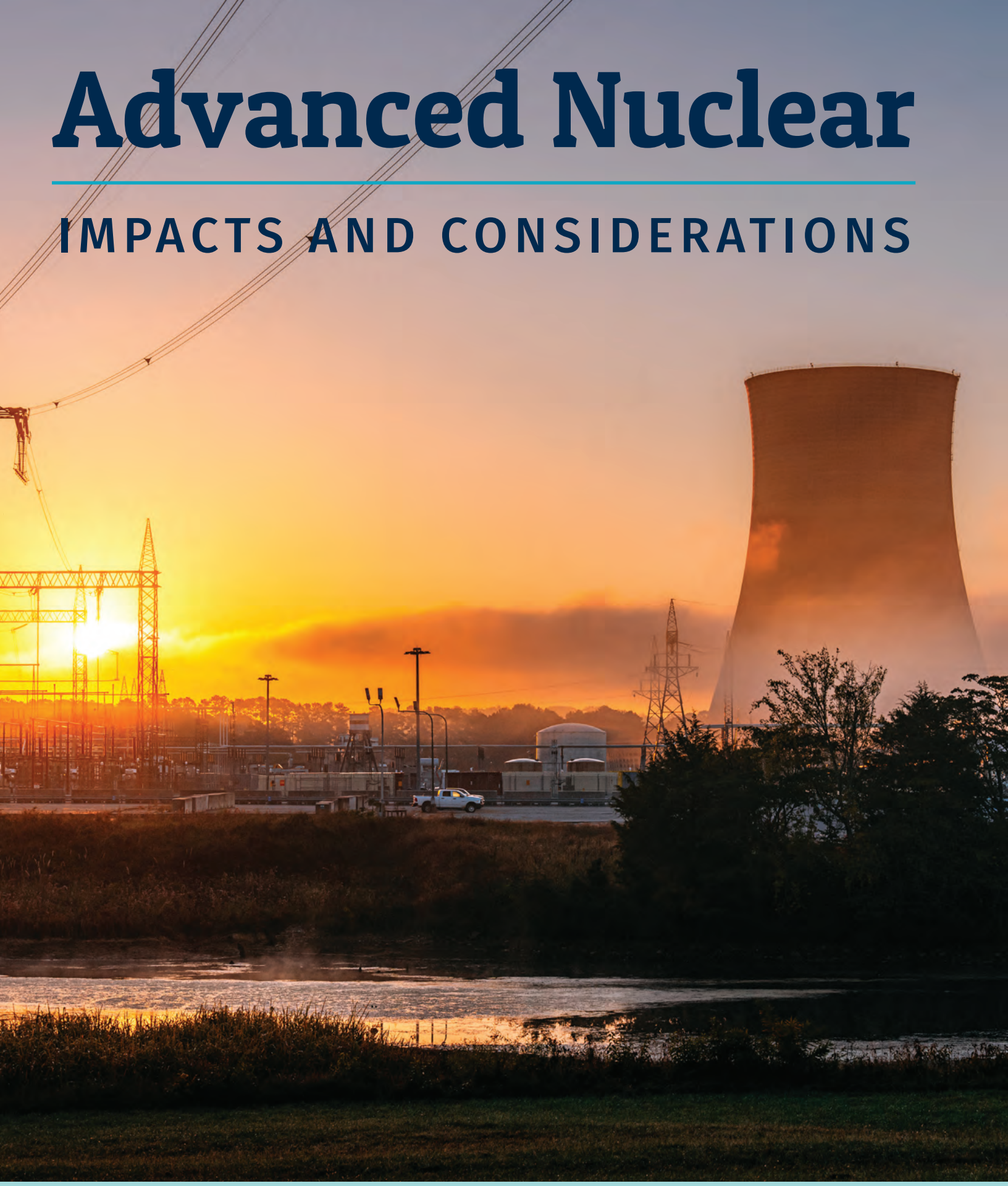
Advanced Nuclear

IMPACTS AND CONSIDERATIONS



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Lead Authors: Sarah Kallgren and April Higa

Author Acknowledgments: We would like to sincerely thank the following individuals for their expertise and contributions to this report: Shriya Pai, Jessica Arriens, Shannon Heyck-Williams, Diane Pataki, Cornia Newsome, and Gloria Tom.

Report Background: This report is meant to inform readers about the current state of advanced nuclear power in the United States, existing federal regulation and incentives, and considerations around potential impacts of advanced nuclear on lands, waters, and the health of people and wildlife. It is structured as an educational document and does not advocate for or against any particular policies or regulations. The National Wildlife Federation works on a broad suite of climate and clean energy solutions, with the **ultimate goal** of confronting the escalating climate crisis and realizing a world with thriving wildlife populations, resilient ecosystems, and sustainable communities. Our work to advance clean energy—which currently includes responsibly developed on- and offshore wind, solar, transmission, and next-generation geothermal—is grounded in collaboration, science, and meaningful community engagement. Readers can access the Federation's archive of policy resolutions **online**.

Suggested citation: Kallgren, S. and Higa, A. 2026. *Advanced Nuclear: Impacts and Considerations,* Washington D.C.: National Wildlife Federation.

Cover image: Sunrise behind cooling towers and lattice towers of a nuclear power plant in Tennessee. Credit: Jeremy Poland/Getty Images.

February 2026

NATIONAL WILDLIFE FEDERATION

1200 G Street, NW, Suite 900

Washington, D.C. 20005

www.nwf.org

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An advanced nuclear reactor test experiment, at Idaho National Laboratory. Credit: Idaho National Laboratory.

Advanced Nuclear: The Basics

Introduction

Energy consumption in the United States is on the rise with no signs of slowing down. Given the growth in demand from data centers the United States is projected to consume more electricity in 2030 from data processing than for producing aluminum, steel, cement, and chemicals combined.[1] Additional reliable and scalable energy sources will be needed to generate this electricity. Along with these supply expansions, other AI-specific energy policies can reduce how much new generation is needed. These levers can include demand shaping, transmission upgrades, interconnection reform, energy storage solutions, and efficiency standards. These additional pathways can help reduce some stress on the supply and generation side.

Advanced nuclear energy—an umbrella term that refers to a suite of more modern and still-evolving nuclear technologies and designs—could be part of that energy mix. Currently, the U.S. uses 4,300 terawatt hours of electricity annually, 60% of which is generated from fossil fuels, 19% from conventional nuclear, and 21% from renewables.[2] At COP29 in 2024, the U.S. announced the ambitious goal to triple its nuclear energy capacity by 2050, adding 35 GW of new capacity by 2035 and eventually

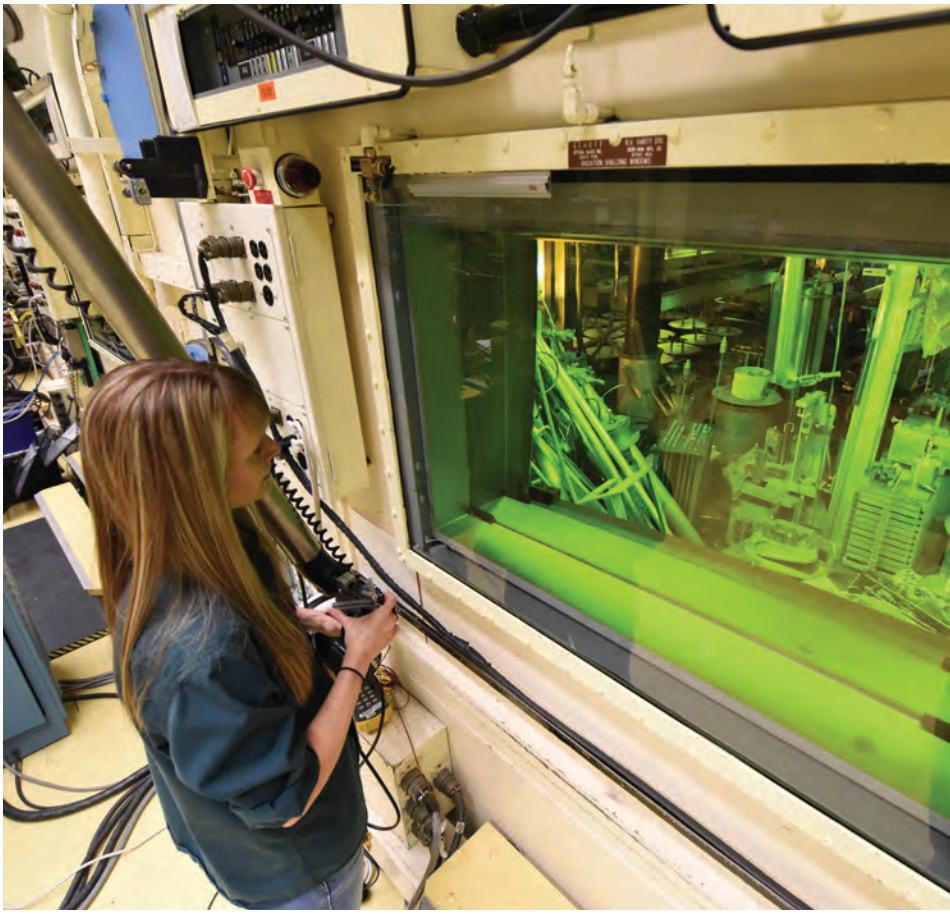
sustaining an additional pace of 15 GW per year by 2040.[3] While Americans remain more supportive of wind and solar energy development, advanced nuclear energy has bipartisan support, with 69% of Republicans and 52% of Democrats in favor of nuclear energy use for electricity production.[4]

Advanced nuclear provides a non-greenhouse-gas-emitting (at the point of electricity generation) and continuous source of power, often called "clean, firm," with potential safety and sustainability improvements over conventional nuclear. But concerns remain, especially around nuclear waste and uranium extraction impacts to lands, waters, wildlife, and communities. Advancements in nuclear energy technology have not fully eliminated some of the major safety and health concerns associated with nuclear, including radiation and national security risks. Advanced nuclear is very much still a developing industry. But understanding what it is can be a helpful first step for conservation and climate advocates and decision-makers.

This paper begins with an overview of advanced nuclear and how it differs from conventional nuclear technologies, especially focused on potential improvements in reductions of nuclear waste. Then we discuss potential impacts from advanced nuclear, focusing on land use, water, and human and wildlife safety. Finally, we outline how the federal government and numerous states are exploring and investing in advanced nuclear technology, which is useful to understand where (and when) it may be deployed. The vast majority of advanced nuclear reactors are still in the research and development phase, though that is likely to change in the next few years as pilot projects launch. New models and technologies may generate additional concerns, or alleviate some potential impacts.

What is Advanced Nuclear?

Conventional nuclear power includes light water reactors that were commercialized in the 1950s and 1960s and are used throughout the world. Also called Generation 2 reactors, this is the primary type of nuclear power plant that exists at a commercial scale in the U.S. today. (Two reactors in Georgia are considered advanced nuclear, but they are still lightwater reactors that operate similarly to conventional lightwater reactors.)[5] The U.S. currently has 95 operational light water reactors, which provide about 20% of the baseload electricity generation in the country.[6] Designed for a typical operational lifetime of 40 years, conventional light water reactors use ordinary water as both a coolant



Post-irradiation Examination at the Materials and Fuels Complex. Credit: Idaho National Laboratory.

and a neutron moderator—a substance that is used to slow down high-velocity neutrons to increase the likelihood of fission. These designs require relatively large electrical grids and produce significant quantities of used fuel that require high-level disposal or reprocessing. They use traditional active safety features involving electrical or mechanical operations, which are initiated automatically or by a human operator.

Advanced nuclear is an umbrella term that refers to a broad set of designs and technologies inclusive of Generations 3 and 4 reactors. The reactors that fall into this category can be water-cooled or non-water-cooled, and can range in size from a few megawatts to hundreds of megawatts.[7] Any models that generate under 300 megawatts are considered small modular reactors. Technologies that fall into advanced nuclear include but are not limited to: small modular reactors, molten salt reactors, molten fluoride salt cooled high-temperature reactors, sodium-cooled fast reactors, micro reactors, and high-temperature gas cooled reactors. Advanced nuclear reactors tend to have some mix of the following features, compared to conventional/Generation 2 reactors:

- ***Enhanced safety and efficiency.*** These systems take advantage of gravity or the natural circulation of coolant and have safety systems that are considered passive, meaning they are inherent to the system design and do not rely on human intervention or power to function. Thus, in the event of power loss, the nuclear reactor should remain at a safe temperature limiting the risk of a melt down.[8] That said, the effectiveness of passive safety varies across designs and depends on factors like core geometry, fuel form, and coolant behavior. Many non-lightwater reactors (reactors that use coolants other than water) provide passive cooling for the initial period after shutdown, but long-duration heat removal remains less proven, and some coolants introduce additional failure modes that can complicate passive system performance.

- ***Slower and smaller release of radioactive materials in the event of an accident.***[9] Accident release behavior, however, is highly design-specific. Some advanced reactor concepts use chemically reactive or mobile coolants and fuels (e.g., sodium or molten salts), which can create different release pathways or require additional containment measures if systems fail.

- ***Factory construction, especially for small modular reactors generating 300 megawatts or less.*** This should allow for cheaper manufacturing and a faster construction process. Manufacturing these modular reactors poses its own complications, including high up-front capital costs (though small modular reactors are generally considered less expensive than larger scale reactors).[10] Manufacturing practices will need to be field tested and approved by both users and regulatory bodies before they can be mass produced, and there are challenges around sufficient standardization of each part of the reactor that is manufactured.[11]

- ***Different grid integration designs.*** While conventional lightwater reactors require large, stable grids, many advanced designs (small modular reactors, microreactors, molten salt, sodium cooled fast reactors) are more flexible. But they still have nontrivial grid integration requirements for inertia, frequency stability, voltage support, and thermal hydraulic stability. These designs are marketed as islandable, meaning they are designed to operate independently from the bulk transmission grid while supplying a

A uranium mine at Kakadu National Park in Australia. Credit: Bidgee, Wikimedia Commons.

defined local load or microgrid under limited conditions. Though, practical deployment depends on unresolved engineering challenges related to grid-forming behavior, local grid protection, and operational reliability.

- ***Improved fuel utilization and introduction of "accident tolerant" fuel that offers better performance during normal operation, transient conditions, and accident scenarios.***[12] Some new fuel designs incorporate fuel that is expected to last longer, which could potentially lead to less waste production.[13] The Union of Concerned Scientists notes that data around this accident tolerant fuel remains sparse and they remain generally skeptical of the concept.[14]

In the United States, several advanced reactor designs have already undergone demonstration testing, while others are currently in testing or pre-licensing phases. None have reached commercial deployment, though commercial-scale demonstration reactors are now being planned in the U.S.

Nuclear Fuel Background: Uranium Mining

Uranium exists in fixed quantities in the Earth's crust and must be mined, making it fundamentally different from other clean energy sources like wind and solar. Globally, 44% of uranium comes from conventional open-pit mines, while 52% of uranium comes from in-situ leaching, and the remaining 4% from byproducts of other mineral extractions.[15] Many advanced reactor designs require HALEU-uranium enriched above the 3-5% that is used in current light-water reactors. HALEU stands for high-assay low-enriched uranium; "assay" refers to how much usable fuel is in the uranium. Because enrichment energy use and chemical waste rise nonlinearly with enrichment level, large-scale HALEU production could significantly increase front-end environmental burdens, including additional mining, greater energy consumption, and higher enrichment-related waste streams. Once used in a reactor,

however, most of this material remains unburned: Spent fuel still contains about 95% unused uranium and roughly 1% plutonium formed during operations, which is why some countries pursue reprocessing.

Conventional mining from open-pit and underground mines involves removing overlying rock to access uranium ore deposits, where it is collected and then further processed. In-situ leaching works by using water and additional elements and oxidants throughout deposits to directly extract uranium. While uranium mining via in-situ leaching has become increasingly more efficient than its open-pit extraction counterpart, due to lower production costs and higher recovery rates,[16] the issue of radioactive waste remains. Globally, Kazakhstan, Namibia, and Canada are the lead producers of uranium.[17] While the U.S. is the largest nuclear power producer, it imports approximately 99% of its uranium supply,[18] raising major concerns about supply chain dependence and energy security. As the U.S. expands its nuclear power and advanced reactor development, pressure to develop domestic uranium sources will likely increase.

In 2024, there were eight operational uranium mines in the United States,[19] but as the country expands nuclear energy production, new uranium development is expected to grow. The U.S. Department of Energy's (DOE) current efforts to strengthen domestic nuclear fuel production are likely to drive additional uranium mining and expanded front-end fuel cycle infrastructure. Programs such as the HALEU Availability Program[20] aim to produce the high-assay low-enriched uranium needed for many advanced reactor designs, which require higher enrichment levels than the existing commercial fleet. These initiatives also require new deconversion facilities (which convert uranium-containing gas back into solid form needed to make reactor fuel), and transportation facilities, each generating its own distinct chemical and radiological waste streams beyond the impacts associated with mining. Although uranium had previously been excluded from the U.S. Department of Interior's list of critical minerals because the federal statute barred fuel minerals from being listed as "critical," the Trump Administration recently reclassified uranium as a critical mineral.[21] The move also aligns with broader federal permitting reform efforts; some U.S. policymakers aim to accelerate domestic mining and processing projects to reduce reliance on Russian and Kazakh uranium in particular.

However, as the National Wildlife Federation's *Critical Minerals for Clean Energy* guide notes, domestic uranium mining raises complex challenges for wildlife, habitats, and communities, stressing the need for responsible and equitable extraction practices.[22] Mining practices may fragment or destroy habitat, and pollute streams and other waterways. Open pit mining in particular can cause pit lakes to form, in which harmful elements that are associated with uranium bearing rock formations, like selenium, can leech into and harm aquatic organisms.[23] Waterborne selenium can impair reproduction and potentially kill aquatic birds at higher concentrations.[24]

There is a history of harm in the uranium mining industry, including lasting implications from uranium tailings, especially for western states and Tribal Nations.[25] In 1979 a uranium mill dam collapsed on the Navajo Nation in Church Rock, New Mexico and leaked 93 million gallons of radioactive and chemically contaminated liquids, and 1,100 tons of solid radioactive materials, into the Puerco River which contaminated downstream water for over 60 miles.[26] Church Rock communities

Sunset at the Cattenom nuclear power plant in France, one of the country's largest. Credit: Matthieu Nioufs, Flickr.

have been fighting for more than 40 years to rid their land of uranium mine waste that has harmed both their land and physical health.

Nuclear Fuel Background: Waste

Nuclear waste is produced from nuclear reactors, weapons programs, and low-level civilian and defense activities. Spent nuclear fuel is the radioactive byproduct produced by nuclear fission. It can no longer produce energy without further reprocessing. Although nuclear energy remains one of the most reliable and consistently available power sources once operational, concerns over radioactive waste continue to limit its deployment and shape public opposition to new projects.

While most nuclear waste is classified as low and intermediate level waste, 3% is considered high-level waste (HLW). HLW is mostly made up of the spent fuel removed from reactors after it can no longer generate power, but can still cause fatality after short durations of exposure.[27] Although the percentage of HLW seems small, HLW remains dangerously radioactive for 1,000 to 10,000[28] years and is a significant problem that requires robust multibarrier containment and deep geological long-term disposal to protect humans, wildlife, and the environment.

In recent years policymakers and industry leaders have promoted advanced nuclear as a more cost-effective, safe, and flexible alternative to conventional nuclear. Conventional nuclear reactors rely primarily on uranium-235 (i.e., a uranium atom whose

nucleus contains 92 protons plus 142 neutrons). To be used as fuel, uranium-235 must be separated from the more naturally plentiful uranium-238 in a process called "enrichment." Lower enrichment levels are typically achieved for nuclear energy, while higher levels are needed for nuclear weapons. In contrast, some advanced reactors can convert the more abundant uranium-238 and thorium-232[29] into new reactor fuel, potentially allowing more of the original material to be used before disposal and thereby extending energy output while reducing the amount of long-lived waste that must ultimately be managed.[30] Supporters argue that advanced nuclear reactors could lower waste volumes via recycling more effectively than in conventional reactors[31], shorten radioactivity timescales, and provide industrial heat.

Most advanced nuclear designs remain in their infancy, and concerns remain around whether these designs will truly reduce waste. Studies by Stanford University and the University of British Columbia concluded that small modular reactors (a subset of advanced nuclear designs), will actually generate more radioactive waste than conventional nuclear power plants.[32] This is because many small modular reactor designs use higher enrichment fuels, experience greater neutron leakage (which makes surrounding materials radioactive, increasing local radiation levels and raising occupational exposure risks), and require more cladding and structural material per unit of electricity generated. All of this increases the volume of radioactive waste. While the nuclear industry and DOE remain staunch advocates for advanced nuclear technologies, there remain critical questions about whether advanced nuclear investment and current regulatory strategies realistically support long-term sustainability and safety goals.

Whether advanced nuclear reactors generate less nuclear waste will not address how to handle the waste itself. For many advanced reactor designs, producing higher-assay fuels also creates additional upstream waste, including chemical residues from fuel processing and larger amounts of depleted uranium (which is less radioactive than fresh fuel, but still carries chemical toxicity risks), that are distinct from spent fuel waste. Nuclear waste is first kept underwater for five to eight years to cool and for radioactive levels to decrease before it is either recycled or moved into dry casks (large concrete containers) for disposal.[33] Alternatively, spent fuel can be recycled where unused plutonium and uranium can provide an additional 25-30% more energy from the original mined uranium.[34]

Over 90% of nuclear waste contains its original energy, and while certain countries like France, Japan, Russia, and the United Kingdom operate a "closed nuclear fuel cycle"

Dry casks at the Diablo Canyon Site near Avila Beach, California. Credit: The U.S. Nuclear Regulatory Commission.

that reprocesses spent fuel into mixed-oxide (MOX) fuel for reuse in reactors,[35] the United States does not. The U.S. does not reprocess spent fuel largely because President Carter halted reprocessing in 1977 over proliferation and national security concerns.[36] President Reagan later lifted the ban[37] to encourage private-sector nuclear development, but public opposition, proliferation concerns, and high economic costs meant that the U.S. ultimately stayed on a disposal-focused path centered on interim storage and an ultimately stalled attempt to build a deep geologic repository. France has been a long-time pioneer in the nuclear sector, with its La Hague facility processing 23,000 tons of spent fuel since the mid-1960s, enough for 14 years of reactor power and a roughly 17% reduction in uranium consumption.[38] These foreign examples show that recycling is both technically achievable and financially viable, particularly in nations that heavily rely on nuclear energy.

By contrast, U.S. reactors operate on an "open nuclear cycle," where spent fuel is stored and ultimately destined for geological disposal. Because the United States does not have an operational permanent repository, most spent fuel remains in interim storage: on-site spent fuel pools and dry-cask facilities at reactor sites across dozens of states, and at major interim sites such as Hanford (Washington), Idaho National Laboratory (Idaho), Savannah River Site (South Carolina), and Fort St. Vrain (Colorado).[39] Interim storage allows reactors to continue operating and allows the industry to remain "open" to considering advanced fuel cycles or future disposal technologies. Some advanced reactor designs would also produce non-standard waste forms, such as chemically reactive crystallized salts or activated sodium, that current U.S. dry cask systems are not certified to store, leaving

The entrance of Yucca Mountain under construction in 2007. Credit: The U.S. Nuclear Regulatory Commission.

interim storage approaches for these fuels unresolved. Moreover, interim storage requires extensive security and monitoring measures, active cooling for its pools and ongoing maintenance. Prolonged storage also increases the risk of leaks and accidents, and therefore potential for exposure to local communities and wildlife.[40]

Nevada's Yucca Mountain was designated as the nation's permanent geologic repository for high-level nuclear waste under the Nuclear Waste Policy Act of 1982, but it never became operational due to technical concerns about the site's hydrologic and geologic stability, political opposition, public pushback, and concerns from Tribal nations, local communities, and environmental groups.[41] DOE has also not moved forward because the long-term safety of the site's geology remains unresolved,[42] showing a broader challenge of finding a waste solution that communities trust and that

meets scientific, cultural, and environmental standards. Its stalled status also forces the U.S. to rely on interim storage and reveals the sociopolitical barriers that continue to impede long-term nuclear waste management solutions.

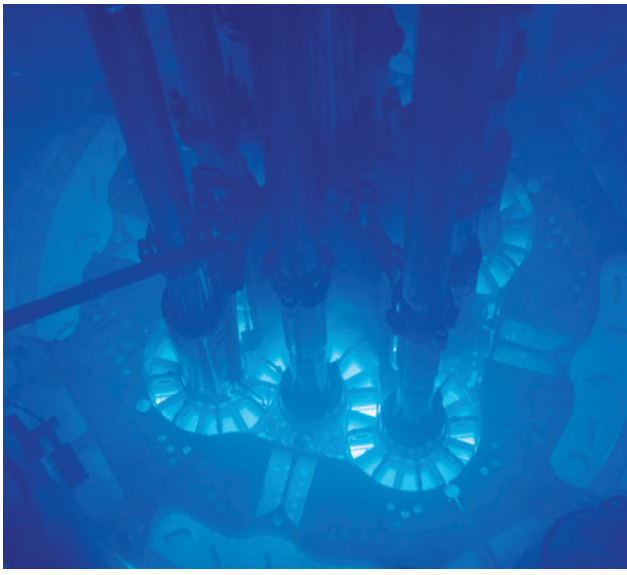
Operating a closed fuel cycle, as in France, Japan, Russia, and the United Kingdom, reduces the need for fresh uranium mining, lowers the volume of high-level waste, and recovers some energy remaining in spent fuel.[43] However, closed cycles also require routine chemical reprocessing of spent fuel, a step that introduces additional environmental, worker exposure, and proliferation risks that do not arise in once-through cycles. Historically, reprocessing plants have experienced more operational incidents and contamination problems than once-through reactor sites. For example, repeated leak and waste-management issues at the UK's Sellafield[44] complex and worker-exposure events at Japan's Rokkasho[45] plant. While technically feasible, implementing such a system in the U.S. would require substantial investment, strong regulatory oversight, and careful engagement with affected communities to address the environmental justice concerns and mitigate risks, particularly given the history of contamination at federal and commercial nuclear sites, like with legacy waste and leaks at Hanford[46] and Savannah,[47] and abandoned mines and leftover contamination on the Navajo Nation.[48]

No country currently operates a permanent repository for high-level commercial nuclear waste. Nations operating closed cycles combine interim storage with fuel recycling, recovering energy and reducing waste volume before permanent disposal. Finland[49] and Sweden[50] are among the few nations actively developing deep geological repositories, but even these have not yet received commercial spent fuel. In practice, this means that the U.S.'s open cycle is functionally similar to long-term interim storage. But unlike its closed cycle counterparts, it neither recovers energy nor reduces waste volume. Though, DOE efforts in advanced nuclear technologies are aiming to make productive use of this nuclear stockpile.

Recycling Nuclear Waste

DOE is the primary financier of spent fuel management projects through its Advanced Research Projects Agency-Energy (ARPA-E). Notable initiatives include:

- CURIE (Converting Used Nuclear Fuel Radioisotopes into Energy), a $38 million program launched in 2022 to develop technologies that recycle spent light-water reactor fuel (used fuel from light-water reactors that contains usable uranium and plutonium) into new nuclear fuel that can be used in advanced reactors.[51]



The Advanced Test Reactor at Idaho National Laboratory, which is used to support research on nuclear reactors around the world, including advanced reactor designs and tests of new nuclear fuels that reduce waste generation. Credit: Idaho National Laboratory.

- ONWARDS (Optimizing Nuclear Waste and Advanced Reactor Disposal Systems), a $40 million program announced in 2021 to reduce the volume, heat load, and storage of spent fuel.[52]

- NEWTON (Nuclear Energy Waste Transmutation Optimized Now), a 2025 initiative providing $40 million for 11 projects focused on reducing long-lived radioactivity and increasing recoverable fuel, with the goal of making domestic reprocessing economically viable within the next 30 years.[53]

Beyond these ARPA-E programs, national laboratories have played an outsized role in enabling recycling pathways. Idaho National Laboratory (INL), Argonne National Laboratory, Oak Ridge National Laboratory (ORNL), Fermilab, and others offer large and unique inventories of legacy spent fuel for research, pilot-scale facilities, advanced irradiation testing, and overall established reactor infrastructure that are hard to replicate commercially. Under the NEWTON program, Argonne and Fermilab are working to develop technologies that reduce waste radioactivity.[54] These national labs also collaborate via the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative, connecting DOE research infrastructure with private companies to accelerate advanced reactor and fuel cycle innovation.

Private firms are beginning to work with national labs and ARPA-E awards to demonstrate commercial concepts. Oklo, a Silicon Valley-backed nuclear energy startup, received an ARPA-E cost share award under CURIE and has been working with Argonne and INL on recycled fuel feedstock.[55] Building on this work, the DOE's Fuel Line Pilot Program—announced in June 2025—is developing domestic production lines that turn recycled and new nuclear materials into fuel for advanced reactors, helping move technologies from laboratory research to commercial-scale deployment.[56]

Advanced Nuclear: Impacts

In addition to the fuel-related impacts outlined above, advanced nuclear energy presents potential impacts to lands, water, and human and wildlife health.

Land Use

Advanced nuclear requires a much smaller land footprint compared to other energy sources including natural gas, other renewables, and conventional nuclear.[57] Advanced nuclear projects can range in size from micro reactors that fit inside of a semi truck (producing 2-50 megawatts)[58] to a small modular reactor requiring approximately 35 acres (producing 920 megawatts).[59] For context, a conventional nuclear plant producing 920 megawatts requires nearly 500 acres.[60] Utility-scale solar projects require between 5-7 acres of land per megawatt—requiring thousands more acres of land than an advanced nuclear project.[61] Solar facilities may also support dual use applications, such as agrivoltaics or pollinator habitat, depending on site design. Terrestrial wind energy may require up to 85 acres per megawatt but this can vary depending on location, and that land can be used for other purposes simultaneously.[62] While

advanced nuclear reactor sites themselves have relatively small physical footprints, total land impacts must also reflect upstream and downstream activities such as uranium mining, fuel processing, and waste storage.

The U.S. Nuclear Regulatory Commission (NRC) prefers to site conventional nuclear plants in areas with low population density to satisfy safety measures. It is likely that the NRC will prefer to site advanced reactors away from densely populated areas as well, although at least one city in Utah is looking to site a small nuclear power plant within city limits.[63] Siting options are also limited by seismic risk, local hydrology, and access to sufficient cooling water, which can significantly narrow the number of feasible locations for new reactors. The NRC also requires the development of emergency planning zones (EPZ). The size and shape of these zones vary from project to project based on geographical features and demographic information. There are two types of EPZs: a plume exposure pathway, which is the smaller zone closest to the reactor site, and an ingestion exposure pathway, which is larger and is more concerned about indirect exposure to radiation via contaminated food or water.[64] The 35-acre small modular reactor example above received NRC approval for a plume EPZ to be inclusive only of its 35-acre footprint.[65] This smaller EPZ was made possible through an NRC rulemaking that provides alternative emergency preparedness requirements for small modular reactors and other new technologies.[66] Some critics worry that this one-size-fits-all approach with such new and still-developing technology may not provide sufficient safety protections.

Advanced nuclear used for utility-scale power will also need to be connected to the U.S. electrical grid. While many advanced nuclear reactors proposed for coal-to-nuclear conversions will inherit interconnection rights,[67] they will not necessarily inherit adequate transfer capability, often requiring new or upgraded high-voltage lines to reliably deliver power to load centers without curtailment.

Water

Conventional nuclear power plants, and some advanced nuclear reactor designs, use water as a coolant to keep reactors running safely and effectively. This water demand may put stress on water-scarce regions, such as the western U.S. There are different cooling designs, each with different impacts on water use. One design is a “once through” cooling system, which is more common in conventional nuclear plants located near large water bodies. In this system, cool water from the nearby water source runs through pipes to help condense steam from the power

Japan’s Fukushima Dai-ichi nuclear complex in 2010, prior to the 2011 earthquake and tsunami that crippled the site. Credit: AP Photo/ Yomiuri Shimbun, Masamine Kawaguchi.

production process back into water. The water used to cool the steam is then pumped back into the nearby water body.[68] Discharging this water can have negative impacts on aquatic wildlife; it can alter water temperature by making it too warm, which can affect species survival, such as through impacts to fish spawning.[69] There are also dangers to fish and other wildlife during the water collection process as wildlife can get caught in water intake systems. All power plants, nuclear or otherwise, that use water-cooled systems face this challenge and must find ways to mitigate these harms to wildlife.

Many advanced nuclear designs include water-based cooling designs with closed loop systems. These systems take water, heat it either inside or outside the reactor, and use the steam generated to spin a turbine and generate electricity. In closed loop systems, the steam is then condensed back into water in cooling towers or by passing steam through a condenser. The process then repeats, limiting the amount of water required. Reactors can also run on water that is not safe for drinking. A conventional nuclear plant in Arizona, for example, uses water recycled from a sewage plant.[70]

Some advanced nuclear plant designs use non-water based coolants, including molten salt and helium.[71] The first demonstration-level molten salt reactor in the U.S. outside of a national lab is currently under construction at Abilene Christian University in Texas and will be operational by July 2026 or 2027.

After nuclear fuel has been used, the remnants are still very hot and must be stored to cool down and reduce the risk of radiation poisoning. This storage process can last as long as 15 years.[72] The fuel is sometimes stored in water-filled storage pools, which also increases demand for water, although the demand tends to be up-front and the pools do not need to be replenished frequently.

Potential contamination from nuclear fuel or waste leaching into water sources is a major concern. Japan's Fukushima Daiichi nuclear disaster in 2011 led to a large amount of radioactive materials escaping into the environment, impacting drinking water sources as far as 130 miles from where the meltdown occurred.[73] This disaster was the largest discharge of human-made radioactive material into marine ecosystems in history, and impacted marine life throughout the food chain for years.[74] It also halted the fishing industry in nearby communities for over a year.[75] The industry remained economically stunted for years after it was safe to consume fish, primarily because of public skepticism around food safety.[76] In the U.S. states like Washington, Idaho, New York, New Mexico, Utah, Texas and South Carolina are still contending with radioactive waste leaching into their water and broader environment from uranium mining or Cold War-era weapons production.[77] Additionally, climate change-fueled sea level rise and increased storm surge may be a concern for coastal reactors. While power plants have redundant levels of safety mechanisms to protect the reactors on site, it is worth considering the risk of a superstorm and storm surge overwhelming safety measures, leading to the discharge of hazardous materials. Cleanups following the discharge of these radioactive materials are resource- and time-intensive, and have life-changing impacts for people living even miles away from contaminated sites.

Human and Wildlife Health and Safety

When people think of safety risks from nuclear power, they may first think of large-scale nuclear meltdowns like Chernobyl or Fukushima. According to one study, there have been eight accidents since 1952 that have had some level of core-melting activities. Under normal operating circumstances, atoms split in a process called fission and this process produces heat. This heat then boils water, which creates steam, and spins a turbine to generate electricity. Coolant then flows through the system to cool the core and prevent overheating. Core melting activities happen when something disrupts the ability of the coolant to moderate the nuclear reaction. If the coolant is unable to cool the core a series of chain reactions causes the temperature inside the core to rise dramatically and can lead to different stages of meltdowns. Meltdowns can include the melting of the fuel rods, the protective casing around the core, and even the containment building. These meltdowns can lead to dangerous radioactive materials leaching into the environment causing catastrophic harm to people and the environment.

Not all of the eight accidents were large-scale disasters that affected communities surrounding the plants, but all were incidents severe enough to be reported to the International Atomic Energy Agency. In one study, the authors posit that given the number of reactors in the world in 2016 when the study was written (443) the probability of at least one core melt accident in the next 10 years is 69.8%. They also note, however, that given uncertainty levels this value could range from 27.8 to 95.3%.[78] It's worth noting that these statistics are from conventional nuclear facilities, not advanced nuclear. Since the systems that fall under the advanced nuclear umbrella are still in the design and development phase, more research will be needed to see how the updated safety and operation systems may impact these numbers.

A relevant safety distinction between conventional and advanced nuclear designs is that conventional plants' safety mechanisms are "active" meaning that they rely on electricity and are not integrated into the way the system operates independently. Advanced nuclear designs use "passive" safety measures, which are inherent to the design and do not require human or electrical intervention. If an advanced nuclear plant loses power, these passive safety systems use the laws of physics to keep the core cool and prevent damage to the fuel. These systems rely on things like gravity or the natural circulation of coolant to move heat away from the reactor core without the need for external power sources, pumps, or operator action.[79] Additionally, some advanced reactor coolants remain at atmospheric pressure, rather than operating in a pressurized environment, which can put less stress on reactor components.[80] Reactors that operate at atmospheric pressure require less complicated coolant design and safety systems. The extent to which these systems reduce existing risk and balance the additional risks from their novel designs will need to be researched further as more designs are released. The Union of Concerned Scientists says that there is little evidence that advanced nuclear designs will be significantly safer than conventional nuclear power plants.[81]

There are some concerns around advanced reactors with non-water coolants such as sodium, lead, or molten salt. Lead at high

temperatures can corrode structural steel, which would need to be addressed through additional research if these designs are to be commercialized, as some designs encase the reactor in a steel structure. Lead or lead-bismuth coolants can also generate activated polonium isotopes, which pose additional worker safety and maintenance hazards not present in water-cooled systems.[82] Additionally, molten salt cooled reactors would mix dissolved fuel into the coolant, which could pose an added safety concern for plant workers who would need to be protected from this higher level of radioactivity flowing through the system.[83] Coolants that are not transparent like water may also add challenges to visual monitoring and core inspection.

Concerns of radioactive materials from the plant itself leaching into the environment should be taken very seriously. High-level nuclear waste can remain radioactive for thousands of years and have devastating impacts for people and wildlife who are exposed to it directly or indirectly through things like water or dust. High doses of radiation exposure can lead to acute radiation syndrome, which can be life threatening and includes symptoms like skin burns, hair loss, nausea and vomiting, and the inability of tissues and organs to function or repair themselves.[84] Low doses of radiation over long periods of time can increase risk of cancer; prenatal exposure to radiation can lead to birth defects or miscarriage.[85] As stated above, the U.S. has a history of mismanaging radioactive materials, resulting in contaminated water and land and increased rates of conditions like lung and bone cancer in nearby communities.[86] This contamination occurs throughout the nuclear supply chain from uranium mining, along with improper disposal of radioactive materials after mining, milling, and fuel usage. This legacy of contamination, especially in marginalized communities, makes communities hesitant to support any nuclear power generation taking place nearby.

The grassroots organization Georgia Women Against Nuclear Development (WAND) collaborated with the University of Georgia's Savannah River Ecology Lab on their Radionuclide Education, Monitoring, and Outreach Program to conduct environmental sampling in a community near the Savannah River Site in Burke County, Georgia. The Savannah River Site was used to produce nuclear weapons during the Cold War and contributed to high levels of legacy groundwater contamination which continues to impact nearby communities. Today there is very little environmental monitoring conducted in Burke County, and Georgia WAND is using community-based science to help educate residents about legacy contamination.[87] The Burke County community is predominately Black and low income and this is not a coincidence. Underlying systems of racism and classism contribute to the siting of industrial sites, and nuclear is no exception.

Nuclear facilities also pose potential risks to people living nearby or working in the facility. Studies are mixed on determining whether living close to a nuclear facility increases cancer mortality.[88] A 1990 report from the U.S. National Institutes of Health concluded that cancer mortality rates were the same whether a reactor was nearby or not.[89] A more recent meta-analysis of research papers covering 136 nuclear sites from around the world, including some in the U.S., did find a statistically significant increase in childhood leukemia for children living near those nuclear sites.[90] In 2010, the National Academy of Sciences (NAS)

began a study to update that 1990 report, at the request of the NRC. NAS released a plan for a pilot study and recommendations to carry it out, but the work was abandoned in 2015 over concerns about cost, and after NRC staff determined data collected would have limited use in actually estimating the linkages between nuclear facilities and increased cancer risk.[91]

In a 2023 study of contemporary U.S. nuclear workers (over 10,000 people, largely hired after 1960), investigators reported "notable" increases in rates for all solid cancers, lung cancer and colon cancer. The study attributes this increase to better tracking and data, not increases in radiation, but notes that solid cancer risk is still very present despite contemporary workers being exposed to less ionizing radiation than older employees.[92] Additional studies from worker cohorts in France show other elevated, though statistically nonsignificant, rates of cancer in plant workers.[93]

It's also important to consider the security risks of having large stockpiles of nuclear fuel and materials and the implications for nuclear proliferation. While facilities may be constructed with the intent to produce energy, there is a fear from nuclear disarmament advocates that these facilities could, in theory, be used to produce nuclear weapons in the future. Advanced reactor fuel cycles, including HALEU production and plutonium-bearing or molten salt fuels, also re-engage enrichment and reprocessing steps rooted in militarized supply chains, raising dual-use and proliferation concerns that extend beyond today's low-enriched uranium fuel.

Wildlife-specific risks from conventional nuclear include impacts of hazardous pollution from uranium mining sites or leaching of radioactive materials from power plants into the environment, along with avian collisions with cooling structures. According to one study, uranium milling and mining can poison thousands of birds per facility per year.[94] As mentioned in the mining section above, pit lakes at uranium mines have deadly consequences to aquatic wildlife. Birds can also collide with nuclear power plants or cooling towers, leading to injury and death. According to one study, collisions with nuclear infrastructure can kill anywhere from several hundred to several thousand birds annually depending on the size of the nuclear facility.[95] While not insignificant, it's worth noting that avian collisions with buildings are estimated to kill over 1 billion birds annually in the U.S.[96] Further research is needed to understand risks to wildlife from advanced nuclear facilities.

Most advanced nuclear reactors are in the design phase; operational safety systems are yet to be fully established and approved. In time, more concerns may emerge and others may be solved, but more research is required to fill these knowledge gaps.

Relevant Regulations

Regulating a nuclear power plant is a rigorous process—as it should be. Existing permitting processes and regulations aim to minimize the risk of nuclear accidents that could have catastrophic impacts on communities and wildlife. According to one report from an advanced nuclear company that received approval for their demonstration project (i.e., not commercial scale) the approval process took over 1,000 hours of labor over two years.[97] Recent cuts to the federal workforce have put additional strain on an already limited set of technical staff at NRC, which may add a structural barrier for future project approval processes along with eventual nuclear reactor decommissioning.

The NRC and other state regulators have extensive environmental and safety programs that all nuclear facilities, including advanced nuclear projects, are required to follow. Nuclear power plants use a safety approach to prevent and mitigate accidents called Defense-In-Depth. This strategy uses multiple independent and redundant layers of safety measures that compensate for human or mechanical failures, so that one single safety measure is never solely relied on. Measures include use of access controls, physical barriers, a variety of redundant and diverse safety functions, and emergency response measures.[98]

During normal operation of a nuclear facility, small amounts of radiation are released. The limits of these releases are strictly monitored and enforced by the U.S. Environmental Protection Agency (EPA) and the NRC. The amount of radiation released has decreased over the last 30 years, according to the NRC, primarily due to improved reactor fuel performance and waste handling. For context, the federal limit of radiation discharge to the public from a nuclear plant is 25 millirem annually, but the average dose to the public from living near a facility is much lower. The NRC estimates it to be 0.001 millirem per year.[99] For comparison, one chest x-ray releases approximately 10 millirem of radiation.[100]

Facilities are also constantly tracking their radiation discharge levels. Monitoring practices include monitoring radioactivity releases that occur during normal plant operations and accounting for any pathway that could lead to radiation leeching into the environment. They also monitor surrounding air, water (ground and surface), land, locally grown produce, fish living in nearby water sources, and locally produced milk from dairy farms to verify that the actual levels in the environment match what their internal monitoring systems report.[101] This dual monitoring practice serves as a check on each monitoring system. Additionally, independent laboratories test external samples that could be linked to the nuclear facility.

Federal and state regulators also provide regulatory oversight of all nuclear plant environmental monitoring programs. The NRC has an inspector at all nuclear energy facilities; monitoring reports are submitted to the NRC annually and are made publicly available on the NRC's website.[102] Additionally, many state environmental or public health related departments conduct their own monitoring, sampling, and testing programs to ensure safety for surrounding communities and habitats.

Congress and the NRC are working to update regulations that take advanced nuclear designs into account. The ADVANCE Act, which was signed into law in 2024, requires the NRC to take a number of actions specifically around enhancing the regulatory framework for advanced reactors and requiring the NRC to implement systems to review applications for these new designs.[103] The NRC is currently working on a proposed rule called the Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors; a draft is expected by spring 2026 with the final rule issued no later than the end of 2027.[104] This rule establishes an optional technology-inclusive regulatory framework for applicants looking to license commercial advanced nuclear reactors. The methods included in the framework are flexible and are applicable to a variety of advanced nuclear reactor technologies.[105]

Nuclear projects in the U.S. operate under the Price-Anderson Act, which limits industry liability for nuclear accidents and provides a federal backstop for damages above a statutory cap. This framework was recently extended through 2065 and will apply to advanced and small modular reactors as they are licensed, establishing accident liability and financial risk allocation ahead of large-scale deployment of these relatively nascent technologies.[106]

As referenced above the Trump administration has eliminated thousands of federal jobs; the NRC has not been spared from these cuts. In a May 2025 executive order, the administration called for a restructuring of the NRC to "promote the expeditious processing of license applications and the adoption of innovative technology. The NRC shall undertake reductions in force in conjunction with this reorganization."[107] Severe staffing reductions across the federal government—along with attempts to politicize civil service positions and hinder access to reliable scientific data and resource management—have weakened, and in some cases eliminated entirely, crucial staffing and programs that advance conservation, economic development, public health and safety, and more. This context is not unique to the NRC and may well impact the agency's ability to work effectively and independently.[108]

That same 2025 executive order also called for a reform and modernization of NRC regulations, and for DOE and the Department of Defense to apply established categorical exclusions under the National Environmental Policy Act (NEPA) for the construction of advanced nuclear reactor technologies on certain federal sites. DOE announced those exemptions in a proposed rule in the federal register in late January 2026, which proposes to exempt the "authorization, siting, construction, operation, reauthorization, and decommissioning of advanced nuclear reactors" from an environmental impact statement or environmental assessment under NEPA. In a statement DOE said it is "establishing the potential option to obtain a streamlined approach for advanced nuclear reactors as part of the environmental review performed under NEPA. The analysis on each reactor being considered will be informed by previously completed environmental reviews for similar advanced nuclear technologies."

Also in late January 2026, National Public Radio (NPR) broke news that the Trump administration had secretly rewritten nuclear safety rules.[109] NPR obtained copies of over a dozen new orders, none of which were made available to the public, that slashed hundreds of pages of safety and security requirements for advanced nuclear reactors. The orders loosen environmental protection for groundwater, cut record-keeping requirements, and raise the amount of radiation a worker can be exposed to before an official accident investigation is required. This development raises serious doubts about nuclear safety standards at the federal level and reinforces concerns around the NRC's ability to function as an independent regulatory body. Transparency between the public and regulatory bodies is vital for a functioning civil society. The Trump administration's proclivity for shortcutting safety mechanisms in secret undermines community and environmental safety and will only erode trust in public institutions.

Government Investments in Advanced Nuclear

Federal Government

DOE launched two pilot programs in the summer of 2025 to accelerate the development of advanced nuclear reactors and strengthen domestic supply chains for nuclear fuel.[110] It also launched a new reactor pilot program in June 2025 to expedite the testing of advanced nuclear reactor designs that DOE may approve in the future. The program will elevate reactors that have a reasonable chance to operate by 2026. This federal momentum has been spurred by the U.S.'s increased need for energy along with several Executive Orders from the Trump administration: one in January 2025 declaring a national energy emergency, and one from May 2025 calling for the prioritization of advanced nuclear innovation and to bring advanced nuclear technologies "into domestic production as soon as possible."[111] Currently the U.S. has one power plant with an advanced lightwater reactor operating but no non-lightwater reactors in operation. DOE hopes to have the projects in their pilot programs operating by July 2026. There is also a bipartisan Senate bill, the Nuclear REFUEL Act of 2025, that will create regulatory pathways for recycling spent nuclear fuel and would streamline the authorization of recycling centers to reduce spent nuclear fuel that would otherwise need to be stored.

Advanced Nuclear for Data Centers

Rapid growth in data centers and artificial intelligence has significantly increased electricity demand, intensifying concerns about grid reliability, emissions, and long-term capacity planning. Policymakers and energy planners have begun evaluating whether advanced nuclear technologies could play a role in meeting this demand alongside renewable energy and storage.

Unlike variable renewable resources such as wind and solar, nuclear generation can provide continuous, dispatchable power. Proponents argue this characteristic could make advanced reactors relevant for energy-intensive facilities, including data centers, that require high reliability and consistent power supply while pursuing decarbonization goals. In January 2026 Meta struck agreements to buy power from three Vistra nuclear plants and plans to help Oklo and Terrapower develop small modular reactors.[112] While these developments do not represent widespread deployment, they signal growing engagement between the data center and nuclear energy industries amid rising electricity demand from artificial intelligence.

At the federal level, recent policy actions indicate renewed government interest in expanding domestic nuclear policy. Any proposed nuclear development on or affecting Tribal lands is governed by the U.S. government's federal Indian trust responsibility with Tribal Nations, which requires meaningful consultation with Tribes prior to project approval or development.[113] Federal policies mandate that Tribal Nations be engaged early in decision-making processes, particularly for projects with potential impacts on Tribal lands, resources, or cultural sites. Many Tribes emphasize adherence to Free, Prior, and Informed Consent (FPIC)[114] principles when evaluating large-scale energy infrastructure.

In October 2025, the Trump administration announced an $80 billion partnership with Westinghouse Electric to support new nuclear reactor development,[115] signaling a shift toward large-scale investment-based approaches rather than reliance on federal grants alone. While this approach could accelerate advanced reactor deployment, critics warn that without strong safeguards, including robust Tribal consultation and consent processes, it risks externalizing financial, environmental, and social costs onto taxpayers and Indigenous communities if projects fail or generate long-term harm.[116]

States

States with large industrial economies where industry consumes around 50% of their energy demand are looking into advanced nuclear to help meet their energy needs.[117] Over the past decade, several states lifted bans on nuclear projects[118] and an even larger number of states have joined the Advanced Nuclear First Mover Initiative, a coalition led by the National Association of State Energy Officials (NASEO). Launched in February 2025, the Advanced Nuclear First Mover Initiative's objective is to accelerate advanced nuclear commercialization, reduce production costs, and mitigate safety risks by streamlining permitting regulations, improving private-public partnerships, and developing improved developmental policies.

Included in the Advanced Nuclear First Mover Initiative are Indiana, Kentucky, Louisiana, Maryland, New York, Pennsylvania, Tennessee, Utah, Virginia, West Virginia, and Wyoming. They are in the early stages of exploring advanced nuclear technologies via feasibility studies, permitting updates, workforce development programs, and sector-to-industry partnerships.[119] These states represent energy-legacy and coal-transition economies where the deployment of advanced nuclear energy can offer transferability for coal workers and promote stable tax revenue. Coal power plant sites are very promising for repurposing infrastructure towards advanced nuclear energy, especially with small modular reactors (SMRs). SMRs can be sited on former coal plant sites because of existing grids and transmission lines, as well as a workforce with transferable skills.[120] There are environmental, and environmental justice, concerns about the implications of citing new infrastructure in the same location of existing or former polluting industries. Some of these were raised in January 2025 during a NRC public meeting on implementation of the ADVANCE Act, including: further concentration of industrial infrastructure in low-income communities and communities of color; weakened safety oversight, as ADVANCE emphasizes "timely and predictable" licensing that may create pressure to accelerate regulatory review; legacy contamination risks like coal ash, heavy metals, groundwater pollution, and unstable soils; and limitations on public participation and transparency in the licensing process.[121]

Conclusion

Growing industrial and political interest in advanced nuclear energy will demand more investment in research and rigorous assessment of feasibility, safety, and regulatory frameworks. As deployment expands, policymakers must evaluate the entire nuclear fuel cycle to ensure that technological development and governance keep pace at every stage.

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