed and even ran at 5 percent power from 1984 to 1989, while the license to go full power was held back. By 1989 the brand new, operating plant was closed using a flawed evacuation plan as the excuse.

The Nuclear United States Navy

Even with all the missteps, mistakes, costs, rare accidents, and pushback, the US played the role of a first mover of nuclear energy. We did settle on one kind of reactor, even if it might not have been the most ideal option for commercial energy production. The Pressurized Water Reactor (PWR) is a larger version of what was adopted by the US Navy and has been powering submarines and aircraft carriers since 1955. The US Navy has logged more than 5,400 accident-free reactor years of operation, covering 130 million miles, and at any given time 22,000 people are just steps away from these reactors with no adverse effects from radiation ever being recorded. Many naval nuclear engineers, after leaving the Navy, have gone on to serve in keeping our civilian commercial nuclear reactors operating efficiently and safely.

US Navy's Admiral Hyman Rickover

If you spend any time studying the history of nuclear energy, you'll quickly learn that Admiral Hyman Rickover played a pivotal role. He is almost singularly responsible for the birth of our nuclear Navy. He relentlessly and single-mindedly developed a team inside the US Navy that came up with the first nuclear submarine, the USS Nautilus, which first went to sea in early 1954. The downside is that Admiral Rickover's influence extended into civilian use of nuclear energy.

The US had started developing promising, inherently safe, and small nuclear reactors in the 1950s. These projects were conducted at Oak Ridge Labs, under the direction of Alvin Weinberg. They used molten fuel instead of solid fuel and operated at one atmosphere (didn't require high pressure). They were also "breeders," meaning they produced more fuel while they were operating. Admiral Rickover thought these reactors required a lot more research and testing, but the Navy could put PWRs to use immediately. Their continued development threatened to distract his efforts to get the first nuclear submarines built. Over Weinberg's objection, Rickover killed the small nuclear reactor projects. Those early 1950s designs are the ancient foundation behind Generation IV Reactors now in development.

Nuclear energy is successful all over the world

Currently, nearly 450 nuclear power plants operate around the world. In the United States, 56 commercial nuclear plants operate 94 nuclear reactors in 28 states. These numbers are changing all the time, but more nuclear plants are now being built than being retired on a global basis. China is building more new reactors than the rest of the world combined. Nuclear energy represents about 20 percent of US energy production but 52 percent of all greenhouse gas-free energy generated. Nuclear energy generates about 10 percent of the world's total electricity. In addition, as of May 2023, there are 410 active nuclear power plants, another 59 are under construction, 100 in planning, and 325 proposed.

Since 1995, in the United States alone, nuclear plants have prevented 16,000 million metric tonnes of carbon dioxide from entering the atmosphere. According to the Nuclear Energy Institute, each year US nuclear plants are preventing 506 million metric tons of CO2 emissions from being emitted. That equals removing 110 million gas-powered vehicles from the roadways.

11. Why don't we just tax carbon emissions to make nuclear power more price competitive?

Quick Answer

- Carbon taxes and cap and trade schemes are complex and come with a long list of potential unintended consequences.
- Transitioning to denser fuel forms, be they fossil fuels or nuclear power, is the important metric.
- Nuclear fuel is millions of times more efficient than fossil fuels. The physics will eventually (sooner than later now) demonstrate that nuclear power is less expensive than fossil fuels.

More Details

Some economists, academics, and think-tank types believe a carbon tax or a cap-and-trade scheme to permit carbon emissions would give nuclear power (and wind and solar) a more level playing field to attract investment and move the world off fossil fuels faster. The arguments in favor are long, esoteric, and complex.

The arguments in favor often refer to the social cost of carbon, meaning that emitting carbon has an external tax to society, which is not being paid. Cap and trade is a form of permitting, with the rarity of the allowable commodity (carbon) to be traded in the market.

Carbon taxes are like a cryptocurrency in reverse

It's kind of like turning carbon into a cryptocurrency market (Bitcoin) but in reverse. Both commodities are artificially limited. Instead of carbon being valued as a limited asset to increase the capitalized value of a business, carbon would be a cost that reduces the value of a business (and so to the producer, it's a liability not an asset). If you owned a factory that produced carbon, you would have to buy credits to emit the carbon. The incentive would be to reduce carbon emission from your manufacturing process, and phase it out.

One item makes it a non-starter

The potential unintended consequences of such a scheme are long. For example, if it wasn't universal, the countries adopting the scheme would have put themselves at a competitive disadvantage. That alone makes it a non-starter. I am concerned it could make Generation III nuclear reactors look artificially more attractive and delay the progress of Generation IV reactors. The nuclear industry could get bogged down in building more of the massive power plant structures which may be more financially inviting with a carbon tax scheme in place.

Density is the key

This idea of fossil fuels versus renewables is self-defeating. The better vision, which is repeated throughout this Guide, is that the migration needs to be to the next most dense fuel available. In a poor African country, or sections of India, for instance, that might mean using diesel fuel, propane, or natural gas. Eventually very small portable nuclear reactors will be able to reach those populations. In more economically developed countries, using the next most dense fuel available should mean a move to Small Modular Nuclear Reactors (SMRs).

Note: Thorium, which will be used in many Generation IV Reactors, has an Energy Return on Investment (energy output / energy input) of 2000 to 1. That's 27 times better than solid fuel fission (the kind we use in current reactors), 67 times better than coal, and 1,250 times better than solar power. Physics and mathematics are on the side of nuclear power. It really doesn't need an artificial incentive. Most people don't understand the dynamics or importance of energy density in moving the world to sustainable clean energy. Moving to the densest fuels available is the fastest way to address climate change or energy poverty.

Energy poverty

The world's developed countries used fossil fuels for nearly 200 years to build their economies. To insist that developing countries now can't use the next dense fuel available to them is not only impractical and ill-advised, it's a lifetime sentence of living in energy poverty. It's immoral. For Germany and California to voluntarily give up their perfectly functioning nuclear reactors and burn more fossil fuels, biofuels, and mooch nuclear power from their neighbors, then lecture the developing world on not using fossil fuels must be somewhere near the summit of hypocrisy.

Common sense may break out

If antinuclear advocates and government officials did not shut down safely operating nuclear power plants around the world, the carbon profile of the global atmosphere would have been in much better shape. We're quickly approaching the point where average students are going to start asking, "Hey, what's the safest, most dependable, and cleanest form of energy we can use right now?" Nuclear power. What's so complicated?

The elephant and gorilla in the room are not noticed in the literature on carbon taxes

There are numerous well-written pieces on the advantages and disadvantages of a carbon tax. What they all seem to miss discussing is physics. The physics of fission (and soon fusion) will clearly demonstrate that nuclear power is safe, reliable, abundant, clean, and highly affordable. It takes a while to get past the tipping point, but once somebody does it (probably China or a few innovative groups) a massive shift in public awareness and acceptance of nuclear power will occur. The physics and mathematics of fission will eventually supersede any artificial policy scheme that incents more nuclear energy into existence.

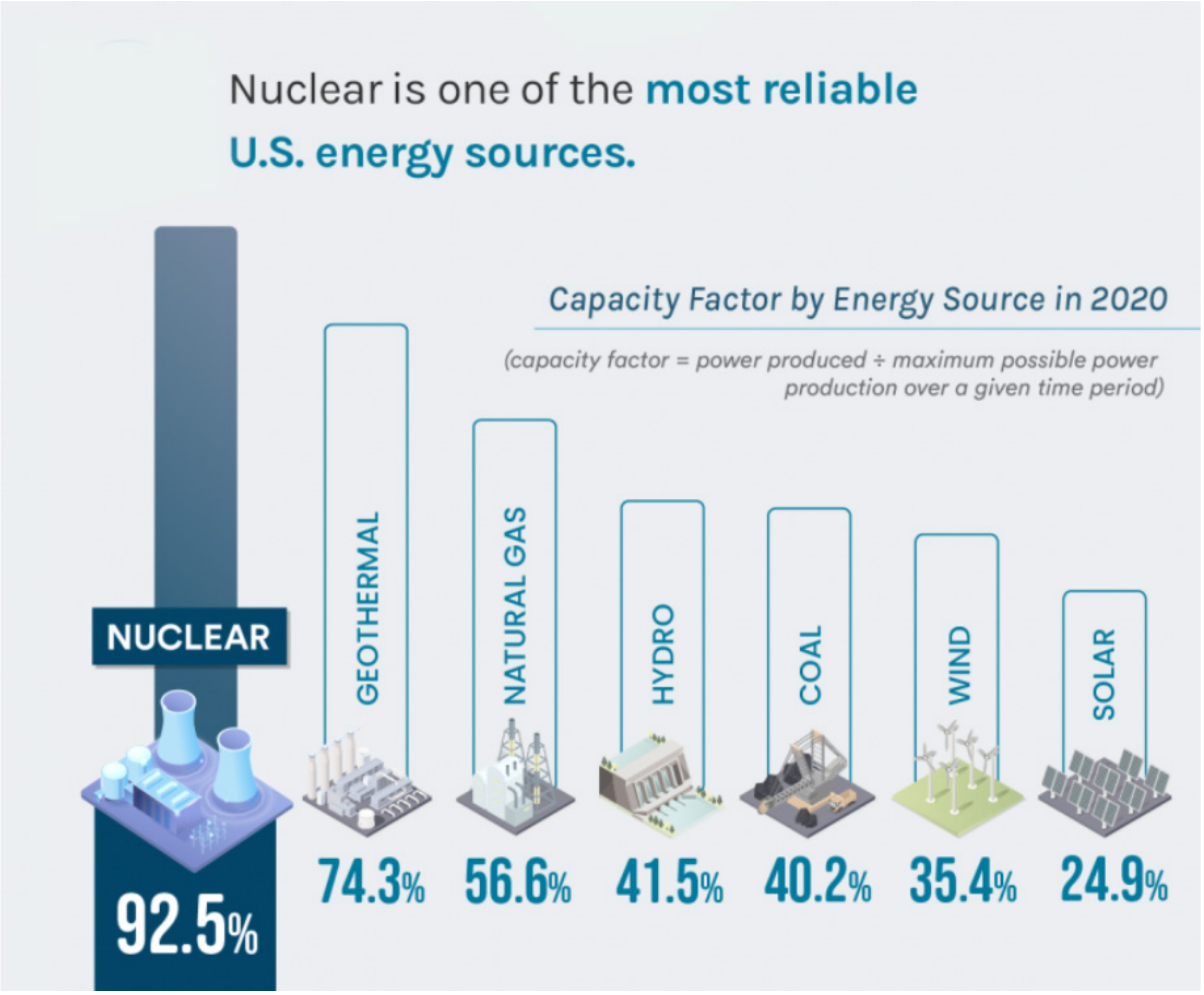


Image courtesy of the U.S. Department of Energy Office of Nuclear Energy

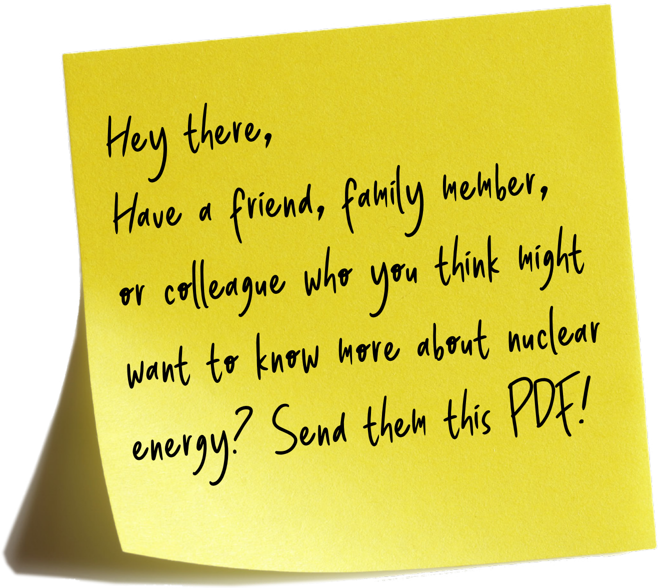
12. Do nuclear reactions happen in nature?

Quick Answer

- One occurrence is known to have taken place 1.5 billion years ago.
- Other than this rare exception during our eon of existence here on Earth, chain reactions only happen in nuclear reactors.

More Details

Yes. One known example was discovered of a chain reaction happening in nature at Oklo, Gabon, Africa 1.5 billion years ago. In fact, a promising small US company called Oklo is working on a new small Generation IV nuclear reactor they call the Aurora. Other than one known natural occurrence of a natural chain reaction, thus demonstrating its existence, a nuclear reaction on the scale we're talking about requires a man-made nuclear reaction to occur. Tiny nuclear reactions also happen in our own bodies, but we don't use that energy.



13. Are operating nuclear power plants safe?

Quick Answer

- YES! All forms of power generation come with risks, but compared to all other forms of power generation, nuclear energy is by far the safest alternative.
- Nuclear plants are monitored 24/7, and all incidents are fully disclosed.
- Eight million people die around the world each year from fossil-fuel emissions.
- More radiation comes off the US Capitol Building than from a nuclear power plant.
- A nuclear power plant can't blow up like a nuclear weapon. And the steam coming off a nuclear plant's cooling tower is not radioactive.
- N2N means natural gas to nuclear, a strategy to end coal use in energy production.

More Details

Deaths per Terawatt Hour (TWh) per year (that's 10,000 megawatts, a trillion watts, or about the power generation of 10 nuclear reactors) is the benchmark for measuring global power use and evaluating the risks of various energy sources. Even with the deaths from the Chernobyl nuclear accident being conservatively estimated (going with a high number) by the World Health Organization (WHO) nuclear averages at .07 deaths per TWh. In almost any given year, that number is zero. In terms of operational emissions, wind and solar also have near zero deaths per TWh.

> I didn't realize that!
>
> ***All forms of power generation come with risks, but compared to all other forms of power generation, nuclear energy is by far the safest alternative.***

Monitored 24/7

Nuclear power plants are intensely monitored and inspected during normal operation even when everything is going as planned. Nearly every deviation from an operational norm is investigated, reported, and acted upon. In the United States, almost all incidents are reported to the NRC and other regulatory bodies. In fact, an NRC resident is present at all US nuclear plants. So, it's not unusual to see a long list of "accidents," which are actually *incidents* in antinuclear pronouncements. Granted, some of these during the last 60 years have been serious and required proportional safety measures. When nuclear plants are referred to as dangerous or unsafe, all the data and observational evidence of 60 years indicates those are false statements.

Full disclosure of incidents and accidents

Nuclear plant incidents and accidents around the world are fully disclosed. Since 1952, the United States has suffered seven fatalities from working at a nuclear plant — three radiation exposure fatalities at Idaho Falls in 1961 (a test reactor), and four non-radiation fatalities at Surry, Virginia, in 1986. There is no record of anyone in the United States outside a nuclear plant dying of radiation exposure or anything else attributed to nuclear-power generation.

Fossil fuels are more risk to human health than nuclear energy

And yet, according to a paper published in the News & Events, Harvard School of Engineering, research from 2018 shows 8 million people per year have died from fossil-fuel air pollution.

> I didn't realize that!
>
> ***8 million people per year have died from fossil-fuel air pollution.***

In addition to fossil-fuel emissions, mining, processing, and transporting fossil fuels also produce risk. It's not uncommon to hear of an explosion at an oil refinery or an accident with a tanker on a ship, truck, or train. Maybe you've heard of the Kingston coal plant slurry spill in Tennessee in 1988. Or the 150-million-pound methane leak in Southern California, at the Aliso Canyon Gas Storage Field in 2015. Or the Deepwater Horizon oil spill in 2010 killing 11 workers and putting 4 million barrels of oil into the Gulf of Mexico over an 87-day period. Or the 1975 collapse of the Banqiao Dam in China along with

31 other dams after the area was hit by Typhoon Nina. Three million acres were flooded, destroying more than 5 million houses, and killing up to 240,000 people. And that is the short list of non-nuclear energy disasters.

> I didn't realize that!
>
> ***The US Capitol Building emits more radiation from its stone than comes off a nuclear plant. Coal plants emit 100 times more radiation than a nuclear plant.***

Radiation emitted from a working nuclear plant

You could spend a 100-year picnic on a nuclear power plant fence line and would be in one of the safest places on Earth, surrounded by a thriving ecology. The US Capitol Building emits more radiation from its stone than comes off a nuclear plant. Coal plants emit 100 times more radiation than a nuclear plant. If a nuclear plant emitted as much radiation (and other toxins), they'd rightfully shut down the nuclear plant and never reopen it. Coal contains thorium and uranium. When that is burned, along with the coal, the radioactive isotope goes into the atmosphere with the coal ash.

Discredited radiation risk theory

The NRC and other nuclear energy regulators have used what is known as the Non-Linear No Threshold Theory when evaluating radiation risk. This theory states that any radiation exposure is a cancer risk. And that the exposure to radiation is cumulative. This theory originated in the 1950s as a legitimate concern about what effect radiation exposure had on causing genetic mutations. The original tests were conducted on fruit flies. The Soviet Union and the United States were conducting hundreds of nuclear bomb tests at the time. And those tests were emitting enormous amounts of radioactive isotopes into the atmosphere.

It wasn't long before other research countered the No Threshold Theory of radiation by demonstrating that low levels of radiation exposure over longer time frames have no detrimental effect on health. Some researchers claim those countervailing results were suppressed. However, the NRC adopted the no threshold theory of radiation for nuclear plants. This added tremendous complexity and cost to building and operating nuclear plants.

Our life is awash in radiation; it's all round us all the time. If they applied the same Non-Linear No Threshold Theory of radiation to the state of Colorado, everyone in the entire state would have to evacuate. Under this theory, one person who ate bananas (the potassium in a banana decays putting out very low levels of radiation) would have a 5.5 percent chance of developing cancer.

Note: It's safe to eat bananas, live in Colorado, or visit the US Capitol. In fact, Colorado has some of the lowest incidence of cancer in the United States. But if a nuclear plant application were to reveal it would emit as much radiation as standing in downtown Denver, it's unlikely the plant would ever be built under the rules exercised over the past four decades.

Nuclear plants are not nuclear bombs, and the steam coming off them is not radioactive

Although a nuclear plant can blow up from a hydrogen explosion like at Fukushima Daiichi in 2010, a nuclear plant can't blow up like a nuclear weapon. That is because nuclear fuel is not enriched enough, and the chain reaction is too slow. In a nuclear explosion, the neutrons are forced into a highly compressed state to make them split at nearly the exact same millisecond. The physics of a nuclear reactor simply will not be able to do that.

The "white smoke" coming off a nuclear power plant is steam. That steam coming off the plant is not radioactive.

N2N

The world will require diverse energy sources to meet the growing thirst for energy, which is anticipated to grow by 50 percent by 2050. No country can become prosperous without abundant energy. Prosperous countries pollute less, their people live and gather in cities, and they have declining or negative population growth. A strategy called natural gas to nuclear, abbreviated as N2N, has gained some support because it allows for transitioning to denser fuels. A natural gas plant puts out half the carbon as a coal plant (critics point out that natural gas emits methane, which is more damaging to the atmosphere than carbon. And methane leaks occur during storage and transportation. This is a legitimate concern). The United States has lowered its carbon footprint by moving from coal to natural gas. In 2018, US carbon emissions fell 10 percent, continuing a long trend.

The N2N strategy suggests that natural gas provides baseline power until nuclear power can eventually be used. This would also apply to developing countries. Meanwhile, Generation IV nuclear reactors could be tested and put in production as quickly as safety allows. This plan does not suggest replacing wind and solar power, but to provide the baseline 24/7 power that those technologies can't supply while emitting the least amount of greenhouse gasses.

14. What about all that nuclear waste?

Quick Answer

- There are 88,000 tons of "nuclear waste" in the United States, but it would all fit within the boundaries of a football field stacked about 10 yards high.
- There are no available US-based, permanent repositories for nuclear waste generated by commercial nuclear reactors.
- MOX is the usable fuel produced after processing current nuclear waste to use again.
- The active repository for receiving nuclear waste from the US military is the Waste Isolation Pilot Program (WIPP). Yucca Mountain is a nearly completed repository in Nevada, idled for political reasons. The Sub Seabed Disposal Program was deemed scientifically sound, but also idled for political reasons.
- Finland offers a good model of how to build a modern nuclear waste repository.
- Cooling pools and dry storage casks hold all the US commercial nuclear waste at many sites around the country.
- Nuclear used fuel (nuclear waste) can be recycled in future reactors.
- Nuclear waste is fine where it is now.
- There has never been a radiation leak from transporting nuclear waste.

More Details

Nuclear power plants are the only power source required by law to shield their toxicity from the environment, capture it, and retain it. If that same law applied to fossil fuels, it would be impossible to comply with because their emissions are in the form of gasses and dispersed into the atmosphere.

The United States has 80,000 metric tonnes (88,000 tons) of used nuclear fuel, stored at 75 sites in 35 states. The same solid fuel volume that goes into a nuclear reactor is the same amount that comes out. The difference is that it's about 1 million times more radioactive (highly lethal) when it comes out (about five years later) than when it went in. Radioactivity causes the solid fuel element to decay, which means it throws off radioactive byproducts (many of the actinides in the periodic table), and it remains extremely hot.

The US Congress has not provided a nuclear waste repository

All this used nuclear fuel could fit inside the boundaries of a football field stacked about 10 yards high. The federal government is obligated to provide permanent repositories for used nuclear fuel. But the US Congress has been negligent in that regard. Thus, the used fuel is stuck at the plants where it's generated. The problem of getting a repository up and running is political, not technical.

MOX fuel is recycled fuel

The technology also exists to recycle used nuclear fuel. It was first developed in the United States, then abandoned in 1977 because of proliferation concerns. However, the technology has been in practice in France for 30 years without incident. France has processed 23,000 metric tonnes (25,300 tons) of used nuclear fuel for reuse in MOX Reactors for its own country and others at just one location.

MOX Fuel (mix oxide fuel) is a nuclear fuel made from extracting the byproduct of plutonium from used nuclear fuel. Once through that process, MOX reactors can burn MOX fuel, which means it can burn used nuclear fuel (nuclear waste) as their fuel source. If the United States recycled its used nuclear fuel, we would add hundreds of years of additional carbon-free power generation. In 2010, General Atomics estimated the depleted nuclear fuel in the United States contains the energy of 9 trillion barrels of oil, more than three times all the known oil reserves on the planet.

> I didn't realize that!
>
> ***Nuclear power plants are the only power source required by law to shield their toxicity from the environment, capture it, and retain it. If that same law applied to fossil fuels, it would be impossible to comply with because their emissions are in the form of gasses and dispersed into the atmosphere.***

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>
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The nuclear used fuel (nuclear waste) can also be recycled and used in future Generation IV reactors. When nuclear fuel is used a second time, the volume is reduced, and the remaining small radioactive amount needs to be stored for about 400 years instead of thousands of years.

For now, it's fine where it is

Many environmentalists are anxious that this used fuel has nowhere to go because the national repository solutions were not politically viable. When Michael Shellenberger, author of *Apocalypse Never: Why Environmental Alarmism Hurts Us All* was asked about this dilemma of having nuclear waste sitting around the country in dry storage casks, he responded, "It's fine where it is." Amen! There's never been a radiation leak from dry casks storage. There are no transportation safety issues. And the used fuel is spread across many locations. If, in the unlikely event, something went wrong, it would be a smaller, more manageable footprint. Plus, it's there for recycling.

Waste Isolation Pilot Program

The Waste Isolation Pilot Program (WIPP) stores nuclear fuel only produced by the US military. There is no difference between military and commercially used nuclear fuel. WIPP is in New Mexico. It's an active site carved into a 2,000-foot salt bed, is geologically stable, and has the potential technical capacity (if not the regulatory approval) to store all the used nuclear waste now in the United States.

WIPP was closed between 2014 to 2017 because of kitty litter

WIPP was shut down from 2014 to 2017 at a cost of $2 billion. A single waste drum exploded. This type of waste is often packed with mineral-based kitty litter and contains lower-level radioactive waste. In this case, an organic kitty litter was used. The organic compounds reacted with some of the drum's contents and an explosion occurred. Then the filtration system within the facility did not function properly. This is a good example of there being no such thing as zero risk. But in this instance, the damage was negligible, nobody was hurt or killed, and an abundance of caution was exercised before the facility reopened.

Yucca Mountain

There is a nearly completed, geologically stable repository located at Yucca Mountain in Nevada that the United States started studying in 1978 and spent $15 billion on preparing for used nuclear fuel. It's large enough to handle all our current used nuclear fuel needs. In 2009, President Obama, acting on a campaign promise, along with support from Nevada's US Senator at the time, Harry Reid, did not renew funding for the Yucca Mountain project. Senator Reid echoed antinuclear activists who claimed the site was not safe for nuclear-waste disposal. He once accused the scientific data of being fabricated.

The Yucca Mountain site was considered scientifically sound by the Department of Energy (the Office of Civilian Radioactive Waste Management), the Nuclear Waste Technical Review Board, the Nuclear Regulatory Commission, the Environmental Protection Agency, and the US Congress. It has also been under international peer review by the Organization of Economic Cooperation and Development's Nuclear Energy Agency in concert with the United Nations International Atomic Energy Agency. The data is in the open. According to Richard Anderson, PhD, who headed an internal review board of the site, as explained in the book, *Power to Save The World, The Truth About Nuclear Energy* by Gwyneth Cravens, "The real problem with the project is that objectives have undergone revision and the conditions under which we're trying to achieve them can be mystifying. There are a few strongly anti-nuke people trying to stop the repository, and they're the ones with the clearer objective."

Sub Seabed Disposal Program

There was also a thorough study done in the early 1970s called the Sub Seabed Disposal Program (or sometimes referred to as 32N164W, referring to the Seabed's location, which is about 600 miles north of Hawaii). Ten countries and 200 scientists studied the project. The sticky, heavy muds and clays at the bottom of that sea basin, known as the mud flats, are well suited to secure nuclear waste. They're not affected by volcanic activity or geological shifting and have been stable for 65 million years. The waste would be put in a torpedo-shaped cask, a hole from 10 meters (32 feet) to 100 meters (328 feet) would be drilled and the canister deposited into it. The temperature is a steady 2 degrees C (just above freezing). Any leaks would be contained by the muds and clays for millions of years. This project also died for political reasons. With environmentalists referring to the program as "dumping our nuclear waste into the sea," the public didn't pause to review the facts.

Finland offers a good model of a working nuclear waste repository

Onkalo underground used nuclear fuel repository near Olkiluoto, Finland, is a model for how to bring a used nuclear fuel repository into operation. Construction started in 2016 and the first spent fuel will be interned in the mid 2020s. This project is like the US Waste Isolation Pilot Program, WIPP (in operation), and Yucca Mountain (not in operation).

Dry storage cask

In the late 1970s and early 1980s, without a national radioactive waste repository available, used fuel cells started building up in the cooling pools at the nuclear plants around the country. Without a nuclear waste repository available, the solution was to use dry cask storage. By 1986, the first dry casks were loaded with used nuclear fuel. They're loaded in the cooling pool, under water, and then drained.

First, contrary to many news reports, the casks are not in parking lots. They're near the secure nuclear plants in designated areas, each on a 3-foot-thick concrete pad that costs over $1 million. The used uranium is placed in a 3.5-inch-thick stainless-steel container and filled with inert gas. Then, that is placed in the larger, lead-lined or cement cask, about 21 inches thick. Casks can vary in size and shape. Many weigh 125 tons with the used fuel representing 10 to 15 percent of that weight. There are no moving parts in the design. And no coolant is required.

The heat from the used uranium radiates via a convection vent through the cask tops. The heat coming off the casks is not radioactive. The cement, lead, and other moderators keep a fission reaction from occurring inside. The heat is caused from decay, not a fission reaction. And the used fuel gets colder over time, not hotter. There have been no radiation leaks from any of these casks anywhere in the world. And they emit less radioactivity than a person would be exposed to in an international flight. A large jetliner could crash into these casks without damaging them.

Transporting nuclear waste

Dry storage casks can also be safely transported. For nearly six decades, more than 2,500 cask shipments (military spent fuel and decommissioning of nuclear power plants' used fuel to other sites) have been transported across the United States without any radiological releases to the environment or harm to the public. The casks are designed to withstand more than 99.9 percent of vehicle accidents, including water immersion, impact, punctures, and fires. The used fuel is a solid, not a liquid, so it will not leak a glowing goo. And the odds of any radioactivity escaping during a transportation accident are 1 in 1 billion.

15. What about the three big nuclear accidents?

Quick Answer

- Three Mile Island (USA) 1979, Chernobyl (now Ukraine/then Soviet Union) 1986, and Fukushima Daiichi (Japan) 2011 are the three big nuclear power plant accidents. The images of the Chernobyl and Fukushima Daiichi accidents are misleading in that the actual damage was limited to the nuclear plant locations.
- In all three cases, the evacuations caused more hardship and death than the accidents.
- Three Mile Island and Fukushima Daiichi had successfully SCRAMed. They both lost coolant for different reasons, and the decay heat is what melted down the reactors. This is known as a Loss of Coolant Accident (LOCA).
- Chernobyl was the worst nuclear plant accident in history. There were 31 deaths at the accident site. It was a military nuclear reactor, with serious design flaws, an unsafe culture, and poorly trained staff.
- As a result of these three accidents, Europe and the United States shut down or prevented the building of new nuclear plants, thus causing millions more tons of greenhouse gasses to be emitted. Seventeen other countries that didn't have nuclear reactors made public statements that they would not build any. These three accidents set the progress of nuclear energy back by decades. Today's nuclear energy community is aware they are scrutinized by a unique standard, that an accident at one plant is like an accident at all plants.

More Details

Three Mile Island provided no image of devastation because there was none, other than the panicked reactions of people who lived near the plant and the news coverage. At Chernobyl, we see the total abandonment of what is now a ghost town. But the reactor didn't cause the town to look that way. Abandoning Chernobyl and leaving nature to overtake it portrayed a lost and damaged city. At Fukushima, the entire town was flattened by a tsunami and nearly 20,000 people lost their lives. But the reactor meltdown didn't cause those deaths or the destruction. Yet, most of the public associates those scenes of destruction with nuclear energy.

Life imitating art, Three Mile Island 1979

On March 16, 1979, a movie starring Jane Fonda, Richard Dryfus, Jack Lemmon, and Michael Douglas was released. It was called *The China Syndrome*. It was about a news crew that secretly filmed the inside of a nuclear plant control room as the plant experienced a near meltdown. The country was ripe for the story. During one part of the movie, a fictional expert on nuclear energy explained, "an accident at a nuclear plant could render an area the size of the state of Pennsylvania permanently uninhabitable."

Just 12 days after *The China Syndrome* hit the theaters, on March 28, 1979, the Number 2 reactor at the Three Mile Island Power Plant in Pennsylvania partially melted down. The situation was eerily like the movie scene. The movie name, *The China Syndrome*, was based on a fictional premise that a nuclear reactor meltdown would result in the melted nuclear fuel burning its way right through the Earth and coming out on the other side, the other side being China (also not accurate). But that seemed logical to the non-nuclear engineer after seeing the movie.

Quick review of the Three Mile Island accident

To this day, Three Mile Island is the most significant nuclear power plant accident in the United States. The emergency started when a SCRAM occurred because of a feedwater problem. Then a relief valve in the primary circuit stuck open. The auxiliary feedwater system had been isolated for maintenance, which was a breach in the plant's operating protocols. The control-room instrumentation showed the relief valve as closed, which caused confusion. Meanwhile, the coolant in the reactor escaped through that open valve. The temperature continued to go up in the reactor core because of decay heat. The operators didn't recognize that coolant was not flowing into the reactor. More alarms started going off, and the emergency escalated due to confusion. The result was the partial meltdown of the Number 2 reactor.

Antinuclear sentiment had been growing in the US before 1979

The United States had pulled out of Vietnam in 1975 because of public opposition to the war. For a decade, millions of Americans protested the Vietnam War. In the mid 1970s, the United States was also in a nuclear arms race (Cold War) with the Soviet Union.

After 1975, the Vietnam protestors stepped up their campaigns against nuclear weapons. Environmentalists joined the antiwar activists in successfully weaving the narrative against nuclear weapons to also be against commercial nuclear energy. So, when the movie *The China Syndrome* came out, there was a receptive audience, many of whom thought a nuclear power plant could blow up like a nuclear weapon (they can't). Even to this day, articles about nuclear energy (some of them favorable) still show the iconic mushroom cloud of a nuclear weapon as part of the headline. After the Three Mile Island accident, the public's perception of nuclear energy turned deeply negative. From 1979 to 1988, 67 nuclear power plants in the planning stages in the United States were canceled.

No injuries. No death. No radiation exposure.

Where else has there ever been an internationally acclaimed industrial accident where no one was injured, and nobody died? There were anecdotal stories of dangerous radiation levels escaping from Three Mile Island, but the containment dome did exactly what it was designed to do: it contained radiation. During the hours after the accident, there were controlled releases of radioactive gasses into the atmosphere (probably to prevent a hydrogen explosion), but not enough to cause the background radiation in the immediate area to go up.

Evacuation

Officials at the time botched the communication to the public. They argued among themselves. They told pregnant women to evacuate (unnecessarily) but were silent about the rest of the family. They said cows' milk may be contaminated (it was not). The public statements were often incorrect and contradictory. The news media was in a froth, and much of the reporting was tied to the movie *The China Syndrome* and was inaccurate. Some 40 percent of the people (50,000 households) who lived within a 15-mile radius of Three Mile Island self-evacuated a mean distance of 100 miles. In retrospect, the best thing to do in any accident near a radiation release is to shelter in place.

Three Mile Island was an extremely serious nuclear plant accident and should not be blown off as insignificant. But the real tragedy was the total lack of good communications inside and outside that plant. It's been more than 40 years since Three Mile Island, and it still frames most Americans' perspective on nuclear energy.

Safety was improved industry-wide

Immediately after the Three Mile Island accident, nuclear operator training was improved, and design changes and emergency protocols were upgraded, making a similar event much less likely. So, the United States' worst nuclear accident did not result in any harm to a single person, and radiation in the area never went above natural background levels. But the US public went into a panic, and nuclear energy lost nearly three decades of progress. Meanwhile, fossil fuels in the form of coal plants filled the vacuum lost by the planned development of nuclear power plants.

Chernobyl, 1986

Antinuclear activists will often say that a nuclear plant is the safest form of energy production until it isn't. All you need is one accident to forever contaminate an area of thousands of square miles for thousands of years. I don't think that's a valid concern. Chernobyl was the worst nuclear accident in history. Thirty-one people died of radiation exposure from being at the accident site. Yet contrary to public perception, the damage stayed close to the accident site, and the radiation exposure in the area was never a high-level risk to public health.

A military reactor

Chernobyl was a military-operated nuclear power plant. It didn't have a containment dome. Its technology was a crude Soviet-made RBMK-1000 boiling water reactor that lacked the more advanced technological features of its western counterparts. The RBMK-1000 had a long history of safety lapses wherever it was used before Chernobyl. The design was fatally flawed, and it couldn't be fixed. In fact, no other country in the world used the Soviet RBMK-1000 because it did not meet safety standards. The Soviet military ran it and disregarded many safety protocols. The plant's primary purpose was to produce plutonium for bomb making. It also generated some electricity. Although other types of accidents are possible in the US, this accident could not have happened.

How the accident happened

The Chernobyl accident started as an unauthorized test to see how long the turbines would spin once the reactor was shut down. The auto shutdown feature was disabled. The operators failed to realize that their type of reactor became very unstable at low power. The chain reaction in the Unit 4 reactors grew unexpectedly, and when they lowered their control rods, which were 1.3 meters (about 4 feet) too short, the rods acted to cause a power surge (positive reactivity) instead of shutting down the reaction (negative reactivity). The 1,000-tonne cover plate over the reactor became partially detached, and all the control rods got jammed. Steam spread as water fed into the reactor because of a ruptured emergency cooling circuit. A secondary steam explosion occurred and spewed out hundreds of pounds of hot radioactive graphite all over the immediate area, about 5 percent of the radioactive core.

Helicopters dumped 5000 tonnes (over 11 million pounds) of boron, dolomite, sand, clay, and lead to extinguish the fire and retard radiation emissions. The fire burned for 10 days. Two people died in the explosion and 29 people perished from heavy radiation exposure fighting the radioactive fire. There were many acts of courage and sacrifice during the emergency.

Note: The plant was never at risk of blowing up like a nuclear bomb as suggested in the hit 2019 historical documentary, *Chernobyl*.

Evacuation & recovery

Some 116,000 people were immediately evacuated from a 30-kilometer (about 19 miles) radius around the plant. Another 230,000 more people followed in the couple years following the accident. Although they couldn't have known at the time, the evacuation could have exposed more people to radiation than sheltering in place. Shortly after the accident, radiation levels around the plant dropped to 50 percent of above normal background radiation. Around 1,000 people returned to the contamination zone to live, many of them escaping war-torn areas for a more peaceful life.

People continued to work at the plant after the accident. The other reactors were eventually restarted and put into service again. Unit 2 was shut down after a building fire in 1991, unit 1in 1996, and unit 3 in 2000.

Misinformation about the potential of birth deformities in the region around Chernobyl were widespread. Many doctors mistakenly recommended abortions, and there were rumors of forced abortions. An estimated 100,000 to 200,000 pregnancies are believed to have been terminated. The psychological impact on the public affected by Chernobyl will be studied for years and can't be understated. Alcoholism and depression are widely reported among the survivors.

Despite rumors that the area is forever contaminated, today it's a tourist destination (although occupied by Russian military forces as we go to press). There is now a huge sarcophagus called the New Safe Confinement over reactor 4, which 40 governments pitched in to fund at a cost of $1.6 billion. It's 354 feet tall and 843 feet wide, with a lifespan of 100 years. It was finished in 2016.

According to the conclusion of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) at Chernobyl:

Although those exposed as children and the emergency and recovery workers are at increased risk of radiation-induced effects, much of the population need not live in fear of serious health consequences due to the radiation from the Chernobyl accident. For the most part, they were exposed to radiation levels comparable to or a few times higher than annual levels of natural background, and future exposures continue to slowly diminish as the radionuclides decay. Lives have been seriously disrupted by the Chernobyl accident, but from the radiological point of view, generally positive prospects for the future health of most individuals should prevail.

Fukushima Daiichi, 2011

The Japanese coast has been hit with tsunamis throughout its history. It was a highly probable risk that a big tsunami could happen during the life of the nuclear plants along Japan's coast. In 2010, one year before the tsunami that hit Fukushima, there was a Chilean earthquake (magnitude 8.8). That event should have been a flashing red light to the owners of the nuclear plant in Fukushima, the Tokyo Electric Power Company (TEPCO), to get their backup generators more protected as they had been advised to do on many occasions. Visiting US nuclear engineers had also voiced their concern during earlier visits.

Just 90 miles away from Fukushima and much closer to the earthquake epicenters, the Onagawa nuclear power plant, owned by Tohoku Electric Power Company, did erect a 46-foot sea wall, and their plant survived the tsunami in good condition.

How the accident happened

On March 11, 2011, the 9.0-level Tōhoku Earthquake hit under the Pacific Ocean, off the northeast coast of Japan's Honshu Island. It's now sometimes called the Great East Japan Earthquake. That quake caused a tsunami (tidal wave) that reached as high as a 12-story building and flooded 200 miles of the Japanese coastline. Approximately 20,000 people died and 500,000 were evacuated.

In a well-explained account found in Colin Tucker's book, *How To Drive A Nuclear Reactor*, all of Fukushima's reactors are early model Boiling Water Reactors (BWRs). Reactors 1 and 4 are closest to the sea and to each other. Reactors 5 and 6 are set away from the first four reactors, and further from the sea. Reactors 4 through 6 were shut down that day, and the fuel had been removed from reactor 4. Reactors 1 through 3 shut down in response to the earthquake as designed to do. Then with all the reactors shut down, the tsunami hit 50 minutes after the earthquake and overwhelmed the sea walls leading to extensive flooding.

Note: Remember, even though the reactor is not critical (when it's off) the fuel inside the reactor is still decaying, creating enormous heat. That's why the reactor core and all used fuel need to continue to be cooled.

Loss of backup power and hydrogen explosions

The backup generator buildings and other equipment for cooling reactors 1 through 4 also flooded. Cooling generators for reactors 1 through 3 failed, as did the fuel cooling pools above each reactor. The cooling pool above reactor 4 wasn't damaged as badly as first feared. Enough stuff worked to keep reactors 5 and 6 cooling, so they were stable. The cores in reactors 1 through 3 started to melt down, along with the fuel in the cooling pools above them. The reactor cores fell into the lower level of the buildings. Due to all the steam and gas being emitted from the melting fuel, it became necessary to release some gas. But it was rich in hydrogen and exploded during the venting process. There has been some post-accident criticism that the venting wasn't done properly. That explosion is what we all saw on television and have seen many times since in news stories and documentaries.

The damage from the tsunami was so extensive around the Fukushima nuclear plant that it was effectively isolated. Emergency personnel and equipment couldn't reach it. The crew at Fukushima eventually got the reactors stabilized.

False news stories stoked panic

The examples of incorrect news stories about Fukushima are so numerous, a whole book could be put together to review them. In one instance I can remember, the National Oceanographic and Atmospheric Administration put out a map of the energy being released from the Fukushima area out into the Pacific Ocean as a result of the tsunami. The scale on that map showed wave heights in centimeters. But when played on national news, the map was presented as a colorful, hot map visual of how radiation was spreading across the Pacific Ocean. Even though this is not what the map showed, that is what was communicated.

There were reports of underground explosions around the plant (false), radiated fish washing up on the west coast of the United States (false), and the inevitable stories about mutant plants and animals appearing because of radiation contamination (false). The United States was never at risk of radiation contamination from the Fukushima Daiichi accident. And as it turns out, even the citizens of Fukushima were at little risk of receiving an unhealthy dose of radiation.

The real tragedy was the evacuation

About 380,000 people living within 20 kilometers (12.4 miles) were told to evacuate within the next couple of days. The Japanese Government encouraged those as far away as 30 kilometers (18.6 miles) to also evacuate voluntarily. Some level of evacuation certainly would have been a reasonable decision at that time, but more than 1,000 elderly and vulnerable people died as a result of the mass evacuation and panic, making the evacuation the real tragedy of the nuclear plant accident. As with Three Mile Island, the communication to the public during the emergency was confusing and contradictory. The US Government advised our citizens located in Japan to remain 50 miles from Fukushima.

Aftermath of Fukushima

One worker died of radiation exposure during the Fukushima nuclear plant accident. Some reports claim two workers drowned inside the plant. No other deaths were a direct result of the nuclear accident.

The radiation levels around the nuclear plant dropped quickly once the damaged reactors were brought under control. Today, the Colorado Plateau is more radioactive than most of Fukushima was after the accident. As a reminder, Colorado is a safe place to live. The Fukushima Daiichi nuclear accident has become associated with mass destruction and worldwide radiation exposure, with the hydrogen explosions as visual proof that nuclear energy is deadly. Worldwide fear of nuclear energy after Fukushima resulted in nuclear energy being taken offline in Japan, Germany, Belgium, Spain, Switzerland, and the United States.

> I didn't realize that!
>
> ***Today, the Colorado Plateau is more radioactive than most of Fukushima was after the accident. As a reminder, Colorado is a safe place to live.***

Japan shut down all their nuclear plants

Japan shut down all 54 of its nuclear plants for safety checks. Only 15 of those 54 were at risk of being hit by a tsunami. By taking all their nuclear power offline, it's been estimated 9,493 lives were lost due to the increased amounts of pollution from fossil-fuel generation. Japan became the second highest importer of fossil fuel in the world, second only to China. Japan had been getting about 30 percent of its electricity production from nuclear energy before the accident. By 2021, only 9 of Japan's nuclear reactors were back online.

Germany shunned all nuclear energy after Fukushima

In 2011, Germany had 17 operating reactors representing 25 percent of Germany's electrical production. Weeks after Fukushima, environmental activists in Germany stepped up their efforts and displaced a pronuclear incumbent, state premier Stefan Mappus, to the Green Party's Winfried Kretschmann. Trained physicist Angela Merkel, Germany's chancellor from 2005 to 2021, had been a pronuclear energy proponent. She changed direction and became antinuclear. Germany closed eight of its 17 nuclear plants with a plan to close all of them by 2022. As a result, Germany is having problems keeping its carbon footprint from growing and keeping its electricity affordable primarily because it shut down the country's perfectly functioning nuclear plants. The intermittent nature of wind and solar means Germany now has to back up that source with coal, natural gas, biofuels (mulched trees), and energy from its neighbors. California has put itself in a similar situation to Germany.

Germany hopes to expand its wind and solar footprint fast enough to replace the greenhouse-gas-free nuclear energy they are removing from the market. But those sources are intermittent. Without a dramatic breakthrough in battery storage technology, Germany is giving up a sure carbon-free source of energy for dependence on fossil fuels. This has Germany relying on natural gas and oil from Russia, which Russia uses to threaten NATO and the Ukraine.

France, which produces about 70 percent of its energy from nuclear energy, exported 8.3 billion kWh to Germany in 2018. Germany's household electricity is twice as expensive as in France. About 39 percent of Germany's energy can be considered clean, representing the power generated from its massive wind and solar buildout. But France's energy is 86 percent clean because most of it comes from nuclear plants.

If Germany had invested the $580 billion that they spent on wind and solar since 2011 on nuclear energy, Germans would now have all their electricity and transportation powered by clean, carbon-free energy.

Year 2022: Radioactive water to be diluted into the sea

Just over 1 million tons of contaminated water from Fukushima have been filtered to remove as much radioactivity as possible. One of the radioactive isotopes in the water (tritium) can't be removed. Tritium in low doses is not a health risk. The tritium in the water to be released from Fukushima into the sea will be quickly dissipated and pose no risk to human or sea life. Of course, antinuclear groups are against this release because of their zero-risk tolerance for radiation. And area fishermen fear the water release. This should not be a concern, as it will not impact public safety. But it is an issue over a decade after the accident and deserves explanation.

Summary of the three big nuclear plant accidents

Because nuclear fuel is so dense, it requires a tiny surface footprint. The damage in each of the three nuclear plant accidents stayed contained to the site where the accident happened. Chernobyl represented the worst accident of the three, with 31 confirmed lives lost; one life was lost at Fukushima; and no lives were lost at Three Mile Island. All three locations have radiation levels safe to live in, and each of them is lower than the natural background radiation found in Colorado (which is very safe). The real tragedy is that authorities and the media panicked, were inaccurate in what they reported, and overreacted by closing nuclear plants and overregulating the nuclear energy industry.

These three accidents reversed the progress of nuclear energy around the world. In each case, when a nuclear plant was closed or not built, the world added millions of tons of greenhouse gasses to the atmosphere. And in each case, we abandon the safest source of power for a less safe alternative.

> I didn't realize that!
>
> ***All three locations have radiation levels safe to live in, and each of them is lower than the natural background radiation found in Colorado, which is very safe.***

16. Shouldn’t we just use wind and solar power instead of nuclear power?

Quick Answer

- No. This is exactly the argument antinuclear advocates advance. The physics of energy production works against this argument as wind and solar have built-in low generation efficiency problems.
- Nuclear power operates at 93-percent generation capacity, which means it’s operating at full power 93 percent of the time.
- Nuclear power is the only baseline, 24/7, non-fossil fuel, carbon-free backup to the intermittent nature of wind and solar.
- Solar panels and wind turbines have front-end rare Earth material shortage challenges, and back-end toxic waste problems.
- Wind and solar farms require many times more surface area to produce the same amount of energy as a nuclear plant.
- Biomass, thermo, and hydro power sources are beyond the scope of this guide. But they each have limitations that make nuclear energy far superior.
- Density is the key difference when evaluating the effciency between nuclear versus wind and solar. A very small amount of nuclear fuel produces an immense amount of power.

More Details

There’s a common, succinct, seemingly obvious, but incorrect saying that *solar and wind are inexpensive to build and expensive to operate, but nuclear is expensive to build and inexpensive to operate.* The saying itself assumes that a fair and balanced metric is being used to evaluate these energy sources. But as you’re learning, things are not that simple once the upfront building costs, lifetime operational costs, and back-end waste management costs are considered.

A nuclear power station operates at 93-percent generation capacity, meaning it’s at full power 93 percent of the time. That makes nuclear power the most efficient source of power generation of all alternatives.

Wind turbines’ top generation capacity in a laboratory is about 50 percent because half the wind gets past the blades. But the wind also ebbs and flows, gusts and stills decreasing that 50 percent. Thus, a wind turbine has a physics limit in practice of about 40-percent generation capacity. Most wind turbines operate at 10 to 30 percent of generation capacity most of the time.

Those differences in generation capacity and fuel density mean a 1,000-megawatt nuclear plant needs 1.3 square miles of surface area to operate. A wind farm would require 260 square miles to 360 square miles, and solar would require 45 to 75 square miles to produce the same amount of energy.

Use it or lose it

And for now, we don’t have a good way to store solar and wind energy as it’s produced, so it’s a use it or lose it proposition. The A/C electrical energy you’re using now was produced less than seconds ago. The sun doesn't always shine, and the wind doesn’t always blow, and sometimes that happens at the same time, in the same areas. Then, at other times, those devices produce so much power we can’t use it all. That is what is referred to as an intermittent power source.

Green energy favoritism is also a form of subsidy

Another form of incentives that distort energy markets are laws that mandate utilities produce or purchase a certain percentage of their power from renewable sources like wind, solar, or biofuels. Nuclear energy is not considered a renewable source under the definition of these mandates. The purpose of these mandates is to decarbonize emissions as quickly as possible. But they often have the opposite effect. Here are a few unintended consequences of energy favoritism:

a. Consumer energy prices go up faster than other areas not under similar laws. Electricity prices in California, Germany, and Great Britain, where these laws have been in place, have risen multiple times faster than their neighbors.

b. Fossil-fuel sources in-state are shut down, and out-of-state sources of energy are imported. Those sources are primarily fossil fuel and nuclear power.

c. Unfortunately, places like California and Germany also shut down working nuclear plants as they’re enforcing these renewable mandates, which include incentives to purchase electric vehicles. When the wind and solar farms’ intermittency leaves the state without enough energy to supply demand, blackouts occur.

d. Utility companies lose control of budget prioritization because they must build out so much renewable infrastructure so fast. Grid maintenance and other infrastructure within the power system suffer. Fires from neglected power lines are caused by financially strapped utilities, as they use resources to meet renewable mandates.

e. The intermittent nature of wind and solar is magnified when they are depended upon for so much of the state's power. Billions of extra dollars have to be used for "balancing costs," which is the role of coordinating all the massive power going up and down on the grid.

Wind and solar are changing the role of baseline power

Over the past several years, nuclear plants have been called upon to back up intermittent wind and solar power. This means instead of producing full power 24/7, nuclear power is being turned up and turned down more often (along with natural gas plants). These nuclear plants were designed to run at full power all the time, so to power them up and down has been challenging, but achievable. Current nuclear plants are playing a larger role in backing up wind and solar power sources. Some Generation IV nuclear reactors are being designed with the specific mission of backing up wind and solar. One example is Terra Power's Natrium reactor funded in part by billionaire Bill Gates.

Note: There are many estimates of how long total battery storage could power the state of California or the entire United States. Obviously, these estimates are for dramatic effect. They're in seconds or minutes. But the truth is there is no realistic backup battery power available that could support a large grid for any amount of time. Even with huge leaps in battery storage efficiency, the only realistic backup for wind and solar are natural gas, coal, or nuclear energy.

It may be that we'll develop batteries that can store adequate baseline power. Liquid metal batteries and solid state lithium-metal battery cells show promise. Still, we may only add hours of backup with these improvements, not days. And the amount of surface area and backend waste issues still make wind and solar power problematic.

The challenge of collecting dispersed solar energy

Wind and solar require huge amounts of surface area and many devices (wind turbines and solar panels) to directly collect energy from the sun (The sun's heat is responsible for the wind too.). Thus, by tapping into the sun directly, we do not need to burn fossil fuels to produce power. But we do need to build and maintain the millions of giant devices that collect that energy from the sun. The rare earth minerals, concrete, and grid infrastructures take massive amounts of fossil-fuel energy to produce. Wind turbines and solar farms are often far from customers and require new infrastructure to connect them to the grid.

Carbon payback

Wind and solar proponents claim the carbon emissions caused in making the devices are offset many times by the fact they emit no carbon during their 20- to 30-year functional life. But wind and solar advocates often make that evaluation by adding in the carbon-producing fossil fuel sources they replaced. For example, a wind turbine farm is used instead of a coal plant. How much carbon was prevented? In that type of scenario, you can come up with a six-month payback on a 2-megawatt wind turbine. But what if the question was, should we use wind or solar farms or nuclear energy in this region? You get a more realistic feel of the carbon payback problem wind and solar have. Wind turbines are huge. Solar panels are rare earth mineral intensive. Both are energy inefficient, and we need many millions of them. For these reasons, I argue that wind and solar don't have a carbon payback because we need to build too many devices.

Wind turbines and solar panels have a recycle problem

One of the world's biggest wind turbines is the SeaTitan, a 10-megawatt monster with a rotor diameter (think wingspan) of 190 meters (over two football fields), and a hub height of 125 meters (about 136 yards). In the nuclear world, 10 megawatts would be considered a micro nuclear reactor that could fit in a standard shipping container. It would take 100 of these wind turbines to equal the output of one 1,000-megawatt nuclear plant. Or we could place a 12-pack of Generation IV NuScale reactors inside an abandoned nuclear or coal plant, plug them into the nearby grid, and produce the same power as 100 monster-sized wind turbines.

Used wind turbines, batteries, and solar panels are not currently recyclable After 20 to 30 years of use, which many of these devices are now reaching, they're classified as toxic waste. There is still no standard on how to affordably recycle them. One solution is to sell the used solar panels to secondary markets (poorer countries) so they can continue to operate even if at less efficiency. That means the devices will then be retired in those places. A poor community is much less capable of responsibly recycling the device than the more affluent community that provided it. This is a recipe for dumping waste in developing countries.

Rare earth minerals

Also, the rare earth metals in solar panels are, for the most part, mined and made in foreign countries like China, where the United States' stringent environmental and workplace laws don't apply. As of now, China produces 80 percent of the world's rare Earth minerals and 90 percent of all solar panels. In fact, China allegedly produces most of the solar panels they export using slave labor. This is believed to be the reason solar panels are considered an inexpensive source of power production.

According to Harvard Business Review, *The Dark Side of Solar*, solar panels will create 50 times more waste in just four years than what experts had been predicting, and cost four times more than projected. Tax credits for solar panels will drop from 26 percent to a permanent 10 percent for installers, and no tax credits will be available to consumers starting in 2023. Improved efficiencies in newer solar panels along with the disappearing tax credit means a massive upgrade is predicted. Millions of solar panels will be retired before their useful life, and without a process in place to recycle them. Because the solar panels themselves are eventually considered waste, they produce 300 times more waste than nuclear plants for the same amount of power generated.

Wind turbines & solar panels are detrimental to wildlife

Wind turbines kill thousands of large birds each year and disrupt whale migration when located offshore; and solar panel farms kill 100 varieties of desert tortoises during relocation. The tip of a large wind turbine blade can travel over 150 miles per hour. Of course, cars and other forms of energy can kill wildlife as well. The large endangered species are threatened by wind and solar technologies when those devices are assembled as a farm for collection. These large birds, whales, and tortoises can't recover quickly enough to replenish their populations.

Density remains the key advantage of nuclear energy

According to *Power to Save The World, The Truth about Nuclear Energy*, by Gwyneth Cravens, one pencil eraser size pellet of nuclear fuel contains the same amount of energy as 149 gallons of oil, 157 gallons of regular gasoline, 17,000 cubic feet of natural gas, or 1,780 pounds of coal.

Note: The Indian Point Nuclear Power Plant outside of New York City closed in 2021 (there was nothing wrong with it). It provided 12 percent of New York state's electricity. It sits on 239 acres of land. You could fit three of those plants inside New York City's Central Park. But if you were to try and replace those nuclear reactors with wind turbines, you would need an area the size of 400 Central Parks. The density issue is the elephant in the room.

17. Are biofuels, thermo, and hydro other options that could help replace fossil fuels?

Quick Answer

- No. The theory is that biofuels use carbon dioxide to grow, then emit carbon dioxide when burned, so they're carbon neutral. But that makes no sense, it just means we're burning that source of fuel millions of years sooner instead of waiting for it to turn into a denser fossil fuel.
- Thermo and hydro power are limited by geography. That constraint alone makes them a less desirable source of power than wind, solar, and nuclear. It's like trying out for a Broadway play and the director saying, "Sorry, we're looking for someone much bigger for this role."

More Details

Biofuels are made from field corn, saw grasses, shredded trees (wood chips), or even dead animals. Some groups claim biofuels are carbon neutral because the plants absorb the same amount of carbon while growing as they emit when they're burning, and they're quickly renewable. Recent research is challenging that theory. But on its face, it doesn't make any sense.

By burning biofuels now, before they become denser fossil fuels in a few million years, we just release the carbon sooner and get less energy per volume in the process. It's like a person who eats the cookie dough and claims it's better for them than the baked cookie. It's the same per calorie.

How any environmentalist finds it attractive to move to a less-dense, carbon-burning energy source at the expense of diverting agricultural output, or cutting down thousands of acres of carbon-reducing trees, is difficult to understand. There are, of course, financial incentives to use biofuels, and we'll learn more about what motivates antinuclear advocates in the face of contradictory data in the question about antinuclear activists. In the case of biofuels, the whole model seems corrupt, economically challenged, and immoral. Biofuels should play no part in reaching Net Zero Carbon by 2050.

> I didn't realize that!
>
> ***By burning biofuels now, before they become denser fossil fuels in a few million years, we just release the carbon sooner and get less energy per volume in the process. It's like a person who eats the cookie dough and claims it's better for them than the baked cookie. It's the same per calorie.***

Thermo and hydro power

Thermo and hydro power sources are beyond this guide's scope. However, without getting into the considerable topic of their positives and negatives, their primary weakness in contributing to worldwide greenhouse gas reduction is that they're both limited by geography. They can only be in certain places. And most places that are candidates for big dams have already been developed. From a global perspective, these two power sources are not competitive with nuclear because of the geographical constraint alone.

18. Can wind and solar coexist with nuclear energy?

Quick Answer

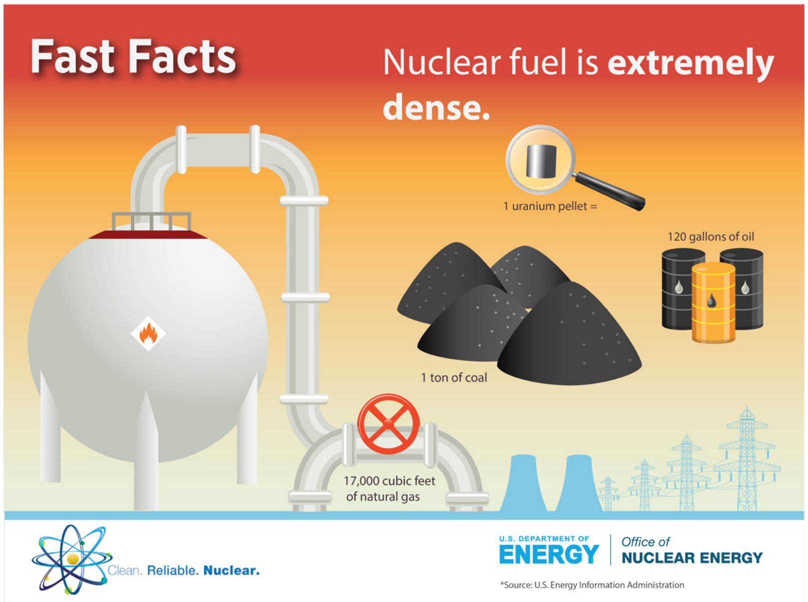
- It feels good to say we need all the above. I once thought of nuclear power like AC energy transmission, and wind and solar power like DC energy transmission. But the more you understand the physics behind these sources, the more it becomes apparent their huge appetite for natural resources and surface area does not come close to justifying itself. In fact, I think they're losing propositions, and we're headed down a dead-end with these sources at present.
- Solar has some potential if governments and communities would focus on placing them on rooftops, contributing power to the facility, home, or vehicle beneath them. This would be a better plan than building solar farms.
- Nuclear power may be a source to produce the aluminum or future alloys required to make solar panels, thus reducing their carbon footprint during manufacturing. It's possible the residual heat of nuclear reactors could also be a solution in melting, separating, and recycling the various metals in solar panels upon their retirement.
- So, I do see solar and nuclear as being compatible. Wind, not so much.

As a result of my basic energy research, I find six things wrong with power generation in general that need to change before we can achieve a sustainable energy future.

1. The power source is located too far from the customer.
2. Current energy production devices and plants are too big.
3. We don't take advantage of the structures and rights-of-way we already have.
4. We have not closed the fuel loop via recycling waste.
5. The densest fuel is not the primary baseline fuel.
6. Government subsidies make rational people technologically illiterate and distort energy markets.

And here are my six next-level recommendations.

1. **Build stuff closer to the customers.** Nuclear and solar power generation can be placed on customers' locations or close to them, eliminating the need for expensive infrastructure buildouts and massive generating stations or farms. Put solar panels on millions of roof tops, and power the facilities and homes below them. Homes represent 65 percent of the US rooftop potential. There are more than 8 billion square meters (more than 86 billion square feet) of rooftops in the United States. Solar panels can partially power the facilities they sit upon. An estimated 3.3 million new roofs will be replaced or added as part of new construction each year. If those roofs had solar panels on them (or the roof material was a solar panel), that would add 30 gigawatts (GW) of solar power per year. That's enough to conservatively power 9 million homes.



2. **Let's shrink all the stuff.** Advanced smaller nuclear reactors, and smaller and more powerful solar panels are in the works. There are bladeless wind turbines being conceived, but their size and efficiencies are far from being convincing as a realistic contributor to achieving a net-zero-carbon future.
3. **Let's go where we've already been given permission to go.** Use abandoned power plants, existing rights-of-way such as power lines, underground gas lines, railways, and highways. And make updating the grid impervious to solar flares (its biggest risk).
   Note: The Good Energy Collective group in conjunction with the University of Michigan's Fastest Path to Zero Initiative has identified 80 idled coal plants where installing Small Modular Reactors could take advantage of the infrastructure and re-employ people in the areas.

4. **Recycle.** Use materials from old solar panels to make new ones. Engineer solar panels so every part is recyclable. Recycle nuclear fuel (waste), use it up, and make sure all new fuels are maximized before considering them waste.
5. **Let's make nuclear energy the baseline.** Consider nuclear energy our long-term primary source of 24/7 baseline and backup power. That will give solar power a chance to operate more efficiently and not create so much havoc within the grid.
6. **Let the market work.** Equalize or eliminate subsidies to all forms of power production, which would result in natural efficiencies and affordable systems. It would also allow the markets to follow their natural historic arc of adopting denser fuels. Under this scenario, in my opinion, we could end up at the dawn of a fusion-powered world within 30 to 50 years. The reason behind this prediction is because competitive innovation will favor denser fuels, which will be the path to abundance and low costs.

Note: All these items have been suggested before. It's time to prioritize them and package them into a national (and hopefully global) strategy outline to guide innovation and build a realistic path to commercial success. I know it will take a while for most people to realize wind power is all hot air, but any average student can see that after a relatively short look at the technology.

A path to success

These six recommendations could give solar a long-term path to success. We may even be able to use the extensive heat generated in a nuclear reactor to help recycle some components of retired solar devices. Natural gas and propane may become more popular in developing countries under this scenario. But in each case, those fuel sources are denser than wood and animal dung. Natural gas and propane are available now and could move those communities along the energy density path sooner.

Also, under this scenario, people would save money by putting solar panels on their roofs, knowing they'll always have power no matter the weather.

Renewable designation

The European Union recently agreed to classify nuclear energy and natural gas as renewable energies. Remember that France is primarily powered by nuclear energy. Germany is powered mostly by natural gas (and coal) after shutting down their nuclear plants. The United States should follow Europe's example by making a similar commitment. Because uranium is an exhaustible source, it's been argued nuclear energy is not renewable. Yet we have enough slightly used nuclear fuel to operate current fission reactors for hundreds of years. When Generation IV reactors breed new fuel and can operate for 20 years or more without being fueled, the amount of mineable uranium available will be a non-issue.

The debate is more about subsidies and grants. If nuclear energy and natural gas are not considered part of a state or nation's renewable portfolio, it stops the natural progression to using denser fuels. The debate is a political one. From a practical standpoint, nuclear power is now contributing more than 50 percent of US carbon-free energy. Regardless of what you call it, the goal of achieving net-zero-carbon by 2050 will become impossible unless nuclear energy plays a central role.

19. Why are so many people antinuclear?

Quick Answer

- Nuclear power (fission and fusion) may be the most disruptive technological development in human history, affecting billions of people's lives, and may hold that No. 1 spot for hundreds or even a thousand years.
- Nuclear power has the distinctive birthmark (brand) of a mushroom cloud because it was first used as a weapon in 1945. It's not surprising, then, that the current public narrative for nuclear energy is commingled with nuclear weapons and nuclear war.
- Strontium-90 is a cancer-causing radioisotope detected in the atmosphere after hydrogen bomb testing in the 1960s. It showed up in babies' teeth and alarmed millions of parents.
- Antinuclear groups justify taking money from fossil-fuel organizations and replacing nuclear power with coal- and natural gas-produced power.
- Antinuclear activists are the number-one greenhouse gas emissions polluters of all causes.
- Other pure-play fossil fuel companies are being pulled into the renewable energy space.

More Details

Natural evolution of new energy sources

There is a general theory introduced in 1977 called The World Primary Energy Substitute by Cesare Marchetti, and explained by Luis de Sousa. In summary, it makes an observation that a new energy source generally takes from 40 to 50 years to go from 1 percent of the market to 10 percent. From the 1 percent point to dominating half the energy market will take 100 years from the date it achieved the 1-percent mark. And society experiences waves of technological energy substitutions at 50-year intervals. Each energy form such as wood, coal, oil, natural gas, wind, solar, and nuclear have long development histories.

Right now, antinuclear and pronuclear advocates are engaged in debate. As you study them, you can review the reasons for certain developments, players' specific strategies and tactics, the delays and advancements of the competing technologies, and the unfairness and shortsightedness of policies and decisions surrounding the evolution. The larger story is that nuclear power is on schedule, from a historic perspective, to permanently disrupt fossil-fuel power generation. The anti- and pro-events detailed during the multi-decade arc of moving to a denser fuel are like monitoring the stock market by the hour. The proper perspective is that of a long-term investor.

Author Michael Shellenberger in his book, *Apocalypse Never: Why Environmental Alarmism Hurts Us All*, and his new book to be released in 2022, with the working title, *The War On Nuclear and Why It Hurts Us All,* offers a detailed history of the influential and effective antinuclear movement. One of his main observations is that extreme environmentalists base their positions more on spirituality or the fatalistic Malthusian theoretical perspective (population growth is the key contributor to scarcity). With such a dire future in mind, these environmentalists started entering convenient alliances, which crossed the line into conflicts of interest.

Nuclear power was first known as a bomb

Nuclear power was introduced to humanity in the form of two bombs dropped on Hiroshima and Nagasaki in 1945 to end WWII. Its destructive force was then improved and displayed in the form of 434 hydrogen bombs exploding in the atmosphere between 1945 and 1963 as the United States and Soviet Union tried to outdo each other during the heat of the Cold War. A hydrogen bomb is 1,000 times more powerful than the one dropped on Hiroshima.

A total of 2,000 nuclear weapons tests have been conducted during the last 70 years. The United States conducted about 1,000 of them. In 1976, the Limited Test Ban Treaty (LTBT) was agreed to and testing ceased between the Soviet Union and the United States.

Note: Don't forget this was also the era when the Vietnam War was in full engagement, the Cold War was intense, and worldwide protests against nuclear weapons and war in general were occurring all over the United States and Europe. When considering the situation at the time, it becomes more understandable why public opinion turned sharply against all things nuclear.

Strontium-90

The radioactive fallout from these nuclear device tests resulted in strontium-90 (a cancer-causing radioisotope) showing up in babies' teeth via grass feed for cows, through the cows, in the milk, and residing in place of calcium in babies' teeth. The amount of strontium-90 was 55 times higher in children's teeth born during nuclear bomb-testing era. It can be picked up by sensors in minute amounts in the atmosphere all over the Earth. Still, it was 200 times less than the levels known to cause cancer.

Note: Although these issues are emotionally charged, commercial nuclear power generation is not responsible for nuclear weapons or any radioactive fallout from testing nuclear weapons. This connection between the commercial and military use of nuclear power was first made in the 1950s when the US Government promoted commercial nuclear power development as a public good via Eisenhower's Atoms for Peace program. Meanwhile, most of the US Government's efforts continued to be dedicated to making more powerful nuclear weapons.

In a strategic move that one must admire, the antinuclear environmentalists just turned this strategy on its head. Either way, it's a false narrative that the nuclear power used to provide commercial energy is one and the same with the nuclear power used to make weapons.

Strange alliances and ironies

By the mid 1960s environmental groups, once in favor of nuclear energy, started being infiltrated by antinuclear advocates (fellow environmentalists). They linked the narratives about nuclear energy and nuclear weapons together, and a war-weary public accepted the connection. With nuclear energy having been successfully tied to weapons and war, it wasn't a stretch for the environmental groups to live by the metaphor "the end justifies the means" as fossil-fuel companies realized "the enemy of my enemy is my friend." Thus, the environmentalists began the practice of accepting millions of dollars in donations from fossil-fuel companies. They used that financial strength to organize and prevent the building or continued operation of nuclear energy plants all over the country. This is still true today.

Three common tactical approaches of fossil-fuel companies pushing back on nuclear energy

1. Support wind and solar, which have a generation efficiency of just 10 to 30 percent. That intermittency combined with the current absence of power storage technology means that mostly natural gas (and coal) will be needed to provide baseline power in the absence of nuclear power. If you ever wondered why fossil-fuel companies have so many beautiful advertisements with wind turbines and solar panels, now you know.
2. Fund and infiltrate antinuclear environmental groups that are highly effective at slowing down or preventing the building of new nuclear plants and shutting down existing nuclear plants. Then support their advocacy for a wind- and solar-only replacement of nuclear power.
3. Form their own foundations and non-governmental agencies to advocate for renewable energy development (that doesn't include nuclear energy) to influence policy and public opinion.

Note: Other fossil-fuel companies have not wanted to invest in wind, solar, or nuclear power. They may think: Why do anything? Sit tight; dense fossil fuels will not be replaced if nuclear power is feared. Let everyone else beat their brains out; you'll keep performing profitably. If that was their thinking, they were disabused of that passive tactic when environmentalists infiltrated their boards and institutional stockholder populations, forcing them to invest in "renewable" energy — wind and solar.

Here's a suggestion to these fossil-fuel companies: Make long-term investments in Generation IV nuclear reactor development and tell the world about why that decision is being made. That way, the risk of building out unpopular and inefficient wind and solar farms can be replaced by more promising bets on the densest baseline power form for the future. The fuels are competitive, but the energy institutions can adapt.

The biggest greenhouse gas polluters in history are antinuclear activists.

Organizations such as the Sierra Club, Greenpeace, Friends of the Earth, the National Resource Defense Council, Center for American Progress, the Environmental Defense Fund, and 350.org have successfully shut down half of all planned and under-construction reactors since the 1960s. In many cases, these organizations understood and approved of coal power and natural gas replacing these nuclear reactors.

The antinuclear community has about 80 organizations in the United States with many affiliates around the world. They're well-funded, extremely organized, have a consistent and disciplined message, and focus on a few clear objectives. They are a formidable opponent for the pronuclear community. However, they're also fighting a migration to a dense energy source. Dense fuels, because of physics, eventually work out to be more efficient and far less expensive than the fuels they're replacing. And the United States isn't the only place developing nuclear power technologies. If we don't lead in nuclear power technology, China is on track to take that position.

I didn't realize that!

If we don't lead in nuclear power technology, China is on track to take that position.

Ironically, antinuclear environmental activists can also be considered the number one polluters of greenhouse gasses by closing down nuclear power plants and preventing the building of new nuclear power plants.

20. Are nuclear plants a target to terrorists set on getting a nuclear weapon or causing a radioactive explosion?

Quick Answer

- No. Nuclear plants are very hard targets.
- The fuel is inadequate for making a weapon or it's inaccessible. It's not a grab-and-go situation.
- A nuclear plant can't explode like a nuclear weapon.
- Nuclear power for electricity is generated much differently than how nuclear weapons are made.
- The path of least resistance is to build your own bomb, as Pakistan did and as Iran is alledgedly trying to do.
- Shutting down nuclear power plants or not building new ones will make no difference in what nations have nuclear weapons.
- Nuclear proliferation will have to be prevented through government policy and international diplomacy.
- Nuclear power used for commercial energy may be a primary contributor to a world at peace.

More Details

Hard targets

A nuclear plant is a hard target. They're the most secured commercial sites in the world. They're isolated from other buildings and populations so a terrorist could not sneak up on them. The containment dome and the dry nuclear fuel storage casks can withstand a direct hit by a jumbo jet. And all nuclear plants are isolated from cyber attacks.

A terrorist organization would have such a low probability of success in infiltrating a nuclear power plant that it's most likely they would choose a softer target.

Note: One group that has infiltrated a nuclear plant with a drone and fireworks, and climbed security barriers are antinuclear advocates for Greenpeace. They wanted to make the point that nuclear plants in France were vulnerable to attack. But no damage was done to the plant, and it was never at risk of being overrun. Of course, the only way the security staff could have proven Greenpeace wrong is to have killed their demonstrators. The challenge for security was probably confirming that terrorists were not posing as Greenpeace advocates.

What about an inside job?

Imagine a compromised physicist or engineer working in a nuclear plant who wanted to cause a meltdown. Nuclear power plants have three concentric security circles around them:

- The outer perimeter (owner-controlled area),
- The protected area (armed guards), and
- The innermost space, the vital area (safety systems and reactor).

For people allowed in the vital area there are classified processes for background checks and controlled access. There is also a list of coordinated security practices such as physical patrols, outer physical barriers, bullet-resistant protection spots, electronic and illuminated detection, barriers to critical entry spots, and highly trained and armed personnel. Nothing is impossible, thus the hit movie, *Mission Impossible*. However, a plan to attack a nuclear power plant is as close to impossible as one can mathematically calculate. Homer Simpson doesn't work inside a nuclear plant, and Ethan Hunt doesn't have a team trying to infiltrate it.

Motivated terrorists are more likely to target other sources of power production or the more vulnerable electrical grid. Vigilance in the form of security is called for in protecting all sources of power generation.

The physics at a commercial nuclear plant makes it almost useless for weapons production

A chain reaction in a nuclear reactor uses low enriched uranium (4 to 20 percent). Uranium in a nuclear weapon requires uranium to be enriched to 90 percent or more. The uranium at a nuclear plant by itself is not enriched enough to cause a nuclear explosion. So just grabbing a pile of uranium won't do the trick.

And a nuclear plant can't blow up like a nuclear bomb. The physics of producing energy just don't allow for that kind of compact, instant, and powerful chain reaction to take place.

Plutonium-239 is a byproduct of a nuclear reaction when uranium-238 is radiated inside an active reactor. This form of plutonium can make a nuclear weapon, but it isn't enriched plutonium. Using plutonium from a commercial reactor to make a bomb is problematic. There are better ways to make a nuclear bomb. Also, a commercial reactor's fuel is only accessed about every 18 months to two years. By then other forms of plutonium have contaminated Plutonium-239. Plus, the physical process of extracting plutonium-239 from a commercial reactor is a massive undertaking. The fuel is extremely radioactive and hot. It would be like trying to steal the hottest, heaviest stove in history with a couple of buddies.

The path of least resistance isn't through a commercial nuclear plant

It's conceivable that a country with an adapted CANDU nuclear reactor could make enough Plutonium-239 to make a bomb, as India once did. But it would take a nation-state supported by another nuclear-armed nation to pull it off, which is the story behind every country outside the United States and Soviet Union that now have nuclear arms capabilities.

A country wishing to produce plutonium-239 for a weapon will build a special reactor specifically for that purpose. That is an expensive proposition, which is almost impossible to do in secret because of the amount of nuclear fuel it requires and its heat signature. A more likely scenario is to enrich uranium in centrifuges and build a bomb with a trigger device. This is the path of least resistance, and it is a path that Pakistan followed, and Iran is allegedly pursuing now.

Out of the 195 countries in the world today, only nine countries have nuclear weapons, and an additional five of them host US-made nuclear weapons. Many countries that could build nuclear arms don't want them. Expense, negative public opinion, and geopolitical isolation make it more attractive not to join that club.

About nuclear proliferation

Nuclear proliferation, the process of more countries obtaining nuclear weapons, is caused by the acquiring nation's desire to deter an already nuclear-armed nation from threatening it. The concept of mutually assured destruction (MAD) means that an offensive nuclear attack will be met with an equal level of destruction in a nuclear counterattack, assuring the destruction of the aggressor, the defender, and possibly the planet. President Ronald Reagan once said, "A nuclear war can never be won and must never be fought."

Some argue that nuclear weapons and the concept of MAD have prevented the large, conventional world wars from happening again. Even if that point is conceded, it's been a classic case of high reward demanding an inordinate number of risks. It's too much risk; there have been too many close calls. We must find a way to eventually eliminate nuclear weapons.

Megatons to Megawatts Program

One good example is the Megaton to Megawatts program. By 1991, the Cold War between the United States and Soviet Union was over, and Russia had 550 tons of highly enriched uranium for making nuclear weapons (enough for more than 20,000 nuclear warheads). In what turned out to be the most effective way in history to prevent nuclear proliferation, the United States and Soviet Union agreed to down blend that stock to commercial-grade nuclear fuel. The fueld was then sold to the United States to fuel commercial nuclear reactors. From 1993 to 2013, the United States powered nuclear reactors with this uranium, representing 10 percent of all electrical energy generated in the United States during that time.

The solution to nuclear proliferation and even the end of all nuclear weapons will have to come from government policy and diplomacy. Shutting down commercial nuclear power plants or preventing future nuclear reactors from coming online would have absolutely no effect on making the world safer from nuclear war. Rather, a world powered by abundant, affordable, clean nuclear energy is likely to be more peaceful.

21. What are Generation IV reactors?

Quick Answer

- They're generally small, inherently safe, proliferation resistant, modular, portable, can burn nuclear waste as fuel, leave very little radioactive waste behind, and produce enough residual heat that many industrial applications can be conducted affordably from it. Once demonstrated, the new nuclear reactors will likely gain broad public support.
- New reactors will be more like the commercial reactors tested between the 1940s to the 1980s than current Generation II and III reactors.
- The first nuclear reactor to generate electricity, EBR-1, was able to breed fuel as it operated, just like future reactors will do.
- The first thorium test reactor ran successfully for 14,000 hours at full power from 1965 to 1969. Thorium could be the fuel that powers the world soon.
- The United States had an inherently safe commercial reactor almost ready to go through broader testing and licensing in the mid 1980s, but the government cut the funding.
- Other countries have used nuclear energy research and reactor test results from US archives to their advantage.
- On September 12, 2021, China brought the first Phase IV nuclear reactor to critical status (initiated a chain reaction) after nearly 30 years of research.
- Modularity means millions of advanced reactors can be made in factories.
- 130 nuclear reactor concepts were reviewed by 100 experts from the Generation IV International Forum. They settled on six types of potential future reactors as promising.
- The performance and safety features of Small Modular Reactors are numerous and promising. They will be the safest and most efficient forms of power generation in existence.
- Heat to desalinate water or make hydrogen may be a bigger benefit than the electricity produced by new reactors.
- An international structure for classifying and developing Generation IV Reactors is in place, and each nation has its own plan for developing and testing under the broader international framework.

More Details

Generation IV Nuclear Reactors will quickly earn broad public support

Generation IV Reactors are sometimes called Advanced Reactors. To compare them to Generation II and III reactors, which are now in use, is like comparing the Wright Brothers' first airplane, the 1903 Wright Flyer, to a SpaceX Falcon 9 Rocket. They both use the laws of aerodynamics, but the similarities quickly diminish from that point.

Note: I'll focus mostly on the features of a Molten Salt Reactor (MSR). Versions of these are being researched and will be tested by places like Filbe Energy, founded by Kirk Sorenson (a leader in Generation IV MSRs), Terrestrial Energy, and Copenhagen Atomics. The other Generation IV Reactors may not share all the same features, but all of them offer similar technologies and similar benefits. They differ in chemical recipes and configurations. For example, some use a combination of solid fuel and a molten (salt or metal) circuit to transfer and store heat, like Bill Gates' TerraPower, a start-up using a Natrium reactor. Oklo's reactor is a novel concept and could be considered a micro reactor, designed to power a remote military base or a village. X-Energy's Xe-Mobile Reactor will fit into a standard size shipping container.

All of them are inherently (walk away) safe. They range in thermal power output, from just a few megawatts on up; but most are under 300 megawatts per unit (300 MW= power for 150,000 high-energy houses). Below I've listed the various kinds of Generation IV Reactors, with links to more information on each.

They've been around for decades

Generation IV Reactor concepts borrow heavily from the reactors tested successfully from the 1940s to 1980s. In fact, Generation IV Reactors have more in common with these early reactors than they do with the big Generation II and III water reactors in use now. The reason is civilian scientists designed these early small, safe reactors for the peaceful purpose of producing energy.

Alvin Weinberg

In the late 1940s and early 1950s, Admiral Rickover's naval team (responsible for the first nuclear submarine, the Nautilus) learned about nuclear power at Oak Ridge Labs, a secret research complex that worked on the first atomic bomb. The person in charge of Oak Ridge Labs was Alvin Weinberg. It was Weinberg and his team who came up with the idea for the Pressurized Water Reactor (PWR), which Rickover selected as his power source for the first nuclear submarine. And later Rickover cut off the funding for the small breeder reactors Weinberg was working on at the time.

According to Weinberg's autobiography published in 1994, *The First Nuclear Era, The Life and Times of a Technological Fixer*, having been discouraged over a lifetime of trying to get the United States to adopt the concept of the smaller, molten, breeder reactors, many years later he said:

We nuclear people have made a Faustian bargain with society. On the one hand we offer, in the breeder, an inexhaustible source of energy . . . Moreover, this source of energy when properly handled is almost nonpolluting. Whereas fossil-fuel burners emit oxides of carbon, nitrogen, and sulfur . . . There is no intrinsic reason why nuclear systems must emit any pollutant except heat and a trace of radioactivity. But the price that we demand of society for this magical source is a vigilance from a longevity of our social institutions that we are quite unaccustomed to.

The big Pressurized Water Reactors (PWRs) in use now are adapted from the technology used to power submarines and aircraft carriers. Military necessity consumed the available nuclear development budgets, and many of these smaller, safer reactor tests were on shoestring budgets until they were finally canceled.

The first reactor to generate electricity

The first reactor to generate electricity was an Experimental Breeder Reactor (EBR) at Idaho National Labs. It's called EBR-1, and it produced electricity on December 20, 1951. EBR-1 confirmed it could breed more fuel than it used in 1953. It operated for 12 years before being shut down in 1963 and is now a National Historic Landmark.

According to Robert Hargraves, author of the excellent book, *THORIUM: energy cheaper than coal*, "In the Cold War the US Air Force wanted bombers that could continuously circle the Soviet Union without landing to refuel, leading to the aircraft reactor experiment (ARE). Oak Ridge [Labs] built the first molten fluoride salt reactor, which ran for 100 hours in 1954 at temperatures of 860 degrees C (1,500 degrees F) — red hot! The ARE demonstrated inherent reactivity stability and automatically adjusted power, without control rods, as the 2.5 MW heat exchanger airflow varied. The Hastelloy-N metal vessel and piping withstood corrosion."

The first thorium reactor

A Molten Salt Thorium Reactor was tested successfully from 1965 to 1969 at Oak Ridge Laboratories in Tennessee where one ran at full power for 14,000 hours. But it was abandoned for various political and military reasons.

Note: We've talked about the advantages of thorium as a nuclear fuel throughout this guide. It will become one of the most popular nuclear fuels used in Generation IV Reactors, and a word that will be very familiar to our grandchildren.

We had a safe reactor ready to go

In April 1986, the Idaho Advanced Reactor Development team was focused on coming up with a safe reactor. They built an Integral Fast Reactor (IFR). Then they tried everything possible to try to melt it down. Years later, we learned that one of their 1986 tests was nearly identical to the 2011 Fukushima Daiichi accident situation. And they duplicated the accident that happened at Three Mile Island in March 1979. No matter the various chain of events they attempted, they could not get the reactor to fail. It simply shut itself down using gravity.

The frozen plug

Molten Salt Reactors (MSRs) are one kind of Small Modular Reactor (SMR). The salt, often fluorides — which give us another reactor you'll be hearing, Liquid Fluoride Thorium Reactors (LFTRs) — operate at 700 degrees C + / 1,292 degrees F. The concept of a meltdown is null because the fuel is already melted. If there would be a power loss to the pumps or an emergency, a frozen plug located below the reactor vessel would melt, and the fuel would dump into big graphite-lined tanks. When the fuel spreads out in those tanks and the moderators absorb the neutrons, the chain reaction stops. The fuel eventually cools to a solid on its own. Also, these reactors operate at one atmosphere (no pressure), and there's no water (hydrogen) in their molten cores that can cause an explosion.

Other countries have used US experience to build their Generation IV Reactors

All the other countries with nuclear power capabilities are well aware of the work conducted at Oak Ridge Labs by the alumni of the Manhattan Project (the massive secret US program to build a nuclear bomb during WWII), and the other early nuclear tests performed around the United States from the 1940s to 1980s. The Chinese attempted to use those documents to build an MSR as early as the

1970s but didn’t have the right alloys on hand. However, in 2021 the Chinese started up a small test SMR with plans to move the technology into commercial production by 2030.

Note: China and India represent the two most populated countries on Earth with 2.8 billion people. That represents 36 percent of the world’s total population. The energy needs of these two countries are growing exponentially. They will consume 31 percent of the world’s energy by 2025 (up from 21 percent in 2008). Right now, more coal plants are being built to quickly provide power to these growing economies. However, China’s population may be pushing back on the pollution caused by burning coal, while India has vast amounts of Thorium (a fertile fuel that can be burned in an MSR) that could make them energy independent and eradicate energy poverty. Both countries are highly motivated (beyond any concern about climate change) to move to baseline nuclear power economies as fast as possible.

MSR features

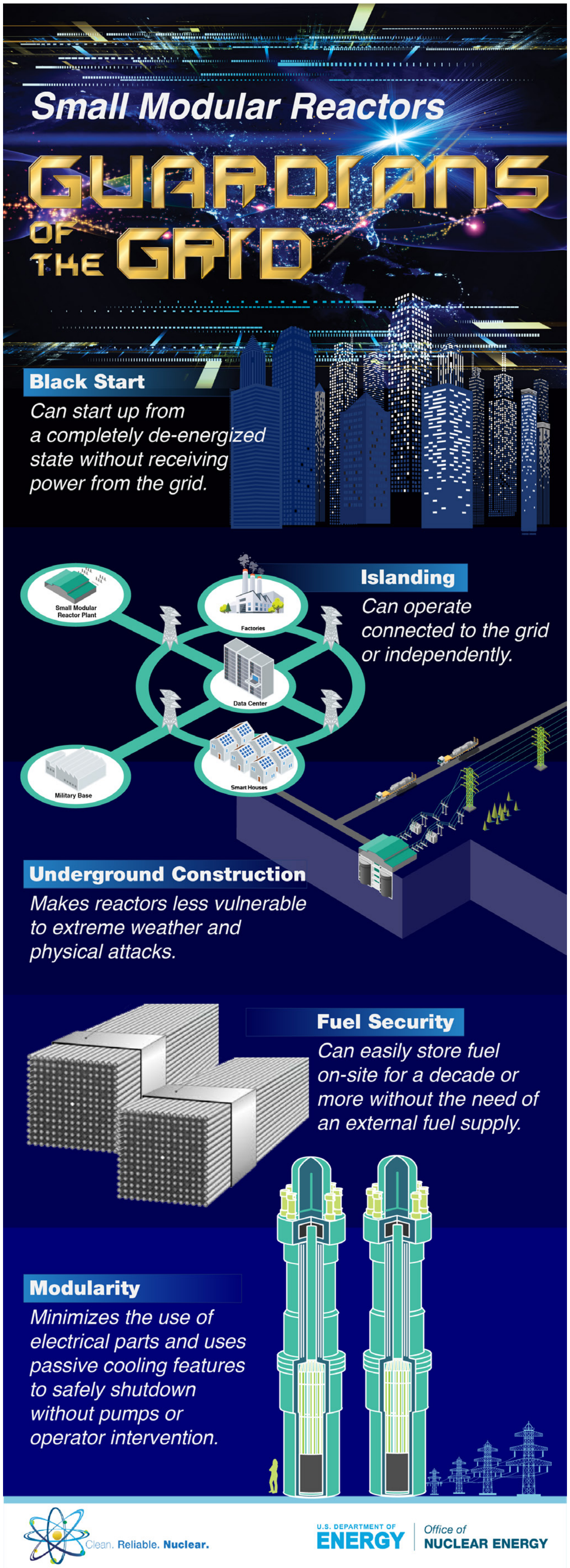
Drawing from the well of our nuclear energy pioneers, but now with 70 years’ experience, advanced alloys, better chemistry, and decoupled from the military complex, these new reactors can’t melt down. The fuel is already melted down as part of their design. These reactors can’t blow up because there’s no high pressure or hydrogen in the core. They can run for years without needing to be refueled because they breed fuel while operating. If something goes wrong, these reactors shut themselves down via physics and gravity. Thus, these reactors walkaway safe. They can burn a wide variety of fuels, including used fuel from Generation II and III reactors. In other word, MSRs can use the radioactive waste stored at nuclear plants now as fuel, leaving very little radioactive waste behind. With a half-life of about 400 years instead of thousands, MSRs can produce isotopes for medical therapy and treatments, making those treatments more affordable and innovative. MSRs are proliferation resistant; the fuel is used up while creating power, and some of the reaction byproducts contaminate any potential weapons-grade material. This means we could place them in foreign countries with assurance they could not be used to make nuclear weapons.

Small and modular

Some are so small they can be put on a standard shipping container and sent to the remote site where power is needed. They can be packed together when more power is required.

The modular design means they can be built in a factory. So once a reactor receives certification, they can be mass manufactured. Artificial intelligence and robotics can assure the manufacturing process is safe and effective. A world with millions of small nuclear reactors is not only necessary but also almost certain in the near future. Their complexity is in chemistry, which has been worked out. The mechanisms are simple. The designs are elegant. Just the opposite of the present bigger nuclear plants.

The modular design also means either the entire unit is exchanged at retirement, or the fuel is contained in a separate module for replacement. Many Generation IV Reactors are designed to operate in an underground facility, on a tiny footprint, making them even more protected than their predecessors.



Their high heat may be more important than the electricity they produce

We often think of nuclear reactors as producing electrical energy. It's possible that the high heat generated by an MSR (700 C + or 1,292 F +) may be more valuable. An MSR could take on functions where currently the energy going in has been much more than the yield. Think in terms of desalinating sea water, making hydrogen without producing greenhouse gasses in the process, sanitizing municipal wastewater, recycling landfill material, and heating buildings to list a few ideas. And don't forget, they can back up intermittent wind and solar power, making those power sources more functional.

Note: Just 15 of the largest ships emit more pollution than 760 million cars. MSRs will be able to produce hydrogen economically and without creating greenhouse gasses. If that hydrogen was used to turn the dirty diesel fuel into more of a hybrid fuel, or power the ships with pure hydrogen, this would be a huge advance in cutting greenhouse gasses and other pollutants. I would suggest just putting a Generation IV Nuclear Reactor on ships and powering them directly, but the international regulatory process for that is far from being in place. For now, MSR-made hydrogen is a solution for powering all types of transportation.

International structure for classifying and developing Generation IV Reactors

One hundred experts from the Generation IV International Forum reviewed 130 reactor concepts. They selected six reactor types:

1. Gas-cooled Fast Reactor (GFR)
2. Lead-cooled Fast Reactor (LFR)
3. Molten Salt Reactor (MSR)
4. Super-critical Water-cooled Reactor (SCWR)
5. Sodium-cooled Fast Reactor (SFR)
6. Very-High-Temperature Reactor (VHTR).

Each of these broader areas has subcategories. For example, China is now operating a Gas Cooled Fast Reactor called a pebble bed. The fuel is loaded in small balls, and the reactor doesn't need to be shut down to be refueled. It just draws from its reservoir of "pebbles."

Thirteen countries participate in the Generation IV International Forum, and each country has various initiatives to produce advanced reactors. In the United States, there is the Advanced Reactor Demonstration. In addition to grants and data sharing, the United States also makes its national laboratories and nuclear fuels available to qualified participants to test fuel applications, reactor designs, and performance of test reactors. They also have a sub-category called the Advanced Demonstration and Test Reactor Options Study, which allows members to study some of the other applications for nuclear power that we've already reviewed, such as, desalination and heating. Canada's Small Modular Reactor Action Plan has laid out a roadmap, a national strategy for taking advantage of Generation IV Reactors. The Russian nuclear energy company, Rosatom, is now forming an International Research Center (IRC) to test a multipurpose fast neutron research reactor called MBIR. France will be working with the United States on advanced reactors to address climate change. The United Kingdom is planning on its first Small Modular Reactor Demonstrator, called the AMR Demonstration Program. This is just a sampling of the work happening around the world on Generation IV Nuclear Reactors.

Summary

Quick Observations

- The historical arc to a new energy source is a long time.
- Risk literacy is low.
- Energy density is either not understood or underrated.
- Physics and math present a glimpse of the future.
- People need not conserve or suffer.
- The optimists are almost always right.
- What future do you want to leave behind?

Signoff

Historical arc

After studying and reading about nuclear energy for some time now, I've come to appreciate the 50- to 100-year historical arc that disruptive energy sources follow before becoming the baseline power source of the era. From that perspective, nuclear energy seems on track to take its rightful position as the world's baseline power in the near future. We can drink from the well that those before us have left behind. We know a lot about nuclear energy now, and we have good reasons to push it.

Risk literacy

Understanding nuclear energy starts with having some level of risk literacy. Nuclear energy has risks as all sources of power generation do. I respect all those who study, discuss, debate, and work to minimize risks. In comparison to not only other power sources, but also to climate change, energy poverty, and growing worldwide demand for more energy, nuclear is by far the lowest risk way to address these concerns the fastest. These issues each present more risk to the world by magnitudes than deploying nuclear power does. In fact, there is no path to a Net Zero Carbon world without nuclear power as a critical part of energy production.

Energy density

The other thing most people either don't understand or underrate is energy density. Density allows us to keep our ecological footprint small both for the size of equipment and surface area it requires. It provides efficient systems (a Generation IV Reactor will be able to operate 20 years or more without refueling). It produces less total waste and in more condensed form. Energy density improves energy productivity, which is the fuel of innovation and human advancement.

The physics and math present a glimpse of the future

The physics and math behind nuclear energy make it inevitable that it will become the world's baseline power source, whether the United States leads that effort or not. The trajectory for the United States to lead the next generation is not promising. But, if we can get past the historical tipping point and public perception changes, the United States still has time to lead the world in nuclear energy.

People need not conserve or suffer

Cutting back on energy consumption is not a viable path to a better world. Countries will not handicap themselves. People will not cut back or go without conveniences in a modern world. Conserving energy is a step backward that almost nobody will take, especially the very people advocating for it. We simply must produce abundant, inexpensive, clean energy for everybody in the world. And, we have the technology now to do that.

The optimists are almost always right

The world is full of critics. Criticism plays an important part in discovery, but it's often overrated. Achievements in transportation, space flight, nuclear power, fossil-fuel extraction, architecture, agriculture, materials, communications, medicine, and computers to name a few, all had a long list of lounge-chair quarterbacks who were wrong. In fact, many of them never saw the improvement coming because it was buried, out-of-sight in its own developmental arc and behind the curtain of negative, apocalyptic news that saturates our days. Turn it off. The optimists are right most of the time.

"The power to save our world does not lie in rocks, rivers, wind, or sunshine. It lies in each of us."

—Gwyneth Cravens

Atomic Garage Movement

Congratulations on finishing *The Quick Read Nuclear Energy Guide*! *The Quick Read Guide* and *Chain Reaction* are the first releases for the Atomic Garage Movement – an organization formed to advocate for nuclear energy in popular culture by telling nuclear energy's powerful story through the arts.

Others are invited to join the Atomic Garage Movement and contribute to advancing the future of nuclear energy through creative endeavors.

Not a writer or artist? No worries, you can help the Atomic Garage Movement and nuclear energy by sharing this guide with others. It makes the perfect gift for any special (and not so special) occasion. Don't forget about social media posts, too. Impress your friends and family with your nuclear-energy knowledge now.

To learn more about the movement and for updates on the release of *Chain Reaction* and nuclear energy in general, visit atomicgaragemovement.com and join us on starting a chain reaction to promote the use of nuclear energy.

The Quick Read Nuclear Energy Guide -

For all ages and all levels of understanding

Wow, we are really impressed with the breadth and depth of your analysis of nuclear power. While we usually get all of our scientific information from the Simpsons rather than peer-reviewed journals, we did find that your analysis added a wee bit more factual information. We were reassured to hear that not all wildlife near a nuclear plant winds up like Blinkie, the three-eyed fish in the Simpsoms. . . It is really refreshing to see someone who cares enough about an issue that they actually do some heavy-duty scientific research to present extremely logical points.

— Christine S.

I'm loving your book! It's very entertaining and amusing, a great read. It's bringing back good memories of my mom. She read everything she could find on nuclear energy when I was a kid, and she was so critical of those opposed to its development.

— Martha L.

It's formatted well and is very easy to learn from. I really like the addition of the hyperlinks throughout the text and in the figures. It's a really nice addition, especially when you wanna go more in depth into a subject.

— Jack S.

Let's start a Chain Reaction together! Visit

www.atomicgaragemovement.com