

## NUCLEAR POWER

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## INTRODUCTION

American nuclear power is experiencing a renaissance, supported by an ideologically diverse set of parties.<sup>1</sup> This shift in public attitudes, which have generally been inimical to nuclear energy, belies a cold economic reality: electricity demand is growing, and more generation capacity is needed to meet it.<sup>2</sup> Nuclear power proponents insist that nuclear is the only practical solution to meet this demand in an environmentally responsible way. Opponents counter that the risks are too great, and the costs are too large.

Too often, however, the debate involves strident assertions of fact that are unmoored from the technical details of nuclear energy itself. For example, advocates sometimes point to the nuclear industry's impeccable safety record to argue for looser regulation to enable innovation, even though that record was compiled in a highly-regulated environment with older, tried-and-true technology.<sup>3</sup> Opponents similarly insist that nuclear power is prohibitively expensive and produces too much radioactive waste, despite new reactor designs that limit costs and reduce waste.<sup>4</sup> Parsing this noise requires understanding how nuclear power actually works.

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<sup>1</sup> Defense experts claim that it is critical to national security, green energy advocates argue that it is the solution to an emission-free energy future, and business leaders claim that it is key to enabling AI development. See generally David Gattie, *Competitive Advantage as a National Security Objective for US Civilian Nuclear Power Policy*, GEO. J. INT'L AFFS. (June 3, 2024), <https://gjia.georgetown.edu/2024/06/03/competitive-advantage-as-a-national-security-objective-for-us-civilian-nuclear-power-policy/> [https://perma.cc/TU4V-KK3P] (discussing national security); Off. of Nuclear Energy, *3 Reasons Why Nuclear is Clean and Sustainable*, U.S. DEP'T OF ENERGY (Mar. 31, 2021), <https://www.energy.gov/ne/articles/3-reasons-why-nuclear-clean-and-sustainable> [https://perma.cc/74L4-ZQDC] (discussing green energy); Lucas Johnson, *Tech Companies and Their Love of Nuclear*, NUCLEAR ENERGY INST.: BLOG (Oct. 22, 2024), <https://www.nei.org/news/2024/tech-companies-and-their-love-of-nuclear> [https://perma.cc/H4RP-ENC3] (discussing business).

<sup>2</sup> U.S. Energy Info. Admin., *After More Than a Decade of Little Change, U.S. Electricity Consumption is Rising Again*, TODAY IN ENERGY (May 13, 2025), <https://www.eia.gov/todayinenergy/detail.php?id=65264> [https://perma.cc/ZT6N-8RWN].

<sup>3</sup> See, e.g., Exec. Order No. 14300, 90 Fed. Reg. 22587 (May 23, 2025) (stating that the Nuclear Regulatory Commission is overly focused on "trivial" risks).

<sup>4</sup> See generally, *Generation IV Nuclear Reactors*, WORLD NUCLEAR ASS'N, <https://world-nuclear.org/information-library/nuclear-power-reactors/other/generation-iv-nuclear-reactors> (last visited Dec. 29, 2025) [https://perma.cc/2JZ9-XQRF]; Mark Jacobson, *7 Reasons Why Conventional Nuclear Energy is Not the Answer to Solve Climate Change*,

To that end, this Technology Explainer explains the basics of nuclear power so that stakeholders can accurately assess nuclear policy, regulations, and technology. In Part II, I start by reviewing the basics of atomic physics. Part III builds on this foundation to explain how nuclear reactions generate energy. Then, in Part IV, I describe how nuclear power plants harness this energy to produce electricity using current technology as a guide. Part V concludes by briefly discussing the design considerations behind emerging reactor technologies.

## I. ATOMS 101

Atoms are made up of three particles: electrons, neutrons, and protons. Protons and neutrons combine to form an atom's core, known as the nucleus. Electrons orbit the nucleus.<sup>5</sup> In chemical reactions, an atom's electrons interact with the electrons of other atoms. Such interactions provide the foundation for processes like combustion, which create heat to power generators and produce electricity. By contrast, nuclear power relies on reactions that occur within atomic nuclei. These reactions produce no chemical emissions and generate millions of times more energy than chemical processes. This enables nuclear power plants to generate much more power with much less fuel than their conventional counterparts.<sup>6</sup>

Nuclear reactions depend on the properties of atomic nuclei, which vary according to their structure. Nuclei are classified by their number of protons, which determines what element they are.<sup>7</sup> They are further classified by their number of neutrons, which determines

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ONE EARTH (June 4, 2025), <https://www.oneearth.org/the-7-reasons-why-nuclear-energy-is-not-the-answer-to-solve-climate-change/> [<https://perma.cc/8T94-QU3G>] (arguing, among other things, that nuclear power is prohibitively expensive and produces too much waste).

<sup>5</sup> This conception of the atom is based on the Bohr model, which is sufficient to understand the concepts here. The electron "orbits" that are commonly shown in drawings of atoms should be thought of as a functional depiction of electron energy levels rather than a reproduction of what a scaled-up atom would actually look like. Other, more complex models more fully describe atomic physics. *See generally, The Bohr Model*, KHAN ACAD.: HIGH SCH. CHEMISTRY, <https://www.khanacademy.org/science/hs-chemistry/x2613d8165d88df5e:atomic-models-and-periodicity/x2613d8165d88df5e:the-bohr-model-and-atomic-spectra/a/the-bohr-model> [<https://perma.cc/NV38-AX45>] (last visited Nov. 16, 2025).

<sup>6</sup> *Fuel Comparison*, EUR. NUCLEAR SOC'Y, <https://www.euronuclear.org/glossary/fuel-comparison/> [<https://perma.cc/K6LV-72SC>] (last visited Nov. 16, 2025).

<sup>7</sup> The number of protons is also referred to as an atom's "atomic number."

what isotope they are. To illustrate, an atom with twenty-six protons is defined as the element iron, which has many different isotopes containing different numbers of neutrons.<sup>8</sup> Scientists identify isotopes by the sum of their protons and neutrons. Thus, an iron atom with thirty neutrons is an isotope of iron called iron-56 (see Figure 1). The total number of protons and neutrons in a nucleus affects its ability to generate energy, which will be discussed further in Part III.

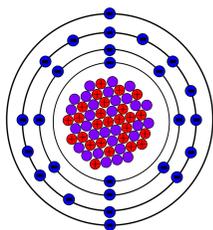


Figure 1: A Bohr model of the isotope iron-56, an atom with twenty-six protons (in red) and thirty neutrons (in purple).<sup>9</sup>

Importantly, nuclear properties attach to isotopes, not elements. For a given element, some isotopes are radioactive or likely to fission, while others are not. Engineers, therefore, leverage the properties of individual isotopes to create controllable nuclear power. Nuclear policymakers similarly set policies regulating specific isotopes rather than elements more generally.<sup>10</sup>

## II. NUCLEAR REACTIONS

In theory, two nuclear reactions, fission or fusion, could be used to generate utility-scale electricity. Both produce heat, which can be harnessed to drive generators. Fusion, which involves binding nuclei together, has yet to be successfully harnessed for electricity

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<sup>8</sup> Elements are listed on the periodic table.

<sup>9</sup> *Iron-56*, Wikimedia Commons, <https://commons.wikimedia.org/wiki/File:Iron-56.svg> [https://perma.cc/8YMM-8VY5] (last visited Dec. 23, 2025).

<sup>10</sup> *See, e.g.*, Atomic Energy Act of 1954 § 11, 42 U.S.C. § 2014 (providing definitions for various regulated isotopes including radium-226, uranium-233, and uranium-235).

generation.<sup>11</sup> As such, fission, which breaks atoms into smaller pieces, is used in all current power plants.<sup>12</sup>

Both fission and fusion depend on two physics principles: binding energy and mass-energy equivalence. Binding energy is the amount of energy it takes to bind protons and neutrons together in an atomic nucleus.<sup>13</sup> This is analogous to a rubber band holding the nucleus together; binding energy is the amount of energy it would take to stretch the rubber band around the protons and neutrons. Unlike with a rubber band, however, protons and neutrons give up some of their mass when they bind together. This “missing mass” is transformed into binding energy according to the principle of mass-energy equivalence.<sup>14</sup>

Mass-energy equivalence was first conceptualized by Albert Einstein. In essence, it means that mass and energy are two sides of the same coin. Einstein related them with the famous equation  $E = mc^2$ , which means that energy is equal to mass times the speed of light squared. Because the speed of light is both constant and large, it follows that a large amount of energy will be released proportionally to small changes in a particle’s mass.<sup>15</sup>

Taken together, binding energy and mass-energy equivalence explain the energy-generating properties of atomic nuclei. Because different isotopes require different amounts of binding energy to form, only some fission and fusion reactions release energy.<sup>16</sup> In an

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<sup>11</sup> Fusion, which involves binding hydrogen nuclei together to form helium, produces significantly more energy than fission. It is also considered “cleaner” since it produces significantly less radioactive waste. Scientists have worked for decades to make fusion reactors a reality but have been unsuccessful thus far. *See* Off. of Nuclear Energy, *Fission and Fusion: What Is the Difference?*, U.S. DEP’T OF ENERGY (Apr. 1, 2021), <https://www.energy.gov/ne/articles/fission-and-fusion-what-difference> [<https://perma.cc/7T4M-K4GL>].

<sup>12</sup> *Id.*

<sup>13</sup> Binding energy is also sometimes defined as the amount of energy required to decompose a nucleus into its constituent parts. Because of the law of conservation of energy, these definitions are equivalent. *See* *Binding Energy*, ENCYCLOPEDIA BRITANNICA, <https://www.britannica.com/science/binding-energy> [<https://perma.cc/3SVF-PCZZ>] (last visited Nov. 18, 2025).

<sup>14</sup> *Id.*

<sup>15</sup> Francisco Ferneflores, *The Equivalence of Mass and Energy*, STAN. ENCYCLOPEDIA PHIL. (Aug. 15, 2019), <https://plato.stanford.edu/entries/equivME/> [<https://perma.cc/SD4T-VRW8>] (*See* § 1.3).

<sup>16</sup> *See* Eric G. Blackmun, *The Curve of Binding Energy*, UNIV. OF ROCHESTER, <https://www.pas.rochester.edu/~blackman/ast104/bindingE.html> [<https://perma.cc/Q7HE-PRP7>] (last visited Nov. 18, 2025).

energy-releasing fusion reaction, the protons and neutrons in the resultant nucleus have less mass than they had in the starting nuclei. This missing mass is transformed into binding energy.<sup>17</sup> Likewise, in an energy-releasing fission reaction, each proton and neutron in the resultant nuclei has less mass than the nucleons in the starting nuclei. As in fusion, this missing mass is released as binding energy.<sup>18</sup>

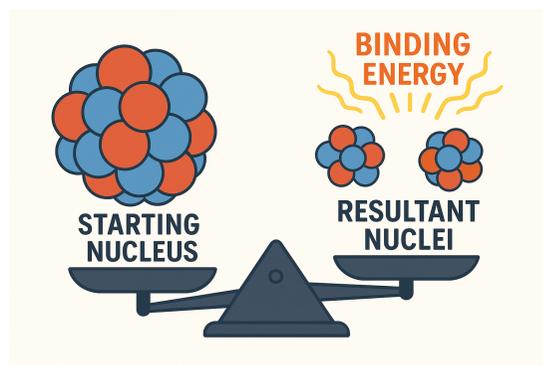


Figure 2: In an energy-producing fission reaction, the protons and neutrons in the starting nucleus (left) have less mass than the protons and neutrons in the resulting nuclei (right). This missing mass is converted to binding energy.<sup>19</sup>

These principles require that the resultant nuclei have a higher binding energy per proton and neutron than the starting nuclei for fission or fusion to release energy. Physicists have figured out that atoms with more protons and neutrons than iron-56 release energy when they fission, but not when they fuse.<sup>20</sup> Conversely, atoms with fewer protons and neutrons than iron-56 release energy when they fuse, but not when they fission.<sup>21</sup> Nuclear fuels, therefore, are distinguished from other materials by their relatively large number of protons and neutrons. This is partly why uranium, the largest naturally occurring element, is used as a nuclear fuel. Figure 3 shows the energy generation characteristics of all types of nuclei by plotting the observed binding energies of nuclei according to their total number of protons and neutrons.

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<sup>17</sup> *Id.*

<sup>18</sup> *Id.*

<sup>19</sup> OpenAI, AI-Generated Image depicting atomic mass decrement (generated Nov. 18, 2025), <https://chat.openai.com>.

<sup>20</sup> Christopher S. Baird, *What Is the Most Stable Nucleus?*, West Tex. A&M Univ. (July 23, 2024), <https://www.wtamu.edu/~cbaird/sq/2024/07/23/what-is-the-most-stable-nucleus/> [<https://perma.cc/48NN-HYYJ>].

<sup>21</sup> *Id.*

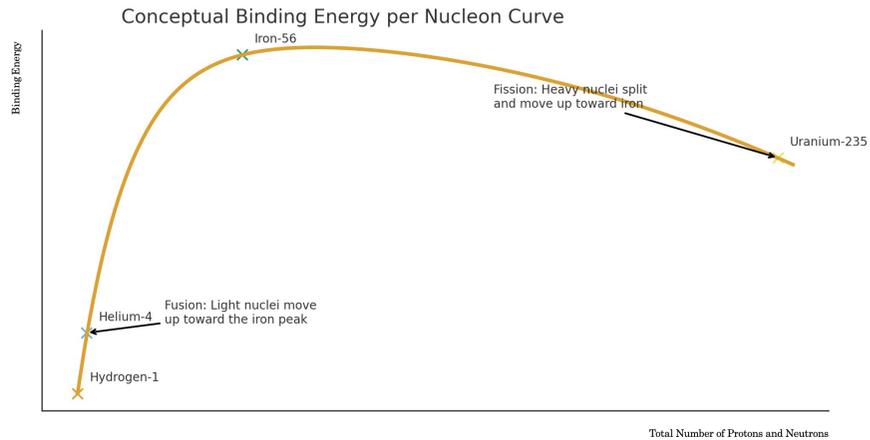


Figure 3: A simplified version of the binding energy per nucleon curve. This plot shows the energy-releasing behavior of all atomic nuclei. Reactions that move "up the curve" towards iron-56 release binding energy.<sup>22</sup>

To induce nuclear reactions, neutrons are made to interact with nuclei. When a neutron interacts with a nucleus, a few things could happen. First, it could bounce off that nucleus (i.e., "scatter").<sup>23</sup> Alternatively, it could be absorbed by the nucleus, creating a new isotope.<sup>24</sup> Finally, it could be absorbed by the nucleus, destabilize it, and cause fission.<sup>25</sup> The probability that one of these reactions happens for a particular isotope is called its "cross-section."<sup>26</sup> Boron-10, for example, has a high absorption cross-section and is used by

<sup>22</sup> OpenAI, AI-Generated Image depicting the binding energy per nucleon curve (generated Nov. 18, 2025), <https://chat.openai.com>.

<sup>23</sup> Ling-Jian Meng, Slideshow on Interactions of Neutrons with Matter, at 8 (Spring, 2020) (available on the University of Illinois website) [https://courses.grainger.illinois.edu/npre441/sp2020/lectr%20notes/lecture\\_chapter4\\_2020\\_interaction\\_neutrons.pdf](https://courses.grainger.illinois.edu/npre441/sp2020/lectr%20notes/lecture_chapter4_2020_interaction_neutrons.pdf) [<https://perma.cc/DVU3-BTWJ>] (last visited Nov. 8, 2025).

<sup>24</sup> *Id.*

<sup>25</sup> *Interactions of Neutrons with Matter*, U.S. NUCLEAR REGUL. COMM'N, at 31, <https://www.nrc.gov/docs/ML1122/ML11229A705.pdf> [<https://perma.cc/4KTU-DWQW>].

<sup>26</sup> *Id.* at 9.

engineers to absorb neutrons.<sup>27</sup> Nuclear fuels, like uranium-235, have high fission cross-sections.<sup>28</sup>

Besides the isotope, cross-sections depend on the energy level (i.e., speed) of the neutrons interacting with the nucleus. The most common nuclear fuel, uranium-235, has a high fission cross-section for slow-moving neutrons (also called “thermal neutrons”) but a low fission cross-section for fast-moving neutrons.<sup>29</sup> Because of this, reactors fueled with uranium-235 need to slow neutrons down to sustain a fission reaction.

Neutrons are slowed down through a process called moderation. Moderation is accomplished by putting a material, known as a moderator, in the reactor core that contains nuclei for fast-moving neutrons to collide with.<sup>30</sup> These collisions, like a ball on a billiards table, slow neutrons down enough to cause fission by transferring some of their momentum to the moderator. Common moderators include water and graphite.<sup>31</sup>

Fission itself produces heat energy, fission products (i.e., new, smaller atoms), and neutrons.<sup>32</sup> Fission products decay to produce additional neutrons.<sup>33</sup> These neutrons can go on to moderate

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<sup>27</sup> Alan Munter, *Neutron Scattering Lengths and Cross Sections Data*, NAT’L INST. STD. TECH. CTR. NEUTRON RSCH. (Nov. 23, 1999), <https://www.ncnr.nist.gov/resources/n-lengths/list.html> [<https://perma.cc/PJD2-VYS8?type=standard>].

<sup>28</sup> Nuclear Data Center, *92-U-235*, JAPAN ATOMIC ENERGY AGENCY, <https://www.ndc.jaea.go.jp/cgi-bin/Tab80WWW.cgi?lib=J40&iso=U235> [<https://perma.cc/V878-79FB>] (last visited Nov. 19, 2025).

<sup>29</sup> *Id.*

<sup>30</sup> *Moderator*, U.S. NUCLEAR REGUL. COMM’N (Mar. 9, 2021), <https://www.nrc.gov/reading-rm/basic-ref/glossary/moderator> [<https://perma.cc/D3CB-PNHH>].

<sup>31</sup> *Id.*

<sup>32</sup> *See generally Reactor Concepts Manual: The Fission Process and Heat production*, U.S. NUCLEAR REGUL. COMM’N TECH. TRAINING CTR., <https://www.nrc.gov/reading-rm/basic-ref/students/for-educators/02.pdf> [<https://perma.cc/3SF5-WC7C>] (last visited Nov. 18, 2025).

<sup>33</sup> These “delayed” neutrons are essential to safe reactor control. Because they result from the decay of fission products, they take longer to appear in the core than the “prompt” neutrons that come from fission directly. This effectively slows down changes to the core neutron population, allowing control systems to respond. When the number of prompt neutrons are sufficient on their own to sustain a chain reaction, the reactor is in a condition called “prompt criticality.” This can have catastrophic effects, as in the SL-1 nuclear accident. *See generally* Bryan Sommers, *Idaho Falls: The First Nuclear Meltdown in America’s History*, ARGON ELECTRONICS: BLOG, <https://www.argonelectronics.com/blog/idaho-falls-first-nuclear->

and cause fission in other fuel atoms. If enough neutrons are produced and induce fission, a sustained chain reaction occurs and generates continuous energy.<sup>34</sup>

### III. GENERATING POWER

In the United States, the most common types of nuclear power plants are pressurized water reactors (PWRs) and boiling water reactors (BWRs).<sup>35</sup> Both have reactor cores composed of fuel (typically uranium-235) and a water moderator, which doubles as a coolant.<sup>36</sup> Heat energy released by fission is removed by the coolant and used to create steam. In a BWR, the coolant boils directly on the core, and the resulting steam is piped to a turbine-generator to create electricity.<sup>37</sup> In a PWR, the coolant is pressurized to prevent it from boiling.<sup>38</sup> Instead, steam is created by piping the hot coolant effluent to a steam generator, where it boils water contained within an isolated secondary cooling system to drive a turbine-generator.<sup>39</sup>

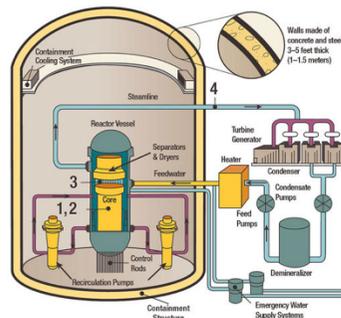


Figure 4: A diagram of a BWR. Steam is created directly on the core and piped to a steam turbine.<sup>40</sup>

meltdown-in-americas-history [https://perma.cc/EG8Y-UAA8] (last visited Nov. 19, 2025).

<sup>34</sup> *Id.* at 2-16.

<sup>35</sup> *Nuclear Explained: Nuclear Power Plants*, U.S. ENERGY INFO. ADMIN., (Aug. 21, 2025), <https://www.eia.gov/energyexplained/nuclear/nuclear-power-plants-types-of-reactors.php> [https://perma.cc/N4P2-EMLX].

<sup>36</sup> Reactor cores do not contain pure uranium-235. Instead, enrichment processes increase the concentration of uranium-235 in natural uranium so that it can be used as nuclear fuel. See *Reactor Concepts Manual: The Fission Process and Heat Production*, *supra* note 32, at 2-13.

<sup>37</sup> *Nuclear Explained: Nuclear Power Plants*, *supra* note 35.

<sup>38</sup> *Id.*

<sup>39</sup> *Id.*

<sup>40</sup> *Boiling Water Reactors*, U.S. NUCLEAR REGUL. COMM'N (Feb. 9, 2023), <https://www.nrc.gov/reactors/power/bwrs> [https://perma.cc/J8P5-JEGB].

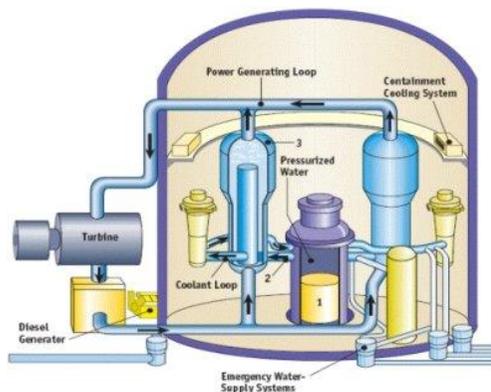


Figure 5: A diagram of a PWR. The power-generating loop (i.e., secondary cooling system) is separate from the reactor cooling loop.<sup>41</sup>

The fission rate, which corresponds to reactor power, is controlled in a couple of different ways. The first is by inserting neutron-absorbing materials, called control rods, into the core.<sup>42</sup> Reactor operators insert and remove control rods to control the number of neutrons available to cause fission. When the rods are fully inserted, they absorb so many neutrons that sustaining a fission chain reaction is impossible.

The second way to control fission is via the moderator. When there are more moderator atoms in the core, neutrons can more easily slow down and cause fission. When there are fewer moderator atoms in the core, neutrons are less likely to slow down and more likely to leak out of the core without causing fission. Adding more or less moderator to the core, therefore, affects reactor power.

In a typical PWR or BWR, the reactor coolant doubles as a moderator. This simplifies reactor control. When more steam is required to produce electricity, additional heat is pulled from the reactor coolant. This cools the coolant and makes it denser, resulting in more moderator atoms in the core. This makes the moderator more efficient at slowing down neutrons, leading to more fission and higher reactor power without any operator input.<sup>43</sup> This process also

<sup>41</sup> *Pressurized Water Reactors*, U.S. NUCLEAR REGUL. COMM'N, <https://www.nrc.gov/reactors/power/pwrs> [<https://perma.cc/T6RF-8RMU>].

<sup>42</sup> *Nuclear101: How Does a Nuclear Reactor Work?*, U.S. DEP'T OF ENERGY (May 19, 2025), <https://www.energy.gov/ne/articles/nuclear-101-how-does-nuclear-reactor-work#:~:text=Inside%20the%20reactor%20vessel%2C%20the,Boiling%20Water%20Reactors> [<https://perma.cc/A3SH-WMDV>].

<sup>43</sup> *Physics of Uranium and Nuclear Energy*, WORLD NUCLEAR ASS'N (May 16, 2025), <https://world-nuclear.org/information-library/nuclear->

works in reverse—when less steam is required, reactor power automatically decreases. Moreover, if reactor power “overshoots” the generator’s demand for steam, the coolant water heats and becomes less dense, leading to less moderation and lower reactor power. This creates a negative feedback loop that prevents uncontrolled fission events without the need for intervention by operators or external safety systems.<sup>44</sup> This behavior is shown graphically in Figure 6.

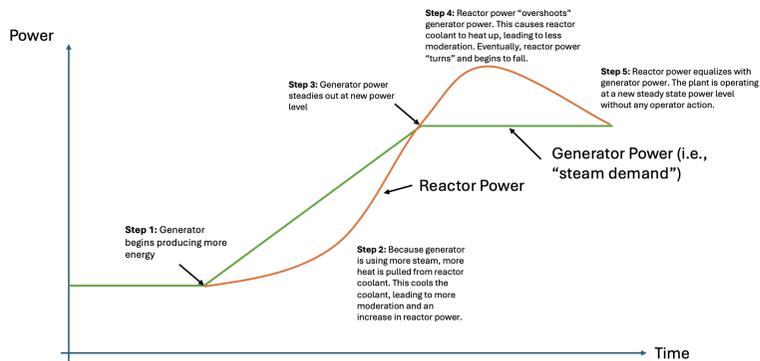


Figure 6: Reactor power behavior in a typical PWR/BWR.

Ultimately, these reactor control methods are designed to enable energy production while preventing radioactive fission products from escaping into the environment. Reactor fuel is sealed in metal plates, tubes, or pellets so that fission products cannot escape and contaminate the cooling water.<sup>45</sup> In PWRs, the isolated

fuel-cycle/introduction/physics-of-nuclear-energy [<https://perma.cc/KZ64-N78C>] (see the section titled “control of fission”).

<sup>44</sup> This feature is subject to reactor design. The RBMK reactors used at Chernobyl, for example, used graphite as a moderator and water as a coolant. For these and other reasons, reactor power would not automatically follow power demand. Thus, as reactor power increased, the rate of fission increased. This created a positive feedback loop which contributed to the Chernobyl nuclear accident. See *Chernobyl Accident 1986*, WORLD NUCLEAR ASS’N (Feb. 17, 2025), <https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident> [<https://perma.cc/5EXQ-5N2Z>] (See the section titled “The Chernobyl site and plant”).

<sup>45</sup> See generally *Nuclear Fuel and Its Fabrication*, WORLD NUCLEAR ASS’N (Oct. 13, 2021), <https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/fuel-fabrication> [<https://perma.cc/29LQ-NPJW>]; *TRISO Particles: The Most Robust Nuclear Fuel on Earth*, U.S. DEP’T OF ENERGY (July 9, 2019), <https://www.energy.gov/ne/articles/triso-particles-most-robust-nuclear-fuel-earth> [<https://perma.cc/8EEK-J84J>].

reactor cooling loop provides an additional layer of protection. The control systems, therefore, limit the amount of energy produced to prevent the fuel from overheating and melting through these containment barriers. Redundant safety systems also independently detect problems and automatically shut down the reactor if necessary.<sup>46</sup>

Even when shut down, however, reactors require cooling water to remove residual heat and prevent containment materials from melting.<sup>47</sup> Because a shutdown reactor is no longer producing electricity, external energy sources such as diesel generators, compressed air systems, grid electricity, or batteries are often required to circulate coolant.<sup>48</sup> In some reactors, coolant recirculates naturally without an external energy source, which simplifies operations and provides an additional safety margin.<sup>49</sup>

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<sup>46</sup> This can be done in several ways, including by emergency inserting control rods. This procedure is called a “scram.” See *Refresh—Putting the ‘Axe’ to the Scram Myth*, NUCLEAR REGUL. COMM’N (Sept. 24, 2025), <https://www.nrc.gov/reading-rm/basic-ref/students/history-101/putting-axe-to-scram-myth> [<https://perma.cc/WZ7Y-ZSMD>].

<sup>47</sup> Heat comes mostly from decay of radioactive fission byproducts. This “decay heat” is one of the most significant nuclear safety concerns. The Three Mile Island and Fukushima Daiichi nuclear accidents both involved shutdown reactors that overheated and melted through containment barriers. The possibility of a shutdown reactor meltdown at the Zaporizhzhia nuclear power plant in Ukraine has generated concern because of external power interruptions due to the Russia-Ukraine war. See *A Brief History of Nuclear Accidents Worldwide*, UNION OF CONCERNED SCIENTISTS (Oct. 1, 2013), <https://www.ucs.org/resources/brief-history-nuclear-accidents-worldwide> [<https://perma.cc/9Y5W-WCUL>]; Andrew E. Kramer, *Danger and Intrigue Hang Over Power Cut at Russian-Held Nuclear Plant*, N.Y. TIMES (Sept. 29, 2025), <https://www.nytimes.com/2025/09/29/world/europe/zaporizhzhia-nuclear-power-plant-russia-ukraine.html#:~:text=In%202023%2C%20an%20explosion%20in,circulat e%20water%20for%2010%20days> [<https://perma.cc/7LX3-MMPZ>].

<sup>48</sup> See *generally Decay Heat – Decay Energy*, NUCLEAR-POWER.COM, [https://www.nuclear-power.com/nuclear-power/reactor-physics/reactor-operation/residual-heat/decay-heat-decay-energy/#:~:text=Decay%20Heat%20Removal,ultimate%20heat%20sink%20\(UHS\)](https://www.nuclear-power.com/nuclear-power/reactor-physics/reactor-operation/residual-heat/decay-heat-decay-energy/#:~:text=Decay%20Heat%20Removal,ultimate%20heat%20sink%20(UHS)) [<https://perma.cc/YJ7E-SVNQ>] (last visited Nov. 19, 2025).

<sup>49</sup> See *Nuclear Power Reactors*, WORLD NUCLEAR ASS’N (Nov. 19, 2025), <https://world-nuclear.org/information-library/nuclear-power-reactors/overview/nuclear-power-reactors> [<https://perma.cc/B34U-M7LP>] (discussing passive decay heat removal for certain kinds of reactor cooling systems).

#### IV. NEXT GENERATION REACTOR DESIGNS

Current challenges to nuclear power include high capital costs, difficulties associated with radioactive waste disposal, and a lack of flexibility in adapting to grid demand.<sup>50</sup> Also, reactor operations typically require teams of specially trained operators who are in short supply.<sup>51</sup> New reactor designs attempt to address these problems and make nuclear power a more attractive investment for both the government and the private sector.

Small Modular Reactors (SMRs) have attracted particular attention. They purport to reduce capital costs, require fewer workers to operate, and are adaptable to the energy requirements of their service areas. Their distinguishing features are compactness and design standardization, which enable them to be prefabricated in factories.<sup>52</sup> This lowers construction costs and allows manufacturers to benefit from economies of scale. Also, SMRs' small land footprint enables them to service individual facilities and small communities while meeting larger communities' needs through the installation of additional reactor units.<sup>53</sup>

Despite their promise, however, SMR development faces challenges. In addition to regulatory hurdles, their small size requires the use of fuel that is enriched to contain a higher concentration of uranium-235 than is necessary for traditional reactors. This is a problem for SMR companies because the United States has had minimal uranium enrichment capacity since the end of the Cold War. To address this issue, policymakers have focused on expanding domestic uranium enrichment capacity and given nuclear companies access to government supplies of nuclear fuel.<sup>54</sup>

Another focus of innovation is fast reactors, which produce much less radioactive waste than traditional thermal neutron reactors. Fast reactors operate with fast neutrons by converting non-fissile atoms into atoms with high cross sections for fast fission

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<sup>50</sup> See *Advantages and Challenges of Nuclear Energy*, U.S. DEP'T OF ENERGY (Jun. 11, 2024), <https://www.energy.gov/ne/articles/advantages-and-challenges-nuclear-energy> [<https://perma.cc/7F9L-Z4PT>]; *Nuclear Power Reactors*, *supra* note 49 (discussing load following capabilities of reactor plants).

<sup>51</sup> Kelly Livingston, *Worker Shortage Looms Over New U.S. Nuclear Power Focus*, ROLL CALL (Nov. 5, 2025), <https://rollcall.com/2025/11/05/worker-shortage-looms-over-new-us-nuclear-power-focus/> [<https://perma.cc/P7VD-M6X7>].

<sup>52</sup> *Benefits of Small Modular Reactors (SMRs)*, U.S. DEP'T OF ENERGY, <https://www.energy.gov/ne/benefits-small-modular-reactors-smrs> [<https://perma.cc/S2Z4-LSZF>] (last visited Nov. 19, 2025).

<sup>53</sup> *Id.*

<sup>54</sup> See, e.g., Exec. Order No. 14299, 90 Fed. Reg. 22581, 22582-83 (May 29, 2025).

through a series of neutron absorptions and nuclear decays.<sup>55</sup> This process results in much more efficient fuel use and drastically reduces radioactive waste. It also, however, produces fissile material that can be used to build nuclear weapons.<sup>56</sup> As such, fast reactors present difficult nuclear non-proliferation issues that may prove challenging to resolve.

Finally, various large thermal neutron reactors are under development that could replace the current crop of PWRs and BWRs. While the design variations are too numerous to discuss in detail here, they use different coolants and fuel types than the current generation of reactors. Much of the focus is on elevating plant operating temperature, which would increase plant efficiency.<sup>57</sup> They also incorporate changes to reduce the risk of meltdown. Very high temperature gas reactors (VHTGRs), for example, use a gas coolant and a uranium fuel that is formed into ceramic pebbles. This configuration allows the plant to operate at higher temperatures and reduces the risk of meltdown.<sup>58</sup> Another design uses a molten salt coolant, which has high thermal conductivity at elevated temperatures, enabling an increase in plant operating temperature.<sup>59</sup> The takeaway from these efforts is that nuclear power technology varies significantly, and the technical details matter. As such, investors, policymakers, and regulators must understand these differences to make informed decisions.

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<sup>55</sup> Because fast reactors do not need a moderator, they can employ coolants like liquid metal, molten salt, or gas which sidesteps the corrosion and pressurization challenges that arise from using water coolant and allows them to operate at higher temperatures. *See generally Nuclear Power Reactors*, *supra* note 49.

<sup>56</sup> *See*, MARK HOLT, CONG. RSCH. SERV., R45706, ADVANCED NUCLEAR REACTORS: TECHNOLOGY OVERVIEW AND CURRENT ISSUES 9 (2023).

<sup>57</sup> Higher temperatures benefit plant efficiency because the laws of thermodynamics dictate that larger temperature differences between a heat source and a heat sink produce more efficient heat engines. Since the heat sink temperature is set by the external environment, the only way to increase thermodynamic efficiency is to raise the operating temperature. *See generally Carnot Efficiency*, UNIV. OF CALGARY, [https://energyeducation.ca/encyclopedia/Carnot\\_efficiency](https://energyeducation.ca/encyclopedia/Carnot_efficiency) [<https://perma.cc/M6BW-PX96>] (last accessed Nov. 19, 2025).

<sup>58</sup> HOLT, *supra* note 56 at 13-14.

<sup>59</sup> *Id.* at 22-23.