United States Government Accountability Office

Report to Congressional Requesters

April 2024

# NUCLEAR POWER PLANTS

# NRC Should Take Actions to Fully Consider the Potential Effects of Climate Change

GAO-24-106326

GAO Highlights

Highlights of GAO-24-106326, a report to congressional requesters

April 2024

# NUCLEAR POWER PLANTS

## NRC Should Take Actions to Fully Consider the Potential Effects of Climate Change

## Why GAO Did This Study

NRC licenses and regulates the use of nuclear energy to provide reasonable assurance of adequate protection of public health and safety, to promote the common defense and security, and to protect the environment. Like all energy infrastructure, nuclear power plants can be affected by disruptions from natural hazards, some of which are likely to be exacerbated by climate change. Most commercial nuclear plants in the United States were built in the 1960s and 1970s, and weather patterns and climate-related risks to these plants have changed since their construction.

GAO was asked to review the climate resilience of energy infrastructure. This report examines (1) how climate change is expected to affect nuclear power plants and (2) NRC actions to address risks to nuclear power plants from climate change. GAO analyzed available federal data and reviewed regulations, agency documents, and relevant literature. GAO interviewed officials from federal agencies, including NRC, the Department of Energy, and the National Oceanic and Atmospheric Administration, and knowledgeable stakeholders from industry, academia, and nongovernmental organizations. GAO also conducted site visits to two plants.

## What GAO Recommends

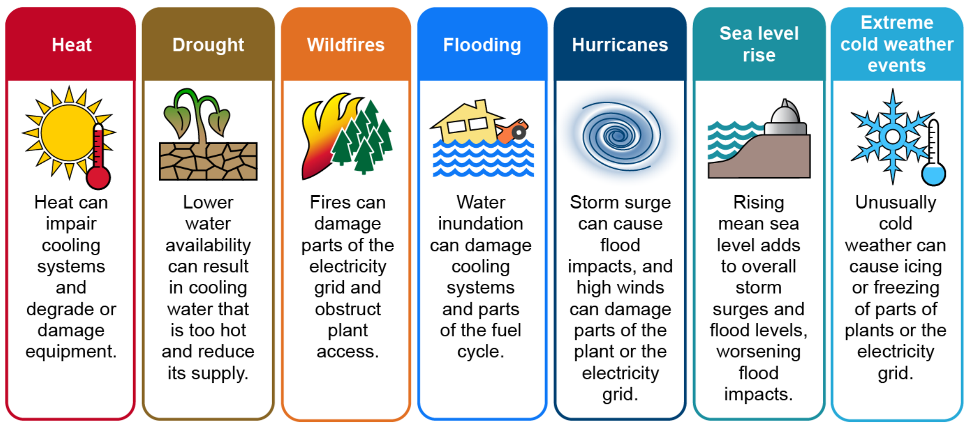
GAO is making three recommendations, including that NRC assess whether its existing processes adequately address climate risks and develop and implement a plan to address any gaps identified. NRC said the recommendations are consistent with actions that are either underway or under development.

View GAO-24-106326. For more information, contact Frank Rusco at (202) 512-3841 or ruscof@gao.gov.

## What GAO Found

Climate change is expected to exacerbate natural hazards—including heat, drought, wildfires, flooding, hurricanes, and sea level rise. In addition, climate change may affect extreme cold weather events. Risks to nuclear power plants from these hazards include loss of offsite power, damage to systems and equipment, and diminished cooling capacity, potentially resulting in reduced operations or plant shutdowns.

**Examples of Natural Hazards that May Pose Risks to Nuclear Power Plants**




Sources: Nuclear Regulatory Commission documents; summary of literature; GAO (icons). | GAO-24-106326

The Nuclear Regulatory Commission (NRC) addresses risks to the safety of nuclear power plants, including risks from natural hazards, in its licensing and oversight processes. Following the tsunami that led to the 2011 accident at Japan's Fukushima Dai-ichi nuclear power plant, NRC took additional actions to address risks from natural hazards. These include requiring safety margins in reactor designs, measures to prevent radioactive releases should a natural hazard event exceed what a plant was designed to withstand, and maintenance of backup equipment related to safety functions.

However, NRC's actions to address risks from natural hazards do not fully consider potential climate change effects. For example, NRC primarily uses historical data in its licensing and oversight processes rather than climate projections data. NRC officials GAO interviewed said they believe their current processes provide an adequate margin of safety to address climate risks. However, NRC has not conducted an assessment to demonstrate that this is the case. Assessing its processes to determine whether they adequately address the potential for increased risks from climate change would help ensure NRC fully considers risks to existing and proposed plants. Specifically, identifying any gaps in its processes and developing a plan to address them, including by using climate projections data, would help ensure that NRC adopts a more comprehensive approach for assessing risks and is better able to fulfill its mission to protect public health and safety.

# Contents

## Abbreviations

| | |
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| FLEX | Diverse and Flexible Coping Strategies |
| NCA | National Climate Assessment |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | Nuclear Regulatory Commission |
| POANHI | Process for the Ongoing Assessment of Natural Hazard Information |
| SAFER | Strategic Alliance for FLEX Emergency Response |

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
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April 2, 2024

The Honorable Joe Manchin III
Chairman
Committee on Energy and Natural Resources
United States Senate

The Honorable Tom Carper
Chairman
Committee on Environment and Public Works
United States Senate

Since 1990, nuclear energy has accounted for about 20 percent of the electricity generated in the United States. In 2022, nuclear energy provided nearly half of our nation's carbon-free electricity, making it the largest domestic source of carbon-free energy. Nuclear power plants emit no carbon dioxide during operations and, unlike many sources of renewable energy, typically operate around the clock, producing on average above 90 percent of their generating capacity.

However, nuclear power plants can be affected by natural hazards—including heat, drought, wildfires, flooding, hurricanes, sea level rise, and extreme cold weather events—some of which are expected to be exacerbated by climate change, with effects varying by region. Most commercial nuclear power plants in the United States were licensed and built in the 1960s and 1970s, and the risks to plants' safety and operations from natural hazards have changed since their construction.

The Nuclear Regulatory Commission (NRC) is responsible for regulating the civilian use of radioactive materials to promote the nation's common defense and security, provide reasonable assurance of adequate protection of public health and safety, and protect the environment. As electricity demand in the United States is expected to continue to grow over the coming decades, Congress and others are turning to nuclear power as one means of meeting the increased demand while reducing carbon emissions. For example, in recent years, Congress has provided incentives for the continued operation of existing nuclear power plants and for the construction of new plants, which, if licensed, could operate into the next century.[1]

You asked us to review the climate resilience of energy infrastructure. This report focuses on nuclear power plants' resilience to climate change and examines (1) how climate change is expected to affect nuclear power plants and (2) what actions NRC has taken to address the risks to nuclear power plants from climate change.

To address both objectives, we interviewed officials from NRC headquarters and its four regional offices, NRC resident inspectors, and officials from the Department of Energy—including the Office of Nuclear Energy and the Idaho National Laboratory—the Federal Energy Regulatory Commission, the Federal Emergency Management Agency, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Forest Service. In addition, we interviewed a nongeneralizable sample of nine stakeholders knowledgeable about nuclear power plant operations and safety, climate change, and resilience measures. We also visited two selected nuclear power plants—Palo Verde Nuclear Generating Station in Buckeye, Arizona, and Turkey Point Nuclear Generating Station in Homestead, Florida—and interviewed plant staff and NRC resident inspectors at these plants. We selected these plants because of their exposure to a variety of natural hazards that may be exacerbated by climate change and regional diversity. Findings from selected stakeholder interviews and site visits are not generalizable to all stakeholders and sites.

To examine how climate change is expected to affect nuclear power plants, we conducted a literature review of articles and reports related to the effects of climate change on nuclear power plants. On the basis of this method, we identified and used 36 articles to support the findings in our report. We also reviewed the fourth and fifth U.S. Global Change

[1]NRC has efforts underway to support the licensing of advanced nuclear reactors—nuclear fission reactors that may offer significant improvements over the most recent generation of nuclear fission reactors and may involve first-of-a-kind designs—which, according to NRC officials, contribute to climate resilience by supporting an alternative to fossil-fuel-based power plants. For more information on NRC's licensing of advanced nuclear reactors, see GAO, *Nuclear Power: NRC Needs to Take Additional Actions to Prepare to License Advanced Reactors,* GAO-23-105997 (Washington, D.C.: July 27, 2023).

Research Program's National Climate Assessments (NCA),[2] federal data on natural hazards, and prior GAO reports.

Additionally, we identified and obtained national-level data sets from relevant federal agencies for six of the seven natural hazards identified by the NCA and our literature review as likely to be exacerbated by climate change: extreme heat, extreme cold, wildfires, flooding, storm surge from hurricanes, and sea level rise.[3] For heat, cold, and sea level rise, we used data that are based on climate scenarios. For heat and cold, we analyzed the projected exposure of nuclear power plants to those hazards.[4] For wildfires, hurricane storm surge, and flooding, we used data that are based on current and past conditions.[5] We assessed the reliability of the data sources used and found the data to be sufficiently reliable for the purposes of our reporting objectives. For more detailed information on our scope and methodology, and the steps we took to assess the reliability of the data used in this report, see appendix I. For more detail on data sources used in this report, see appendix II.

In addition, we obtained NRC data on the location of all 54 operating U.S. nuclear power plants as well as on the 21 shutdown nuclear power plants

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[2]U.S. Global Change Research Program, *Fifth National Climate Assessment*, (Washington, D.C.: 2023); U.S. Global Change Research Program, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, vol. II (Washington, D.C.: 2018).

[3]To identify and select national-level data sets, we used information from the NCA. The fifth NCA was released on November 14, 2023, after we had obtained and analyzed the hazard data sets. We reviewed relevant sections from the fifth NCA and did not identify major differences in the predicted or projected trends for the selected natural hazards. We did not analyze drought data because we were unable to identify national-level geospatial data that was both relevant to nuclear power plants and sufficiently reliable for our purposes.

[4]To analyze projected exposure to heat and cold hazards, we used data from the fourth NCA on the projected exposure to maximum and minimum temperatures by the midcentury (i.e., 2036–2065). We selected data using the projected change by the midcentury time frame under both a low- and high-emission scenario to show the range of potential projected change to selected natural hazards. The midcentury time frame was selected because it captures potential hazard effects during the period in which most U.S. nuclear power plants are likely to remain operational.

[5]To analyze exposure to floods, we used 2023 data from the Federal Emergency Management Agency that categorize flood exposure as a high, moderate, minimal, other, or unknown flood hazard. To analyze exposure to hurricane storm surge, we used NOAA data on storm surge exposure from Category 1 hurricanes (the lowest possible category) and Category 4 or 5 hurricanes (the highest possible categories) to show a range of potential climate change effects. To analyze exposure to wildfires, we used 2023 data from the U.S. Forest Service on wildfire hazard potential.

that have spent nuclear fuel stored onsite in spent fuel pools or in dry cask storage.[6] We analyzed these data using mapping software to identify nuclear power plants located in areas that may be affected by selected natural hazards. We determined that the data were sufficiently reliable for the purposes of our reporting objectives.

To examine NRC's actions to address risks to nuclear power plants from climate change, we reviewed relevant laws and regulations; agency guidance and documents, including NRC's 2022–2026 Strategic Plan; NRC office instructions; and the NRC inspection manual on adverse weather protection.[7] We also reviewed GAO's *Standards for Internal Control in the Federal Government*.[8]

We conducted this performance audit from November 2022 to April 2024 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

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[6]When a company decides to shut down a nuclear power plant permanently, the facility must be decommissioned by safely removing it from service and reducing residual radioactivity to a level that permits release of the property and termination of the operating license. NRC regulates the decommissioning a nuclear power plant and any spent nuclear fuel that will remain on site. See 10 C.F.R. pt. 20, subpt. E; 10 C.F.R. §§ 50.75, 50.82, 51.53, 51.95. For the purposes of this report, we use the term "shutdown" to refer to plants at various stages of decommissioning, including those in the process of decommissioning and those already decommissioned, with spent nuclear fuel stored onsite. Spent nuclear fuel is the fuel that has been removed from commercial nuclear power reactors after it has been used to produce electricity. Spent nuclear fuel is initially stored immersed in pools of water designed to cool and isolate it from the environment. Water circulates in the pools to remove the heat generated from the radioactive decay. Industry practice has been to store the spent nuclear fuel in these pools for at least 5 years or until the fuel has cooled enough to be transferred to dry cask storage. Dry cask storage consists of a steel canister that holds the fuel assemblies, protected by an outer cask made of steel and concrete designed to cool the fuel and provide shielding from its radiation. We also obtained data on the location of the two Strategic Alliance for FLEX Emergency Response (SAFER) centers that maintain emergency equipment that can be provided to plants as a backup to the plants' onsite primary backup equipment.

[7]NRC, *Strategic Plan Fiscal Years 2022-2026,* NUREG-1614, Vol. 8 (Washington, D.C.: April 2022). See also, NRC, *Inspection Manual: Adverse Weather Protection,* Inspection Procedure 71111, Attachment 01 (Washington, D.C.: Jan. 1, 2018).

[8]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: Sept. 10, 2014).

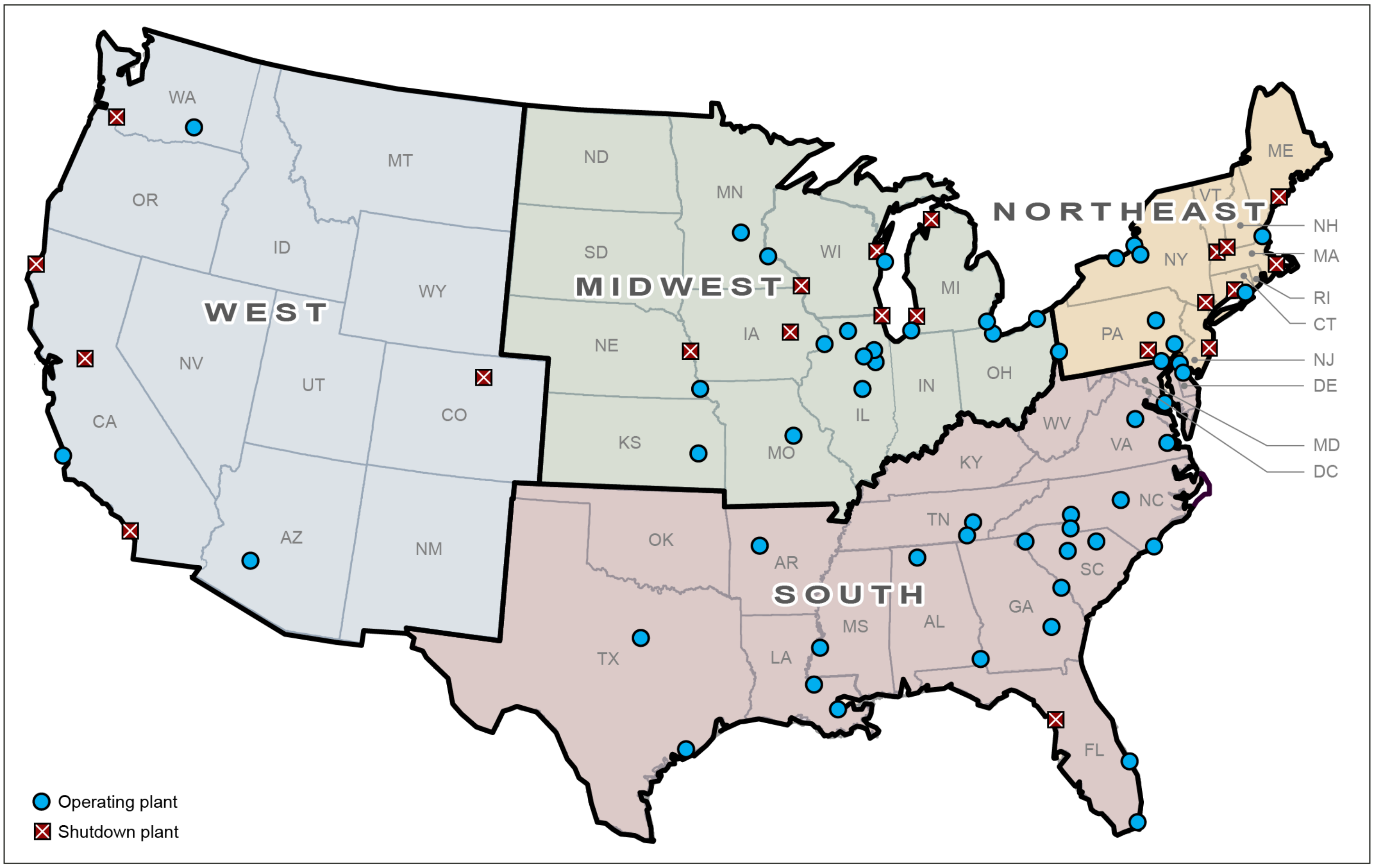
# Background

## The Nuclear Power Industry and U.S. Plant Operations

Private companies own nearly all nuclear power plants in the United States. As of August 2023, the United States had 93 operating commercial nuclear reactors with an average age of about 42 years old, according to the U.S. Energy Information Administration. These reactors are located at 54 nuclear power plants in 28 states.[9] In addition, as of July 2023, there were 21 shutdown plants that have spent nuclear fuel stored onsite in spent fuel pools or in dry casks. See figure 1 for the locations and regions of operating and shutdown nuclear power plants by U.S. Census region.

[9]According to the U.S. Energy Information Administration, nuclear reactors are machines that contain and control nuclear chain reactions while releasing heat at a controlled rate. A nuclear power plant uses the heat that a nuclear reactor produces to turn water into steam, which then drives turbine generators that generate electricity.

**Figure 1: Map of Operating and Shutdown Nuclear Power Plants by U.S. Census Region**




Sources: GAO analysis of U.S. Census Bureau and Nuclear Regulatory Commission data; U.S. Census Bureau (map). | GAO-24-106326

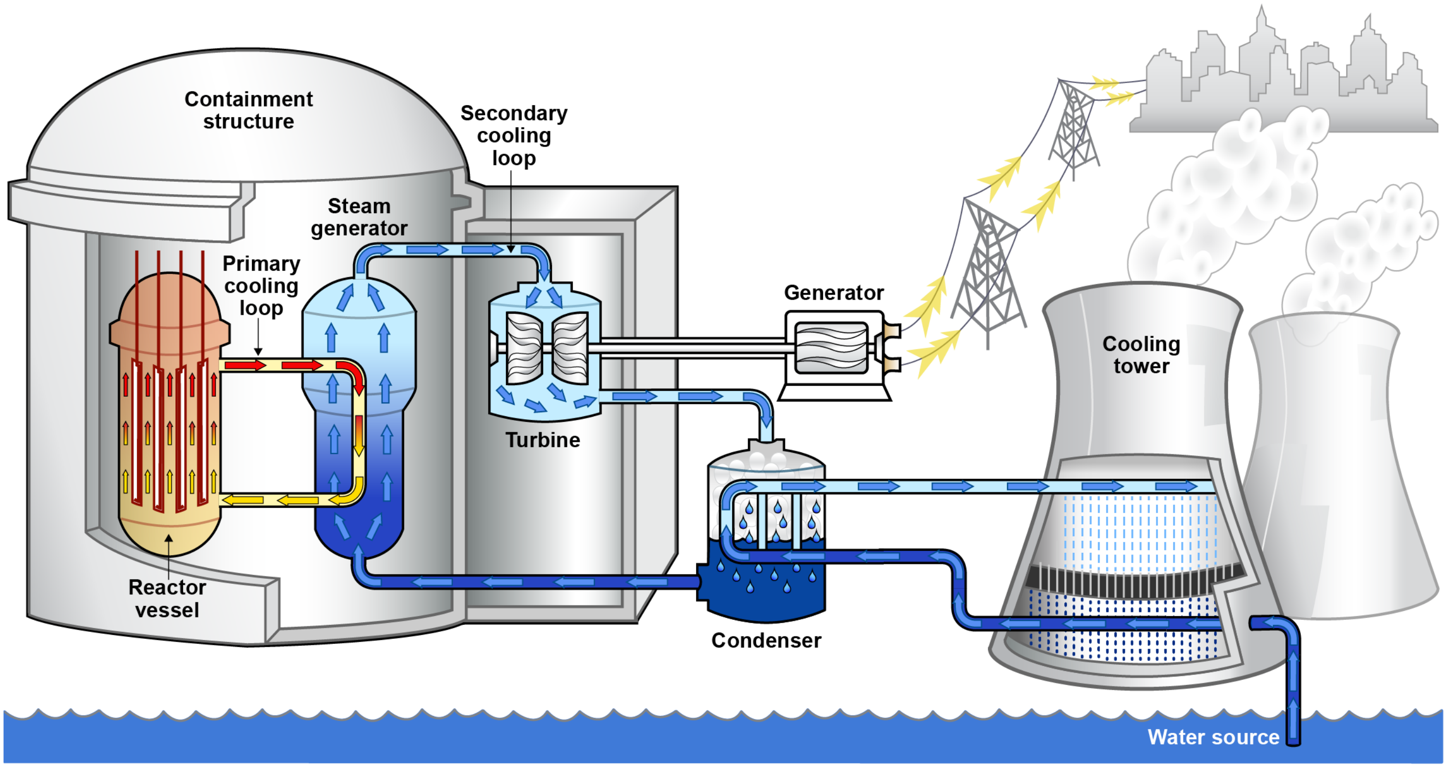
Note: This map includes 75 U.S. nuclear power plants—54 operating plants and 21 shutdown plants with spent nuclear fuel onsite.

Nuclear reactors rely on technologies to initiate and control chain reactions that produce heat through a physical process called fission—whereby atoms are split to release energy. All commercial nuclear power reactors in the United States use uranium as fuel and are light water reactors, which means they use water as both a coolant and moderator to serve critical safety and operations functions.[10] Nuclear power plants use water during normal operations to absorb the heat that is left over after making electricity and to cool the equipment and buildings used in generating that electricity. In the event of an accident, nuclear power plants also need water to remove the heat produced by the reactor core, even when it is temporarily shut down. Water is also used to cool spent fuel once it is removed from the reactor core. Because light water reactors rely on water for key safety and operational functions, nuclear power plants are typically located next to lakes, rivers, or oceans.

There are two types of light water reactors in the United States—pressurized water reactors and boiling water reactors. Pressurized water reactors, the predominant type of light water reactor in the United States, use steam generators to transfer the heat created by fission from the primary coolant loop to the secondary coolant loop, creating steam in the secondary loop that spins a turbine and generates electricity. Boiling water reactors, which constitute a third of the operating reactors in the United States, do not use steam generators or have secondary loops. Instead, the steam is generated directly inside the reactor vessel. See figure 2 for an overview of a nuclear power plant's components for a pressurized water reactor.

[10]The commercial nuclear power reactors currently operational in the United States are known as "light water reactors," meaning reactors that use ordinary water to cool and moderate the reactor, as opposed to heavy water, which contains deuterium, an isotope of hydrogen.

**Figure 2: Nuclear Power Plant Components and Operations for a Pressurized Water Reactor**




Sources: GAO illustration and analysis of Department of Energy and Nuclear Regulatory Commission documentation. | GAO-24-106326

Note: This illustration depicts a pressurized water reactor, the predominant reactor type in the United States. Boiling water reactors, which constitute a third of the operating reactors in the United States, do not use steam generators or have secondary loops. Boiling water reactors boil water directly inside the reactor vessel to produce steam.

To operate the cooling pumps and other systems that manage the water that reactors rely on for key safety and operational functions, nuclear plants need a reliable source of power. Nuclear power plants typically rely on the electricity grid to which the plant is connected for offsite power.[11]

[11]As we reported in 2021, climate change is expected to affect every aspect of the electricity grid—from generation, transmission, and distribution, to demand for electricity. We found that power outages can have significant cascading effects on critical sectors and electric service disruptions can significantly affect the reliability of other parts of the energy sector. These losses are of special concern because outages caused by climate effects can be widespread and affect large geographic areas all at once, according to the Department of Energy. GAO, *Electricity Grid Resilience: Climate Change Is Expected to Have Far-Reaching Effects and DOE and FERC Should Take Actions,* GAO-21-346 (Washington, D.C.: March 5, 2021).

However, if a plant loses access to offsite power, it must rely on backup power sources, such as diesel generators, to power cooling pumps. The loss of power and ability to pump cooling water can have a significant adverse impact on a plant's ability to safely shut down and maintain safe shutdown conditions. This could result in damage to a reactor's core and potentially release radiological material into the environment.

## NRC's Role

NRC is an independent federal agency, headed by five commissioners, responsible for permitting the construction and licensing of commercial nuclear power reactors and regulating and overseeing their security and safe operation.[12] NRC can issue a license to operate a nuclear power reactor for up to 40 years and can renew a license for up to 20 additional years. A renewed license may be subsequently renewed for up to another 20 years, allowing a reactor to operate for up to a total of 80 years. As of December 2023, NRC had issued subsequent license renewals for six reactors at three nuclear power plants in the United States.[13] Spent nuclear fuel may remain onsite long after a plant shuts down.[14]

As part of NRC's process for issuing construction permits and licenses for nuclear power plants, agency staff conduct safety and environmental reviews. As part of the safety review, NRC reviews a plant's design to ensure it meets the technical specifications required for the safe operation of the plant. Specifically, NRC's reactor design criteria require that important safety systems, structures, and components are designed to withstand the effects of natural hazards, including climate-related hazards

[12]NRC's mission is to regulate the civilian use of radioactive materials, to provide reasonable assurance of adequate protection of public health and safety, to promote the common defense and security, and to protect the environment. As such, any new requirements that the agency imposes on commercial nuclear plants must meet this standard, according to NRC officials.

[13]NRC issued subsequent license renewals to Turkey Point Units 3 and 4 in December 2019; Peach Bottom Units 2 and 3 in March 2020; and Surry Units 1 and 2 in May 2021.

[14]The United States does not have a consolidated storage facility or repository where plants can send their spent fuel during operations or after a plant shuts down. GAO, *Commercial Spent Nuclear Fuel: Congressional Action Needed to Break Impasse and Develop a Permanent Disposal Solution,* GAO-21-603 (Washington, D.C.: Sept. 23, 2021).

such as hurricanes and floods, without losing the ability to perform their safety functions.[15]

License applicants are responsible for ensuring their plants are protected against natural hazards by assessing the hazards that may affect their plants and designing the plants to withstand those hazards. NRC is responsible for reviewing plant and reactor designs and comparing the design limits for natural hazards with those found in applicants' hazard assessments, which consider the characteristics of the plant's geographic location. Once a nuclear power plant is licensed and operational, NRC conducts regular inspections of the plant's systems and ensures that the licensee is operating in accordance with its license. If a plant experiences external conditions that exceed the limiting conditions for operation, the licensee is required to either shut the reactor down, take remedial actions as permitted in its license, or request a license amendment or enforcement discretion from NRC to continue operations.[16]

NRC also regulates the decommissioning of nuclear power plants, which means safely removing nuclear power plants from service by reducing residual radioactivity to a level that permits the release of the property and termination of the license.[17]

## NRC's Regulatory Approach

NRC uses conservatism, safety margins, and defense-in-depth to implement regulatory requirements for the design, construction, maintenance, operation, and decommissioning of nuclear power plants to prevent and mitigate accidents that could release radiation or hazardous

[15]10 C.F.R. Part 50, Appendix A, General Design for Nuclear Power Plants, Criterion 2—*Design Bases for Protection Against Natural Phenomena*. According to an NRC document, all currently operating reactors were licensed to meet the intent of the General Design Criteria, which include General Design Criterion 2. See also 10 C.F.R. §§ 50.34, 52.79 (detailing safety analysis and design requirements for a license application).

[16]Limiting conditions for operation are the lowest functional capability or performance levels of equipment required for safe operation of the plant. 10 C.F.R. § 50.36(c)(2)(i). If the limiting conditions are exceeded by an extreme weather event, licensees can request the following from NRC: a temporary enforcement discretion for a brief period to allow them to continue operating despite the exceedance; a temporary license amendment to revise the limiting conditions for a specified period (e.g., 1–3 months); or a permanent license amendment to change the technical specifications.

[17]The NRC ensures that safety requirements are being met throughout the decommissioning process by reviewing decommissioning or license termination plans, conducting inspections, monitoring to ensure that radioactive contamination is reduced or stabilized, and issuing permits for spent nuclear fuel that will remain on site after license termination. See 10 C.F.R. pt. 20, subpt. E; 10 C.F.R. §§ 50.75, 50.82, 51.53, 51.95.

materials. According to agency documents and NRC officials we interviewed, the approach can be described as follows:

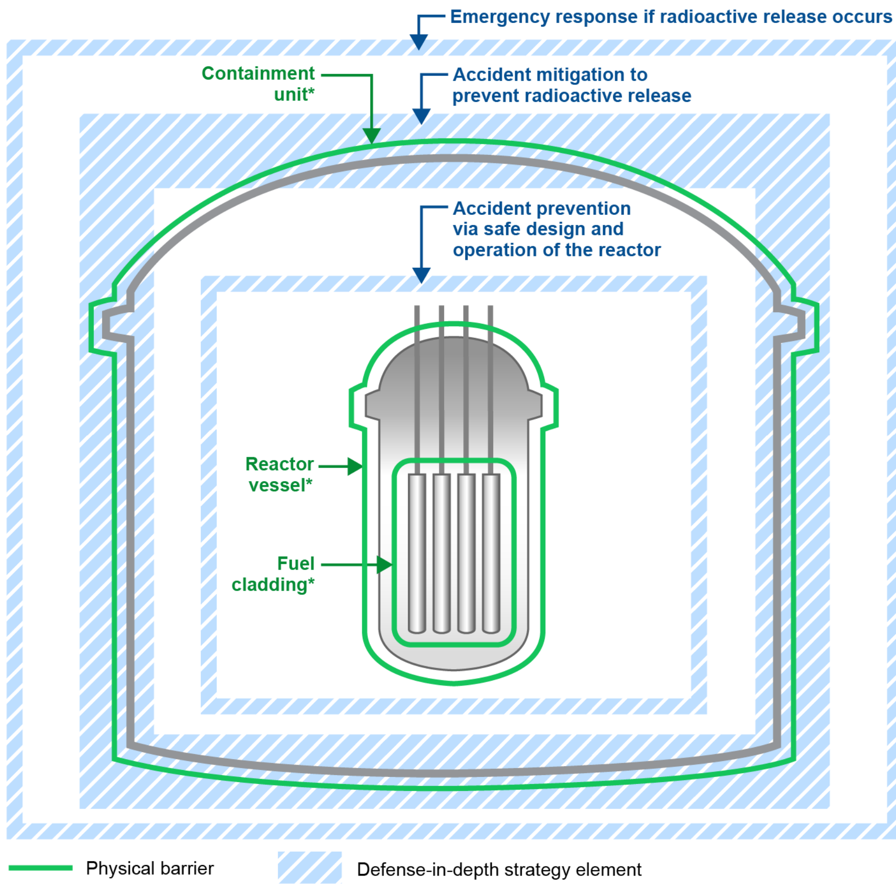
- Conservatism, for example, includes the consideration of the most severe natural phenomena that have been historically reported for a nuclear power plant site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.[18]
- Safety margins are the extra capacity factored into the design of a structure, system, or component so that it can cope with conditions beyond what is expected as a way to compensate for uncertainty.[19]
- Defense-in-depth includes multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon. Defense-in-depth includes the use of access controls, physical barriers, redundant and diverse key safety functions, and emergency response measures (see fig. 3).[20]

[18]10 C.F.R. Part 50, Appendix A, General Design Criterion 2, *Design Bases for Protection Against Natural Phenomena*. See also, NRC, *Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision-Making*, NUREG-1855 (Washington, D.C.: March 2017).

[19]NRC, *Glossary of Risk-Related Terms in Support of Risk-Informed Decision-Making,* NUREG-2122 (Washington, D.C.: Nov. 2013).

[20]For more information on defense-in-depth, see NRC, *Historical Review and Observations of Defense-in-Depth*, NUREG/KM-0009 (Washington, D.C.: April 2016).

**Figure 3: Measures Consistent with the Nuclear Regulatory Commission's (NRC) Defense-in-Depth Approach**




***Containment unit** – airtight enclosure around the nuclear reactor to confine radiation that otherwise might be released to the atmosphere in the event of an accident

***Reactor vessel** – forms a reactor coolant pressure boundary that provides a barrier against the release of radioactivity generated within the reactor

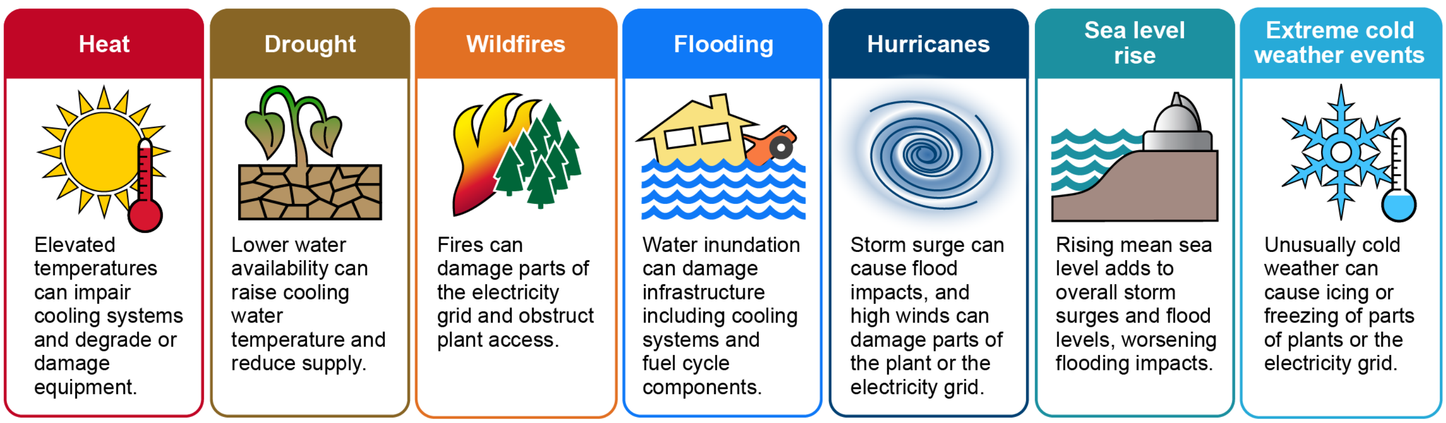
***Fuel cladding** – the thin-walled metal tube that forms the outer jacket of a nuclear fuel rod

Source: GAO and NRC documentation. | GAO-24-106326

## Climate Change Is Expected to Exacerbate Natural Hazards That Pose Risks to Nuclear Power Plants

Climate change is expected to exacerbate natural hazards—including heat, drought, wildfires, flooding, hurricanes, and sea level rise. In addition, climate change may affect extreme cold weather events.[21] These natural hazards pose risks to nuclear power plants (see fig. 4).

**Figure 4: Examples of Natural Hazards that May Pose Risks to Nuclear Power Plants**




Sources: Nuclear Regulatory Commission documents; summary of literature; GAO (icons). | GAO-24-106326

Note: The potential risks to nuclear power plants from these hazards include a loss of offsite power, diminished cooling capacity, flood damage, and reduced operations or temporary plant shutdowns. The loss of offsite power is a complete loss of electrical power from the grid to a nuclear power plant. The loss can decrease a plant's ability to maintain safe shutdown conditions. Diminished cooling capacity refers to any impact which reduces a plant's ability to cool reactor or fuel cycle components and can result in a temporary plant shutdown.

[21]According to the NCA, climate change has driven increases in the frequency and severity of some extreme weather events. For example, climate change caused Hurricane Harvey's rainfall to be an estimated 15 and 20 percent heavier than it would have been without human-caused warming. However, researchers disagree about some climate impacts. For example, whereas emerging research suggests that the frequency of cold-weather events and heavy snowfall may be increasing because of warming Arctic temperatures, there is some disagreement in the research community regarding this projection.

## Heat, Drought, and Wildfires Pose Risks to Nuclear Power Plants, and Climate Change Is Expected to Exacerbate These Hazards, Particularly in the South and Southwest

According to our analysis of NCA and U.S. Forest Service data, all 75 operating and shutdown U.S. nuclear power plants are located in areas where climate change is expected to exacerbate heat, drought, wildfires, or all three.

**Heat and drought.** Heat and drought pose risks to nuclear power plants because they can affect the water used for cooling. Specifically, higher-than-usual ambient air temperatures may increase the temperature of water used for cooling. Drought can also reduce the supply of cooling water. If a plant has an insufficient supply of cooling water or its cooling water approaches or exceeds the maximum allowable temperature for cooling certain reactor components, a licensee may need to temporarily limit or stop operations to ensure plant safety. Higher temperatures in the bodies of water into which nuclear power plants discharge cooling water may also require a plant to limit or temporarily stop operations to comply with laws designed to protect aquatic ecosystems and wildlife.[22] In addition, high temperatures can also degrade the performance or cause failure of pumps and other equipment, reduce the lifetime of plant components, and reduce the overall efficiency of power plants. Warmer temperatures may also increase levels of certain algae or other biological material which can block cooling water systems and lead to reduced production or a temporary plant shutdown.

[22]Some plants that discharge cooling water into rivers or lakes are subject to environmental requirements. These requirements could force a power plant to shut down or reduce power generation. For example, in 2007, 2010, and 2011, the Tennessee Valley Authority had to reduce power output from its Browns Ferry Nuclear Power Plant in Alabama because river temperatures were too high to receive discharge water from the plant without posing ecological risks.

**Heat and Drought at Turkey Point Nuclear Generating Station**

According to the Nuclear Regulatory Commission (NRC) and Turkey Point Nuclear Generating Station officials, in 2014, extended drought conditions and high algae content caused the cooling water for the Turkey Point Generating Station to exceed its maximum allowable temperature in its license. NRC approved the licensee's requests to not enforce the temperature requirement for the plant's cooling water for a limited period. Later, NRC granted the licensee a permanent license amendment that raised the maximum allowable cooling water temperature for the plant from 100 degrees to 104 degrees Fahrenheit.

High temperatures and drought conditions at Turkey Point Nuclear Generating Station potentially created risks to local drinking water sources when decreased water levels and increased evaporation rates led to higher salinity in the cooling canals. Higher salinity levels made the water denser, causing it to sink below the canals that contain it. This could have led to intrusion of higher salinity water into the areas of the Biscayne Aquifer, a source of drinking water for the Miami-Dade area.

To mitigate these risks, the licensee constructed a series of wells to decrease the water salinity in the cooling canals.

Well used to adjust salinity in the Turkey Point Nuclear Generating Station's cooling canals

Sources: Interviews with plant personnel at the Turkey Point Nuclear Generating Station, and review of NRC documents; GAO (photo). | GAO-24-106326

All operating and shutdown nuclear power plants are located in areas where climate change is projected to increase measures of heat, including daily and average maximum temperature, according to our analysis of NCA and NRC data. The effects of climate change on maximum temperatures are projected to be most severe in the South, where one-third of the plants are located.[23] The plants in the South are projected to experience an annual average of from 21 to 31 days with higher maximum temperatures than historical high temperatures. In addition, according to the NCA, climate change is expected to increase drought intensity in some regions, specifically in the Southwest, where two operating and four shutdown nuclear power plants are located.

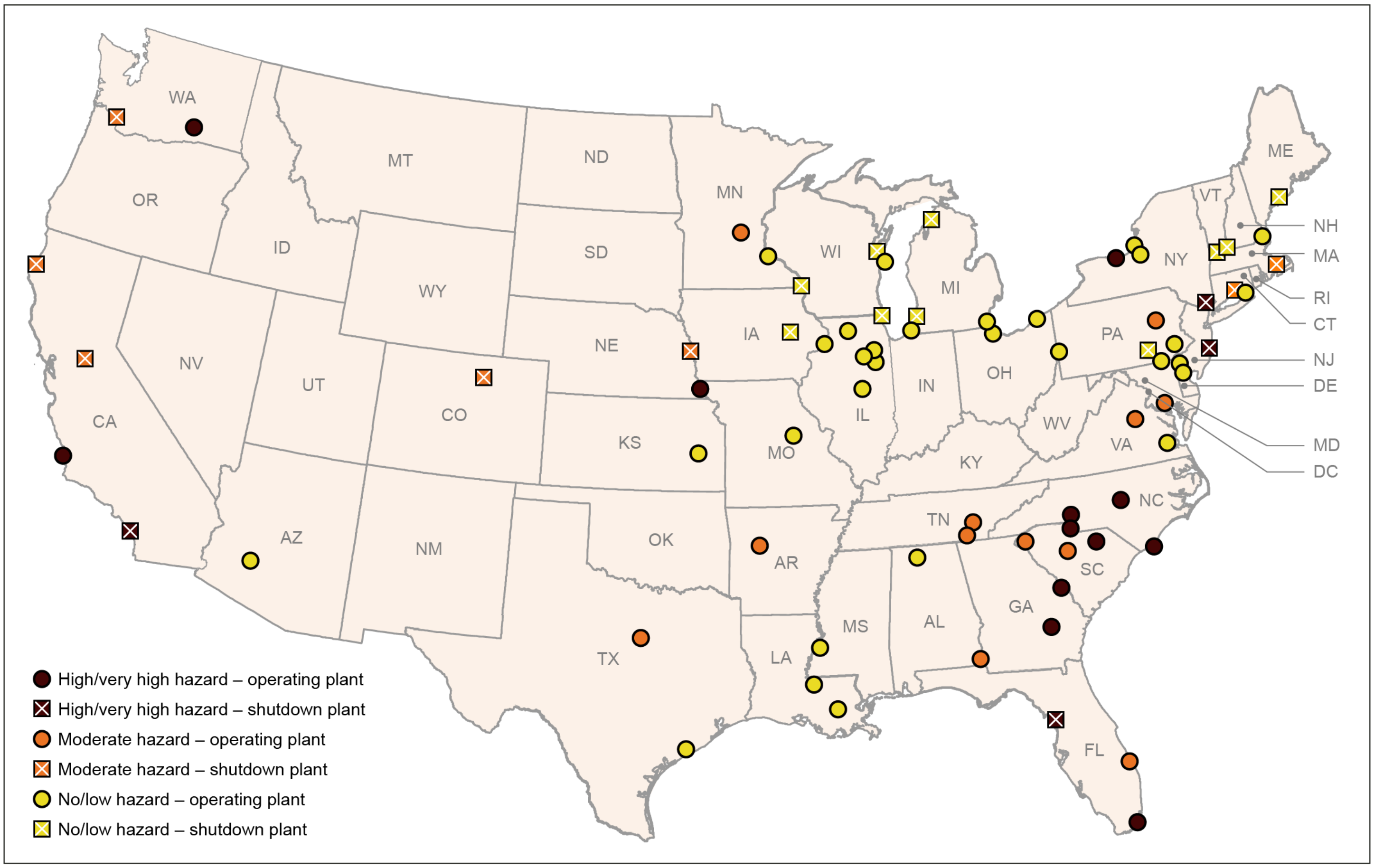
[23]Of the 25 plants in the South, 24 are operational and one is shutdown.

**Wildfire.** According to the NCA, increased heat and drought contribute to increases in wildfire frequency, and climate change has contributed to unprecedented wildfire events in the Southwest. The NCA projects increased heatwaves, drought risk, and more frequent and larger wildfires. Wildfires pose several risks to nuclear power plants, including increasing the potential for onsite fires that could damage plant infrastructure, damaging transmission lines that deliver electricity to plants, and causing a loss of power that could require plants to shut down. Wildfires and the smoke they produce could also hinder or prevent nuclear power plant personnel and supplies from getting to a plant.

According to our analysis of U.S. Forest Service and NRC data, about 20 percent of nuclear power plants (16 of 75) are located in areas with a high or very high potential for wildfire.[24] More specifically, more than one-third of nuclear power plants in the South (nine of 25) and West (three of eight) are located in areas with a high or very high potential for wildfire (see fig. 5).

[24]The U.S. Forest Service maps wildfire hazard potential based on landscape conditions and other observations. These maps include an index of wildfire hazard potential for the United States, based on, among other factors, annual burn probabilities and the potential intensity of large fires. The wildfire potential index is a relative ranking. The U.S. Forest Service categorizes the wildfire hazard potential index into five classes: very low, low, moderate, high, and very high. The U.S. Forest Service designates as “high” those areas with wildfire hazard potential index from the 85th to the 95th percentile, and as “very high” those areas above the 95th percentile. For this analysis, we combined the high and very high wildfire hazard potential categories; we did not identify the number of facilities in each of these categories separately. Of the 16 plants with high or very high potential for wildfire, 12 are operating and four are shutdown.

**Figure 5: Nuclear Power Plants Located in Areas with Exposure to No/Low, Moderate, and High/Very High Wildfire Hazard Potential**




Sources: U.S. Forest Service and Nuclear Regulatory Commission data; U.S. Census Bureau (map). | GAO-24-106326

Note: To determine if a plant is located in an area with wildfire hazard potential, we identified overlap between a 0.5-mile radius around nuclear power plant coordinates provided by the Nuclear Regulatory Commission and wildfire hazard potential data. Overlap indicates that a facility is located in an area that may be affected by the selected hazard. We used the U.S. Forest Service Wildfire Hazard Potential Map to show exposure to wildfire hazard potential. The U.S. Forest Service categorizes the wildfire hazard potential index into five classes of very low, low, moderate, high, and very high. We analyzed the moderate, high, and very high wildfire potential layers, and combined results for the high/very high layers. No/low refers to plants that are not located in an area with wildfire potential of moderate, high, or very high, based on the U.S. Forest Service Wildfire Hazard Potential Map. See appendix I for more details on our data analysis. We previously reported that the primary intended use of the wildfire hazard potential map is to identify priority areas for hazardous fuels treatments from a broad, national- to regional-scale perspective. This analysis does not account for any protective measures plants may have taken to mitigate the risk of selected natural hazards.

Appendix III provides additional details of exposure to heat and wildfire hazard potential in areas where nuclear power plants are located.

## Flooding, Hurricanes, and Sea Level Rise Pose Risks to Nuclear Plants, and Climate Change Is Expected to Exacerbate These Hazards, Particularly in Coastal Regions

According to our analysis of NOAA and NRC data, about 63 percent of nuclear power plants (47 of 75) are located in areas with exposure to either Category 4 or 5 hurricane storm surge or high flood hazard, and nine are located on a coastline, where NOAA projects a range of sea level increases.[25] In addition, 20 percent of nuclear power plants (15 of 75) are located in areas with exposure to both Category 4 or Category 5 hurricane storm surge and high flood hazard. The NCA predicts that climate change will exacerbate all three hazards.

[25]To identify coastal plant locations, we used nuclear power plant coordinates from NRC and added a 0.5-mile radius around NRC's plant coordinates as a proxy for an average size nuclear power plant. Coastal plants were those with a radius that intersected with or beyond the coastline.

**Flood Protection**

To mitigate the impacts of flooding, licensees have implemented various measures, including the elevation of spent fuel pools and use of flood barriers.

Flood barrier protecting part of the Turkey Point Nuclear Generating Station

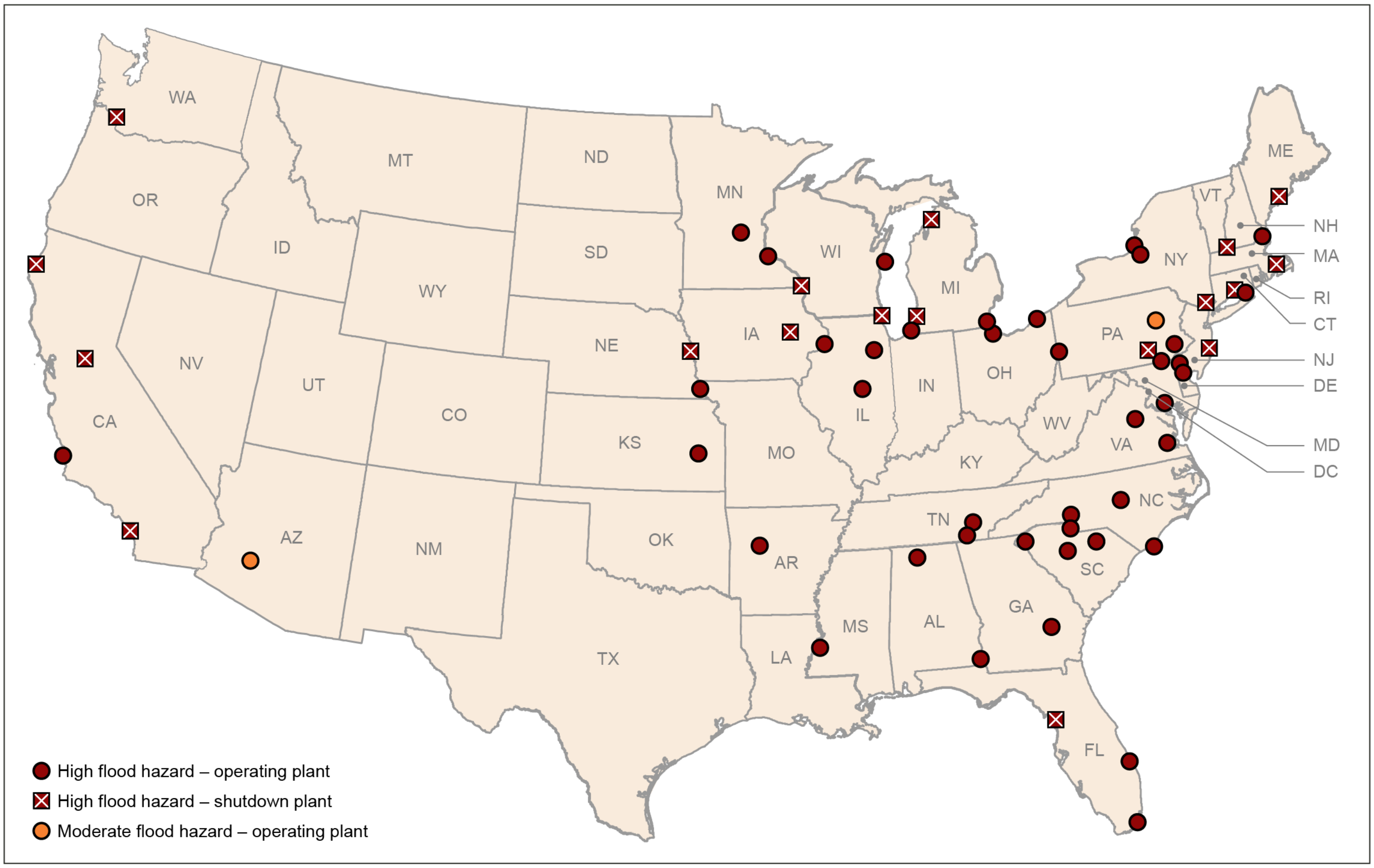
Sources: GAO site visit and interviews with plant personnel at the Turkey Point Nuclear Generating Station; GAO (photo). | GAO-24-106326

**Flooding.** Flooding could pose risks to nuclear power plants by, among other things, diminishing a plant's cooling capacity. Flooded roads could prevent personnel, equipment, and supplies from reaching a plant. Flooding could also cause damage to buildings, equipment, and electrical systems that could require a plant to curtail operations or shut down. In addition, flood waters could interfere with heat removal from spent fuel pools by blocking ventilation ports with water. Prolonged exposure to salt water from coastal flooding could also degrade or corrode a cask's exterior, potentially posing risks to the environment and human health.

Our analysis of Federal Emergency Management Agency data found that 60 of the 75 nuclear power plants in the United States are located in areas with high flood hazard and two are in areas with moderate flood hazard.[26] Just over one-third of the plants (21 of 60) located in areas with high flood hazard are in the South (see fig. 6). According to the NCA, heavy rainfall and flooding are expected to become more frequent and severe across the United States. The NCA predicts that climate change will continue to exacerbate hurricane storm surge, rainfall, and flood events in U.S. coastal areas.

[26]We analyzed Federal Emergency Management Agency data from 2023. For our analysis, high flood hazard corresponds to areas in 100-year floodplains (areas with a 1 percent or higher annual chance of flooding), moderate flood hazard corresponds to areas in 500-year floodplains (areas with a 0.2 percent or higher annual chance of flooding), and no/low corresponds to areas with minimal, unknown, or other flood hazards, including areas with reduced risk because of levees as well as areas with flood hazard based on future conditions, such as the future implementation of land-use plans. Of the 60 plants located in areas with high flood hazard, 42 are operating and 18 are shutdown. Both of the plants located in areas with moderate flood hazard are operating.

**Figure 6: Nuclear Power Plants Located in Areas with High and Moderate Flood Hazard**




Sources: Federal Emergency Management Agency and Nuclear Regulatory Commission data; U.S. Census Bureau (map). | GAO-24-106326

Note: To determine if a plant is located in an area with exposure to moderate or high flood hazard, we identified overlap between a 0.5-mile radius around nuclear power plant coordinates provided by the Nuclear Regulatory Commission and the flood hazard data. Overlap indicates that a facility is located in an area that may be affected by the selected hazard. See appendix I for more details on our data analysis. To show exposure to flooding, we use the Federal Emergency Management Agency's National Flood Hazard Layer, which estimates several levels of flood hazard, including high flood hazard (areas with a 1 percent or higher annual chance of flooding), and moderate flood hazard (areas with a 0.2 percent or higher annual chance of flooding). This analysis does not account for any protective measures plants may have taken to mitigate the risk of selected natural hazards.

**Hurricanes.** High winds from hurricanes can generate projectiles capable of damaging parts of nuclear power plants and electricity transmission lines that provide nuclear power plants with power. In addition, storm surge from hurricanes can cause flooding, which could diminish a plant's cooling capacity and damage buildings, equipment, and electrical systems. About 23 percent of nuclear power plants (17 of 75) are located in areas that may be inundated by storm surge from Category 4 or Category 5 hurricanes,[27] according to our analysis of NOAA and NRC data.[28] All 17 of these plants are in the East and South, and the six plants with exposure to Category 5 hurricanes are located in the South (see fig. 7).[29] According to the NCA, climate change is expected to heighten hurricane storm surges, wind speeds, and rainfall rates.[30]

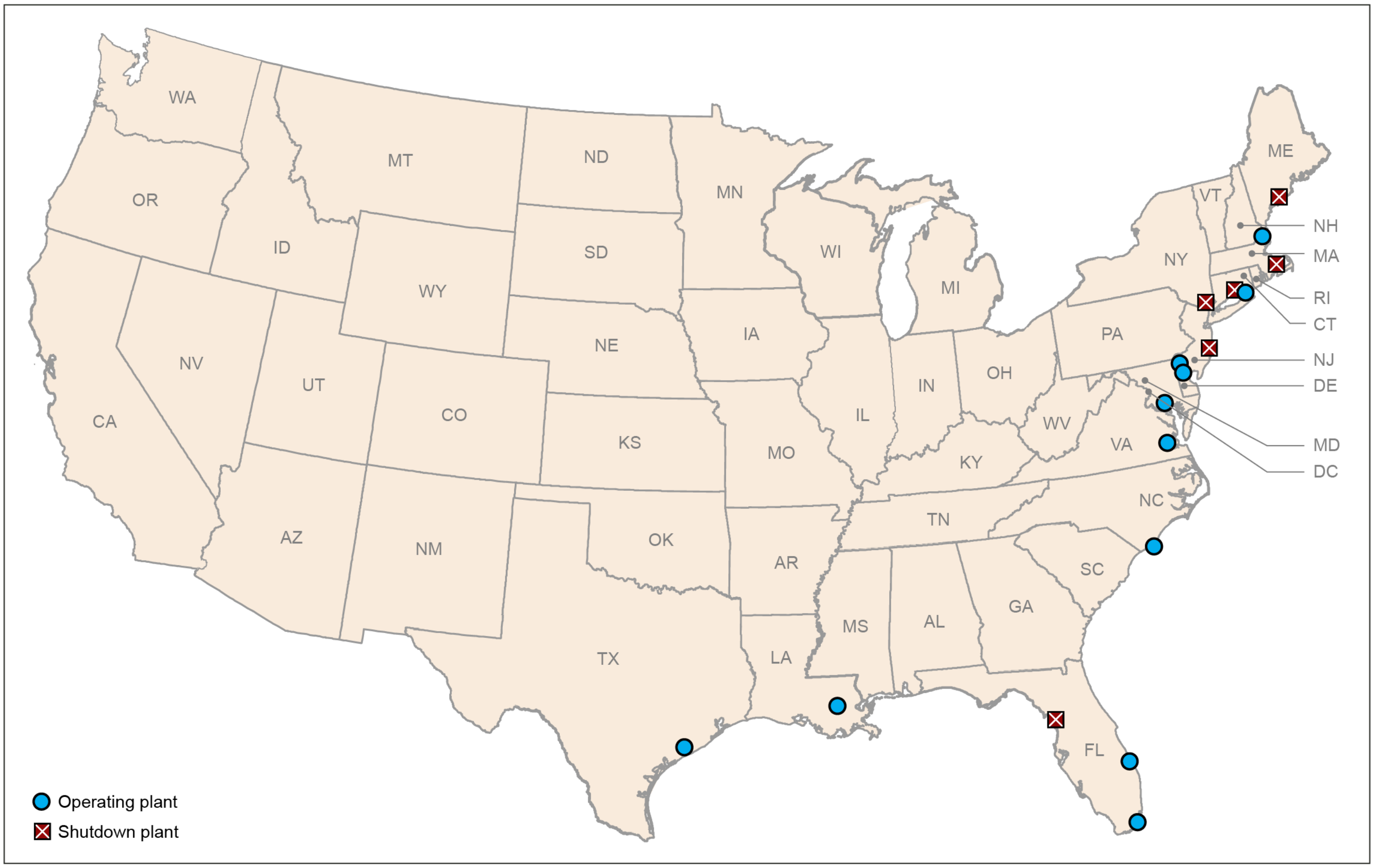
[27]Of the 17 plants located in areas that may be inundated by storm surge from Category 4 or 5 hurricanes, 11 are operating and six are shut down. For the West Coast of the United States, storm surge data were only available for Southern California.

[28]Our analysis of NOAA storm surge data is based on a model that estimates the maximum extent of storm surge at high tide. NOAA provides estimates of hurricane storm surge using a model called Sea, Lake, and Overland Surges from Hurricanes. This model includes hypothetical hurricanes under different storm conditions, such as landfall location, trajectory, and forward speed. Hurricanes reaching Category 3 and higher are considered major hurricanes because of the potential for significant loss of life and damage. In our analysis, we used the maximum extent of storm surge from Category 1 hurricanes (the lowest possible category) and Category 5 hurricanes (the highest possible category) to show a range of potential climate change effects. Category 4 hurricanes carry sustained winds of 130–156 miles per hour. Category 5 hurricanes have sustained winds exceeding 156 miles per hour.

[29]Storm surge impacts to nuclear power plants would depend on several factors, including a plant’s elevation and protective measures.

[30]Climate change leads to warmer ocean surface temperatures. This, in turn, makes hurricanes more powerful because the temperature increase causes more water to evaporate from the ocean. Evaporation adds moisture to the air, and warmer air temperatures can hold more water vapor. The increased moisture in the air leads to more intense rainfall. In a hurricane, spiraling winds draw moist air toward the center, fueling the thunderstorms that surround it.

**Figure 7: Nuclear Power Plants Located in Areas with Exposure to Storm Surges from Category 4 and Category 5 Hurricanes**




Sources: National Oceanic and Atmospheric Administration and Nuclear Regulatory Commission data; U.S. Census Bureau (map). | GAO-24-106326

Notes: To determine if a plant exists in an area with exposure to hurricane storm surge, we identified overlap between a 0.5-mile radius around nuclear power plant coordinates provided by the Nuclear Regulatory Commission and storm surge data. Overlap indicates that a facility is located in an area that may be affected by the selected hazard. See appendix I for more details on our data analysis. To show exposure to hurricane storm surge, we use the National Oceanic and Atmospheric Administration's Sea, Lake, and Overland Surges from Hurricanes Model, which estimates storm surge heights resulting from the various categories of hurricanes. This analysis does not account for any protective measures plants may have taken to mitigate the risk of selected natural hazards.

**Sea level rise.** Sea level rise could affect nuclear power plants by contributing to greater storm surges and flooding. According to NOAA officials, a rise in sea level can increase corrosion from saltwater intrusion and lead to chronic long-term erosion of coastal cliffs, where some plants are located.[31] According to a NOAA report, over the next 30 years sea levels will continue to rise as climate change warms glaciers and ice sheets, causing additional water mass to enter the ocean.[32] The rise in sea level is expected to increase coastal flooding by contributing to higher tides and storm surges that reach further inland, potentially affecting coastal nuclear power plants.

Our analysis of NOAA and NRC data indicates that about half of nuclear power plants (37 of 75) are located in a coastal region, and nine of these are located on the coastline.[33] Projected sea level rise in 2050 varies by coastal region, from 0.5 feet in the Northwest to 1.9 feet in the Western Gulf (see fig. 8). In addition, sea level rise may increase saltwater intrusion into the coastal rivers or groundwater aquifers that some nuclear power plants use for service or potable water.[34]

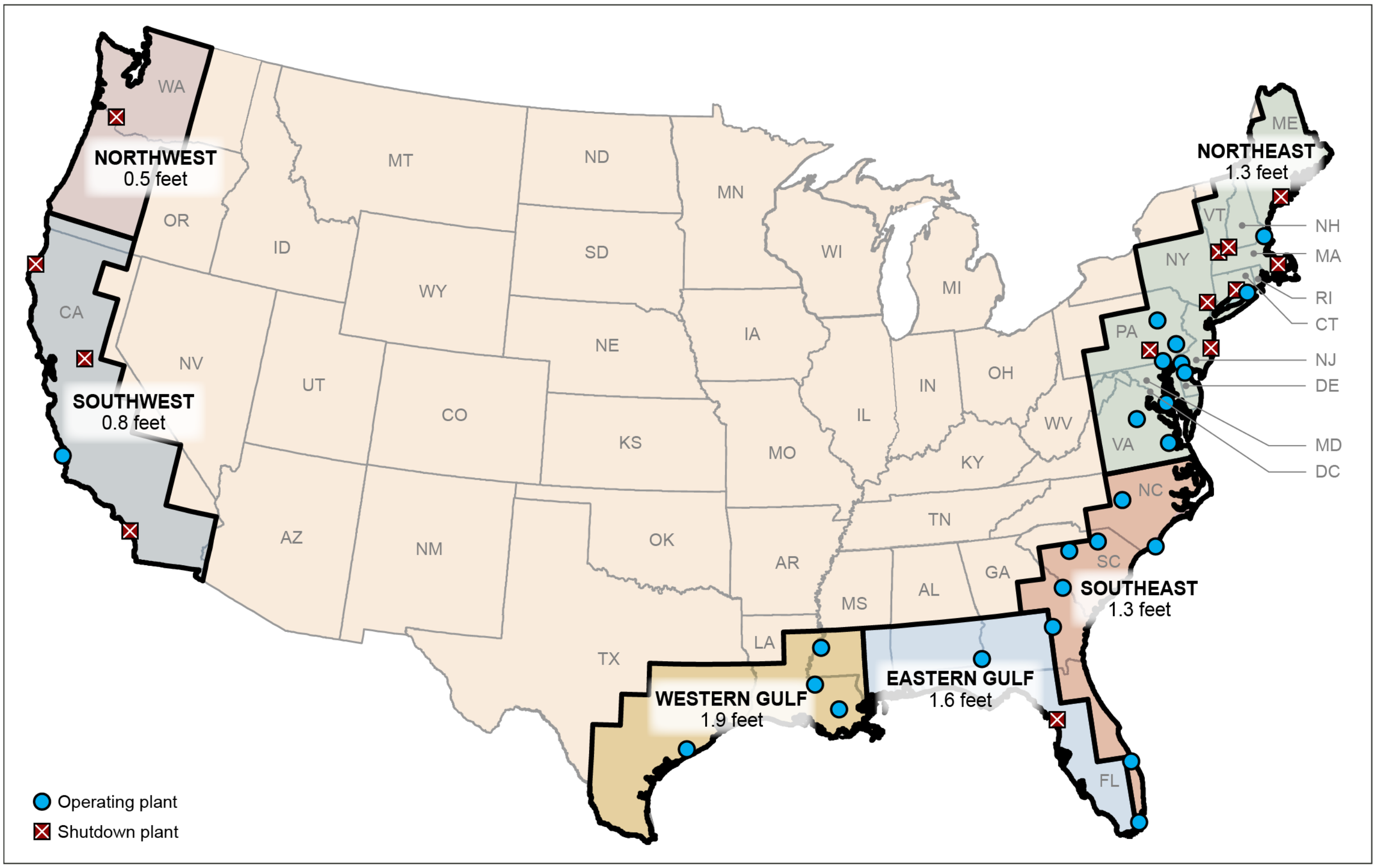
[31]NOAA officials said that Turkey Point Nuclear Generating Station is an example of a plant where, if unaddressed, sea level rise could lead to saltwater intrusion into the plant's cooling canals. Officials also said that Southern California is an example of an area where cliffs consist of unconsolidated rock, a type of loose rock composition that is particularly vulnerable to long-term erosion from sea level rise.

[32]W. V. Sweet, B. D. Hamlington, R. E. Kopp, C. P. Weaver, P. L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A. S. Genz, J. P. Krasting, E. Larour, D. Marcy, J. J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K. D. White, and C. Zuzak, *2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines*, NOAA Technical Report NOS 01 (Silver Spring, MD: Feb. 2022).

[33]Of the 37 nuclear power plants located in a coastal region, 24 are operating and 13 are shut down. Of the nine nuclear power plants located on the coastline, seven are operating and two are shut down. To determine which nuclear power plants are located on the coastline, we identified plants whose coordinates intersect with a coastline. NRC provided coordinate data, and we used a 0.5-mile radius as a proxy for plant size in our analysis.

[34]According to one U.S. Environmental Protection Agency source, sea level rise may increase river levels and the risk of saltwater intrusion into rivers and coastal groundwater aquifers, especially during dry periods. According to NRC's Generic Environmental Impact Statement for License Renewal of Nuclear Plants, saltwater intrusion into groundwater aquifers can degrade the quality of groundwater used for potable and service water at nuclear power plants. See NUREG-1437, Vol. 1, Revision 1.

**Figure 8: Nuclear Power Plants in the National Oceanic and Atmospheric Administration (NOAA) Coastal Regions and Projected Sea Level Rise in 2050**




Sources: National Oceanic and Atmospheric Administration and Nuclear Regulatory Commission data; U.S. Census Bureau (map). | GAO-24-106326

Note: The regional sea level rise values for 2050 are regional observation-based extrapolations from an interagency report covering sea level rise scenarios. These extrapolations use observed changes in sea level rise and other factors to estimate the trajectory of sea level rise in the near term. Sea-level rise primarily affects coastlines but may also affect the salinity and level of coastal rivers and groundwater aquifers. This map includes all nuclear power plants that are located in NOAA coastal regions. The analysis does not account for site-specific plant elevation or protective measures plants may have taken to mitigate the risk of selected natural hazards.

Appendix III provides additional details of our analysis of exposure to flooding, hurricane storm surges, and sea level rise in areas where nuclear power plants are located.

## Extreme Cold Weather Events Pose Risks to Nuclear Power Plants, and Climate Change May Affect These Events in Certain Regions

Cold temperatures can diminish cooling capacity and lead to the loss of offsite power, posing risks to nuclear power plants. Specifically, extreme cold conditions may create ice that could block a plant's cooling water intake system, potentially reducing the supply of cooling water to safety-related systems and components. In addition, frozen precipitation can cause icing of power lines and lead to full or partial loss of off-site power, potentially forcing a plant to rely on backup diesel that may be vulnerable to extremely cold air temperatures.

**Extreme Cold at South Texas Project Nuclear Power Plant**

On February 15, 2021, the South Texas Project experienced an automatic reactor shutdown when a 5-foot section of uninsulated water line froze, causing the failure of a feed water pump. The Nuclear Regulatory Commission (NRC) found that the facility shut down safely, but the licensee failed to implement a required Freezing Weather Plan to insulate the line. According to one NRC official, a cold weather event nearly rendered another plant's diesel generators inoperable when the air intake temperature dipped to -50 degrees Fahrenheit.

South Texas Project, reactor units 1 and 2

Sources: GAO analysis of NRC documents; U.S. NRC Blog (photo). | GAO-24-106326

Climate change may affect extreme cold weather events.[35] While the NCA found that climate change is expected to cause an overall increase in average temperatures, a 2021 study funded in part by NOAA found that Arctic warming caused by climate change may cause extremely cold air from the Arctic to stretch into the United States.[36] The study links climate change to extreme cold events, such as the record cold temperatures in Texas in 2021. Our analysis of NCA climate projections data and NRC location data found that the average operating nuclear power plant will

[35]As noted previously, according to the NCA, there is disagreement among researchers about some climate impacts. For example, whereas emerging research suggests that the frequency of cold weather events and heavy snowfall may be increasing because of warming Arctic temperatures, there is some disagreement in the research community regarding this projection.

[36]J. Cohen, L. Agel, M. Barlow, C. I. Garfinkel, and I. White, *Linking Arctic Variability and Change with Extreme Winter Weather in the United States*, Science, Volume 373, Issue 6559 (Washington, D.C.: 2021) 1116-1121.

experience from 17 to 22 fewer frost days annually.[37] However, certain regions may also see an increase in extreme cold weather events.

**Cold Protection**

Licensees have insulated water lines and added cold-weather insulation for turbines to protect against freezing water in pipes and damage to other plant equipment.

Example of insulation at an industrial facility

Sources: Interviews with plant personnel at the Turkey Point Nuclear Generating Station; rootstocks/stock.adobe.com (photo). | GAO-24-106326

Following 2021's Winter Storm Uri, the Federal Energy Regulatory Commission approved a new standard, effective October 2024, that will require certain owners of certain electricity generating units, including nuclear power reactors, to implement freeze protection measures to operate for at least 12 continuous hours at the unit's recorded extreme cold weather temperature.[38]

Appendix III provides additional details of our analysis of exposure to cold weather events in areas where nuclear power plants are located.

[37]Climate projections are used to show a range of future outcomes, and are limited by uncertainties in emissions, natural variability, and scientific models. To show a range of possible outcomes, we used climate projections for a low-emission scenario (17 days) and a high-emission scenario (21 days). Climate projections rely on a variety of assumptions about the future. These limitations are further discussed in appendix II.

[38]In 2023, the Federal Energy Regulatory Commission (FERC) approved Emergency Operation Standard 012-01, also known as the Extreme Cold Weather Preparedness and Operations standard. Effective October 1, 2024, the standard addresses the effects of operating in extreme cold weather by ensuring owners and operators of generating units like nuclear power reactors develop and implement plan(s) to mitigate the reliability impacts of extreme cold. FERC defines extreme cold weather as the temperature equal to the lowest 0.2 percentile of the hourly temperatures measured in December, January, and February. The standard exempts certain generating units, including nuclear power reactors, which have an extreme cold weather temperature exceeding 32 degrees Fahrenheit or operate only in a backup or non-winter capacity.

## NRC's Actions to Address Risks to Nuclear Power Plants from Natural Hazards Do Not Fully Consider the Potential Effects of Climate Change

NRC's processes for licensing and overseeing nuclear power plants include actions to address risks from natural hazards. However, NRC's actions do not fully consider the potential effects of climate change.

### NRC's Oversight of Nuclear Power Plants Includes Actions to Address Risks from Natural Hazards

NRC's existing processes are designed to address risks to the safety of nuclear power plants, including risks from natural hazards. For example:

- **Defense-in-depth.** A nuclear power plant must be designed and built to withstand phenomena or events such as earthquakes, tornadoes, hurricanes, and floods without the loss of the structures, systems, or components necessary to ensure public health and safety. According to NRC, NRC's defense-in-depth approach focuses on protecting plants against risks such as those related to events that exceed a plant's design basis, including flooding from intense precipitation or hurricanes.[39] As such, NRC's defense-in-depth approach includes verifying that plants have multiple physical barriers and equipment backups to ensure plant safety if plant structures and equipment are damaged due to such severe weather events or if a power outage threatens a plant's ability to continue cooling the reactor.

[39]The design basis for a plant includes the specific functions to be performed by the structures, systems, or components that could be compromised by an adverse weather event that exceeds what the plant was designed to withstand, such as the maximum flood elevation or maximum temperature limit allowed for a plant to continue operating. 10 C.F.R. Part 50, Appendix A, General Design for Nuclear Power Plants, Criterion 2—Design Bases for Protection Against Natural Phenomena.

**Defense-in-Depth at Duane Arnold Energy Center**

In 2020, the Iowa "Derecho Windstorm" brought heavy rains and winds up to 130 miles per hour to the Duane Arnold Energy Center. The storm resulted in the loss of offsite power, which caused an emergency shutdown of the reactor. Winds from the storm also damaged two cooling towers and buildings housing the reactor, turbine, and equipment.

However, according to a Nuclear Regulatory Commission (NRC) document, the plant's safety margins and use of a defense-in-depth approach mitigated the effects of storm damage. Specifically, the plant had multiple backup generators and pumps as well as physical barriers to protect the plant.

During the storm, the plant lost offsite power, and the cooling pump for the spent fuel pool turned off. Before the outage, two emergency diesel generators started automatically due to grid-related storm impacts. Staff immediately started a second cooling pump. This action prevented the water in the spent fuel pool from boiling and potentially exposing the fuel rods. According to NRC, the winds also damaged the reactor's containment unit, but it remained functional and would have prevented a release of radiological material in the event of damage to the reactor core.

Duane Arnold Energy Center

Sources: Nuclear Regulatory Commission; AsNuke (photo), https://creativecommons.org/licenses/by-sa/4.0/deed.en. No changes were made to this photo. | GAO-24-106326

- **Licensing**. During the licensing process, NRC assesses a plant's risks from natural hazards as part of its safety evaluation. In doing so, NRC reviews reactor and plant designs and compares the design limits for natural hazards with the site's expected exposure to natural hazards on the basis of the licensee's hazard assessments. According to NRC officials, NRC also conducts a confirmatory analysis of the licensee's hazard assessments, which if deemed insufficient, must be revised by the licensee.
- **Inspections.** NRC resident inspectors use inspection manual procedures to inspect licensees' preparations for addressing adverse weather events and extreme temperatures.[40] As part of their inspections, NRC resident inspectors verify that selected systems and components will function when affected by adverse weather. NRC officials explained that an inspection includes observing licensees repair and run pieces of equipment, conducting emergency drills, and verifying that licensees are taking appropriate actions in response to severe weather conditions. Inspectors from NRC regional offices may also conduct plant inspections after adverse weather events, such as floods or hurricanes.
- **Probabilistic risk assessments.** NRC uses probabilistic risk assessments in its licensing and inspection processes to analyze various risks, including safety risks posed by natural hazards.[41] These assessments are a systematic method for assessing what can go wrong, its likelihood, and its potential consequences to provide insights into the strengths and weaknesses of the design and operation of a nuclear power reactor. Probabilistic risk assessments are used to estimate the risk of reactor core damage, radioactive material release, and related consequences to the public and environment based on the as-built, as-operated plant.
- **Operating experience program.** NRC's operating experience program collects and evaluates information from various regulatory oversight activities and inspection findings and shares information about plants' operating experiences with NRC staff. In addition, according to NRC officials, NRC has a research office that analyzes long-term trends, such as the loss of offsite power due to severe

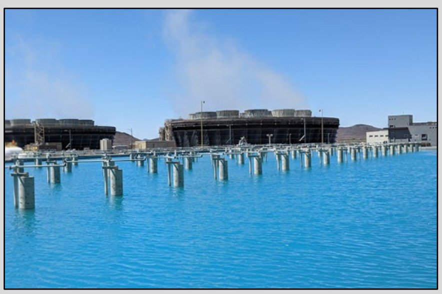
[40]Inspections by resident inspectors at the plant level are called baseline inspections, and different types of baseline inspections occur either daily, quarterly or annually.

[41]Applicants for certain licenses for new reactors must submit a description of the plant-specific probabilistic risk assessment and its results to NRC as a part of their application.

**NRC Inspectors Address Heat Risks at the Palo Verde Nuclear Generating Station**

To prepare for extreme summer heat, Nuclear Regulatory Commission (NRC) resident inspectors at the Palo Verde Nuclear Generating Station in Arizona inspect systems likely to be affected by high temperatures, such as diesel generators and spray ponds, both of which are used to cool the reactor. The spray ponds contain a 26-day supply of water to ensure that plants have adequate cooling capacity to safely shut down.

Because high temperatures can cause water held in the spray ponds to evaporate, the plant relies on its reservoirs and deep wells as backup sources of water.



Palo Verde Nuclear Generating Station spray pond

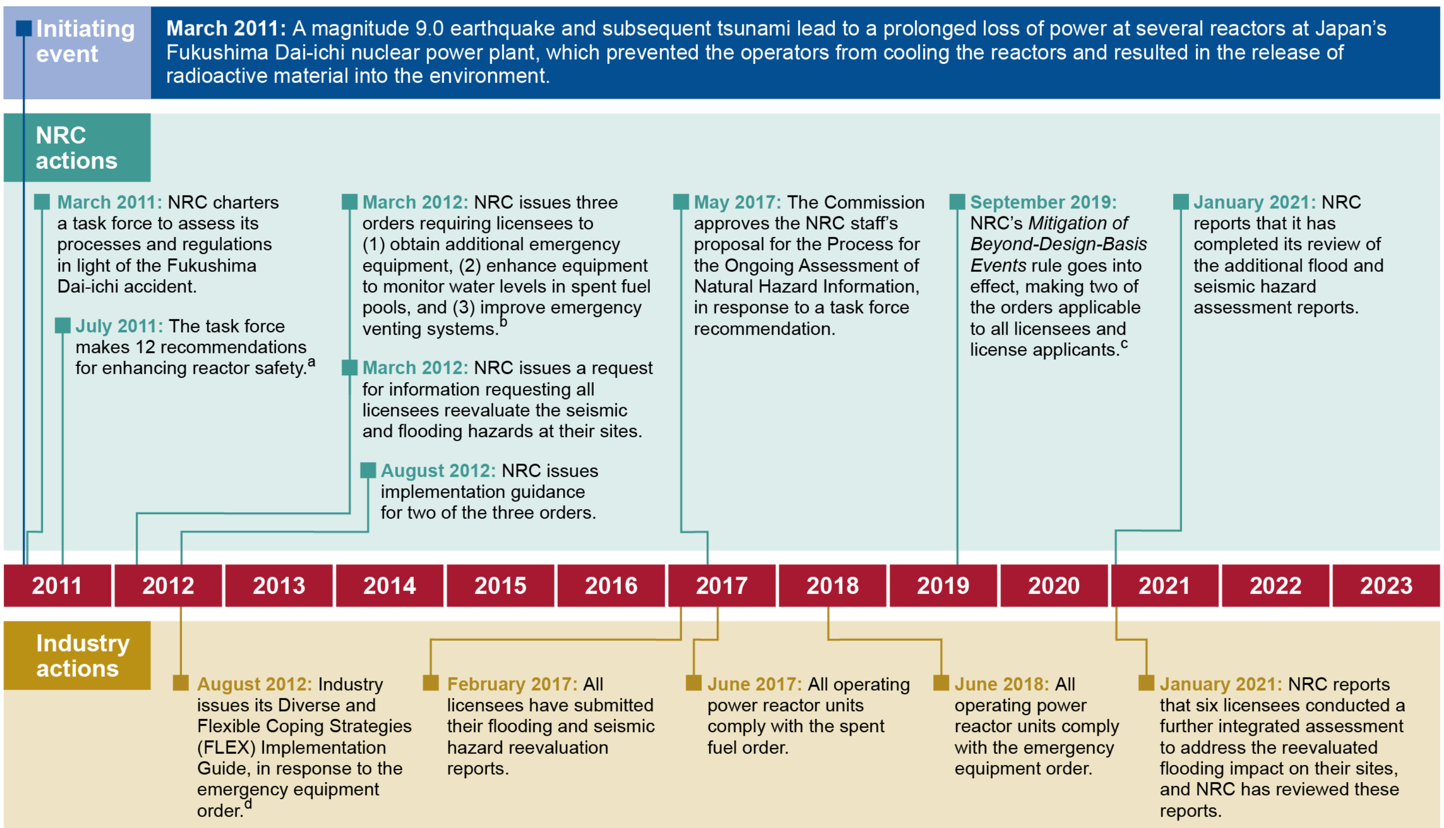
Sources: NRC; GAO (photo). | GAO-24-106326

weather, to identify lessons learned that could be applied to the oversight of other plants.

Following the 2011 accident at Japan's Fukushima Dai-ichi nuclear power plant, NRC and industry took several actions to further address risks to nuclear power plants from natural hazards.[42] Some of these actions were taken in response to recommendations from a task force NRC established to assess its regulatory approach (see fig. 9).

[42]On March 11, 2011, a 9.0-magnitude earthquake and subsequent tsunami devastated northeast Japan and led to the most extensive release of radioactive material at a nuclear power plant since the 1986 Chernobyl disaster. The Fukushima Dai-ichi nuclear power plant suffered extensive damage when a 45-foot-high tsunami wave exceeded the plant's seawall and flooded the site, causing a prolonged loss of electrical power at several of its reactors. As a result of the loss of power, plant operators were unable to keep three of the reactors cool, which led to fuel melting, hydrogen explosions, and the release of radioactive material into the environment. The disaster displaced tens of thousands of residents and contaminated the surrounding area. Nuclear-power-generating countries worldwide have since taken actions to prepare for an event like this, which far exceeded the Fukushima Dai-ichi plant's design basis.

**Figure 9: Timeline of Selected Nuclear Regulatory Commission (NRC) and Industry Actions after the Fukushima Dai-ichi Accident in 2011**




Source: GAO review of NRC and industry documents. | GAO-24-106326

[a]NRC prioritized the recommendations in three tiers: (1) recommendations NRC should implement without unnecessary delay; (2) recommendations that could not be initiated in the near term due, in part, to resource or critical skill set limitations; and (3) recommendations that required further study by NRC to determine if regulatory action was necessary, among other factors.

[b]NRC, Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events, Order EA-12-049 (Washington, D.C.: Mar. 12, 2012); Issuance of Order to Modify Licenses with Regard to Reliable Spent Fuel Pool Instrumentation, Order EA-12-051 (Washington, D.C.: Mar. 12, 2012); and Order Modifying Licenses with Regard to Reliable Hardened Containment Vents, Order EA-12-050 (Washington, D.C.: Mar. 12, 2012).

[c]NRC, Mitigation of Beyond-Design-Basis Events, 84 Fed. Reg. 39,684 (Aug. 9, 2019). Orders EA-12-049 and EA-12-051 are applicable to all licensees and construction permit holders. Order EA-12-050 applies to licensees with boiling water reactors that feature certain containments that require proper venting to ensure safety.

[d]Nuclear Energy Institute, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide, NEI 12-06 (August 2012) and NRC, Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events, Order EA-12-049 (Washington, D.C.: Mar. 12, 2012).

The actions NRC took in response to the task force recommendations include the following:

- **Required licensees to assess flooding risks.** NRC required all licensees to assess updated flood hazard risk information and reevaluate and upgrade, as necessary, their plants' flood protection of structures, systems, and components. On the basis of these assessments, NRC did not identify the need to require any plant modifications or revise plant safety procedures.[43]
- **Created a process for ongoing hazard assessments.** In May 2017, the Commission approved the Process for the Ongoing Assessment of Natural Hazard Information (POANHI) to determine the need for site-specific assessments, additional research, or regulatory action.[44] POANHI involves collecting and maintaining hazard information in the

[43]NRC required all nuclear power plant licensees to conduct on-site inspections of safety-related systems to verify that plant features that protect against flooding are available, functional, and properly maintained. All licensees conducted flood reevaluations for their plants, and licensees at six plants conducted further integrated assessments, which are requested by NRC if the plant's design for a potential flood is exceeded by the reevaluation's estimates of potential maximum elevation of flood waters. These assessments evaluate the plant response to flooding hazards and the effectiveness of existing systems and procedures to mitigate risks from flooding. In addition, NRC required licensees to identify and address plant-specific vulnerabilities related to flooding and verify the adequacy of monitoring and maintenance for protection features in the interim period until longer term actions were completed to reevaluate design-basis flooding hazards. Also, following the accident at the Fukushima Dai-ichi plant, NRC issued a temporary instruction directing its inspection staff to independently assess the adequacy of actions taken by licensees. NRC also required licensees to assess seismic hazard risks. Seismic hazard risks are not included in the scope of this report.

[44]Preceding the approval of POANHI, NRC conducted a 2013 Probabilistic Flood Hazard Assessment workshop following the accident at the Fukushima Dai-ichi nuclear power plant, in which participants from federal agencies and other organizations shared information about probabilistic assessment of extreme rainfall, flood-induced dam and levee failures, tsunami flooding, river flooding, extreme storm surge, and combined-events flooding. NRC continues to host Probabilistic Flood Hazard workshops nearly annually, and these workshops often share research results with the public. For example, NRC contracted with the Pacific Northwest National Laboratory to publish four national and regional reports on the potential impacts of climate change, which as of 2022 have not yet led to additional NRC guidance for probabilistic flood hazard assessment. These reports are publicly available at https://www.osti.gov/biblio/1259942, https://www.osti.gov/biblio/1593340, https://www.osti.gov/biblio/1524249, and https://www.osti.gov/biblio/1605280.

Natural Hazards Information Digest[45]—a database that supports POANHI—and reviewing and assessing the hazard information to determine whether a hazard has a potentially significant impact on plant safety.[46] To ensure that NRC is aware of new hazard information from a variety of sources for inclusion in this database, NRC regularly interacts with internal and external stakeholders, including other federal agencies, academia, industry, regulators from other countries, and other technical and scientific organizations, according to NRC officials. If a POANHI assessment of new hazard information identifies a potentially significant effect on plant safety, NRC refers the issue to the appropriate regulatory program, at which point the program office determines how to proceed. POANHI leverages and is integrated into other existing processes, such as the operating experience program, for the assessment of new information and the determination of whether a change is needed to a particular plant's licensing basis. According to NRC officials, NRC has not taken any regulatory actions as a result of POANHI.[47]

- **Required enhanced safety and emergency equipment**. In 2012, NRC ordered all licensees and nuclear power plant construction permit holders to ensure that a plant's key safety functions could be

[45]NRC incorporates new hazard information, such as records of site-specific or regional extreme weather events, into its Natural Hazards Information Digest, which NRC began using in 2019. This database is NRC's repository for information on natural hazard-related events at or near nuclear power plants. The database captures documentation provided by licensees in response to site hazard reevaluations and plant inspections as well as historical site-specific events and information about natural hazards that could affect plants. In addition to informing POANHI, the database also supports NRC efforts to (1) respond to emergent events associated with natural hazards by providing relevant information, (2) engage with stakeholders, (3) evaluate natural hazard-related inspection findings to determine their safety significance, (4) implement natural hazards research plans, and (5) update regulatory and staff guidance.

[46]According to NRC policy, the significance assessment determines whether the new information indicates that the hazard could adversely affect the capability of a plant's structures, systems, and components to perform their intended safety functions. To make this determination, NRC staff either conduct a quantitative assessment that compares the new information with risk insights from past hazard analyses to assess the impacts of plant response or conduct a qualitative assessment that considers the likelihood of the event, identifies vulnerabilities and actions to address them, and adheres to defense-in-depth principles, among other factors.

[47]NRC is reviewing new seismic information from a 2018 report to assess updated seismic hazards at the nuclear power plants located in the region addressed by the report. See Pacific Earthquake Engineering Research Center, *Central and Eastern North America Ground-Motion Characterization: NGA-East Final Report*, (Berkeley, CA: December 2018). After reviewing this report, NRC determined that 13 nuclear power plants located in the central and eastern United States needed further assessment. Based on assessments conducted as of March 2024, NRC determined that no regulatory action was needed.

maintained during a natural disaster that exceeds a plant's design basis. In response, the nuclear industry developed and implemented the *Diverse and Flexible Coping Strategies (FLEX) Implementation Guide,* which NRC has endorsed as one method to comply with the 2012 order.[48] FLEX is a strategy that uses controls, procedures, and backup equipment to ensure that the key safety functions related to cooling a reactor's core and spent fuel, as well as containment to prevent accidental releases of radiation, are maintained if a disaster occurs at a plant. According to NRC officials, as part of this strategy, all plants have backup equipment on site. In addition, the nuclear power industry operates two Strategic Alliance for FLEX Emergency Response (SAFER) centers that maintain emergency equipment that can be provided to plants as a backup to plants' primary backup equipment onsite.[49] See figure 10 for examples of FLEX and SAFER equipment.

[48]Nuclear Energy Institute, *Diverse and Flexible Coping Strategies (FLEX) Implementation Guide*, NEI 12-06, August 2012.

[49]The SAFER centers are located in Phoenix, Arizona, and Memphis, Tennessee. The SAFER centers' staff comprises staff from a private company that has contractual agreements to manage and deploy offsite equipment with every nuclear licensee in the United States as part of FLEX. The SAFER centers maintain generic equipment useful for multiple plants, including various types of generators and pumps, and site-specific equipment unique to certain plants. NRC determined there is reasonable assurance that equipment at the SAFER centers can be deployed to any plant in the United States within 24 hours, as specified by licensees' SAFER response plans. To date, no SAFER response plan has been activated. According to our analysis of federal hazard data, SAFER centers are in areas with no exposure to sea level rise or hurricane storm surge, and either low (Memphis) or high (Phoenix) flood hazard. The centers are located in areas projected to see an increase in daily temperature from 3.6 to 4.9 degrees, and the Phoenix SAFER center is in an area with high or very high wildfire risk.

**Figure 10: Examples of the Diverse and Flexible Coping Strategies (FLEX) and Strategic Alliance for FLEX Emergency Response (SAFER) Center Equipment**


Top: Water purification equipment, located at the National SAFER Response Center in Phoenix, Arizona, is designed to facilitate the use of higher quality water for the reactor coolant system's makeup. Bottom left: Arizona's Palo Verde Generating Station high-pressure reactor coolant system injection pump is used to support the FLEX strategy and receives borated water from an onsite storage tank to inject into the reactor coolant system to maintain reactor coolant system inventory and nuclear reactivity. Bottom right: Florida's Turkey Point Nuclear Generating Station steam generator FLEX well pump is a piece of backup equipment used to refill a storage tank from an artesian well for the purpose of adding water to the steam generator.

Sources: GAO analysis of Nuclear Regulatory Commission documents and interview with licensee staff; GAO (photos). | GAO-24-106326

## NRC's Actions Do Not Fully Consider the Potential Effects of Climate Change

NRC's actions to address risks to nuclear power plants from natural hazards in its licensing, license renewal, and inspection processes do not fully consider the potential increased risks from natural hazards that may be exacerbated by climate change.

- **Licensing.** NRC does not use climate projections data to identify and assess risk as part of the safety reviews or probabilistic risk assessment reviews it conducts during the initial licensing process.[50] Rather, NRC uses historical data to extrapolate the future risks of natural hazards that may occur during the lifetime of a nuclear power plant.[51] Extrapolating historical data into the future assumes that existing climatological trends will continue.[52] According to NRC officials, NRC uses historical data in conjunction with other information to establish a conservative licensing basis, and many of the natural hazards considered during licensing target annual exceedance probabilities such that an event is unlikely to occur during the lifetime of the plant. In such a case, NRC expects the event to occur only once in 10,000 to 10 million years, depending on the hazard. NRC officials we interviewed told us that they review regional climate projections information for some hazards but do not incorporate site-specific climate projections data, which include hazard assessments, design bases, or determining the adequate safety margin for plants. For example, NRC officials said they review the projected average increase in temperature that applies to a multi-state region according to the NCA designation and compare that with the maximum temperature limits for a particular plant in that region. The officials said that they do not use data on the projected temperature increase to inform licensing decisions at the plant site itself.

- **License renewals.** Following an initial 40-year licensing period, NRC does not reevaluate natural hazard risks, including climate-related

[50]The NCA defines a "climate projection" as the simulated response of the climate system to a scenario of future emissions or concentrations of greenhouse gases and aerosols, generally derived using climate models. Projections data could be based on a range of possible future scenarios for particular time frames, such as the projected temperature of a specific location in the year 2050, as identified by models that consider climate systems' physical, chemical, and biological properties and their interactions. According to NRC officials we interviewed, probabilistic risk assessments use current estimates of the probability of external events, and neither licensees' nor NRC's assessments incorporate climate projections data, despite their role in assessing the likelihood of future events. NRC officials said that while it is both technical and feasible to update these models with the latest information reflecting their current state of knowledge, using climate projections data would increase uncertainty in the results of the probabilistic risk assessments, and no historical trends have emerged to suggest the need to adjust these.

[51]For example, NRC regulations for evaluating sites for initial licensing require NRC to consider the seismology, meteorology, geology, and hydrology of the site and to estimate the "maximum probable flood" using historical data, among other factors. 10 C.F.R. § 100.20(c). These regulations do not preclude NRC from using climate projections data.

[52]As noted previously, according to the NCA, climate change is altering the characteristics of many extreme weather events. Specifically, some of these events have already become more frequent, intense, widespread, or of longer duration, and many are expected to continue to worsen.

risks, to update the safety reviews required for the license renewal process. NRC's license renewal process focuses on evaluating and managing the effects of aging on the extended operations of nuclear power plants and considers the original licensing basis in that context.[53] As of January 2024, NRC had issued license renewals to 49 of the 54 operating nuclear power plants, meaning most plants are operating on the basis of assessments of natural hazard risk that are over 40 years old.

- **Inspections.** During regular inspections, NRC resident inspectors are responsible for focusing on the immediate day-to-day safety of plants rather than on the potential long-term safety risks. Inspections do not include an assessment of future climate projections data. In addition, while NRC sometimes conducts additional inspections using outside teams—including staff from NRC regional offices—to address recent events or emerging issues related to safety, these inspections also do not focus on long-term safety risks.

NRC officials we interviewed told us that while their regulatory processes—including licensing, license renewals, and inspections—do not use climate projections data to assess climate risks, they believe conservatism, safety margins, and defense-in-depth provide an adequate margin of safety to address climate risks to the safety of nuclear power plants.[54] However, NRC has not conducted an assessment to demonstrate that this is the case.

Moreover, NRC actions taken to address risks to nuclear power plants from natural hazards post-Fukushima did not fully consider the effects of climate change. Specifically, NRC required licensees to assess flooding risk and enhance safety and emergency equipment, but NRC did not require licensees to use climate projections data to assess future flooding

[53]Licensees are not required to reevaluate their plant's design basis pertaining to natural hazards as part of the license renewal process.

[54]According to NRC officials, NRC uses the NCA, which includes climate projections, in the environmental reviews it conducts during licensing and license renewals to assess the expected effects of nuclear power plants on the environment. For example, NRC addresses the greenhouse gas emissions associated with the life cycle of the plant as well as the potential effects of climate change on the environment in these reviews.

risks as part of these assessments or in the FLEX equipment needs assessments.[55]

NRC also created POANHI—its process for ongoing hazard assessments following Fukushima—which, according to NRC officials, NRC relies on to identify and assess changes in natural hazard risks, including those driven by climate change. However, POANHI has several limitations as a mechanism for comprehensively identifying and assessing climate risks. Specifically:

- While POANHI was designed to assess all natural hazards, NRC has not used POANHI to assess potential changes to all natural hazards, nor has NRC comprehensively reviewed natural hazards on a regular basis to determine whether available information indicates the need for a POANHI assessment. NRC officials told us that while POANHI requires continuous evaluation of new information on natural hazards, NRC conducts POANHI assessments for one hazard at a time, and the agency does not have a schedule for reviewing natural hazards beyond the assessment of seismic hazards currently underway. As such, POANHI is used to react to new hazard information or events when NRC staff become aware of them.
- NRC has not documented the new hazard information it reviews as part of POANHI or the way it incorporates climate projections data to determine whether to initiate a POANHI assessment, require additional plant-specific assessments, conduct an overall hazard reevaluation, or take regulatory action.
- NRC has not implemented POANHI and the Natural Hazards Information Digest at all levels of the agency. For example, several regional branch chiefs and resident inspectors we interviewed were unaware of POANHI and this information database. An official from one NRC regional office said that if the database were shared more broadly, it would benefit resident inspectors, who could access and use information on weather-related events and inspection findings to inform probabilistic risk assessments. According to NRC officials, the

[55]According to NRC officials, the plant-specific mitigation strategy relied on information each licensee had previously been required to provide as part of reevaluations of external events for comparison against the current licensing bases and FLEX equipment reflect the most severe external events that could occur based on known available meteorological, geological, and geographical data. According to NRC officials, the external hazards needing to be considered were both extreme and rare in nature which resulted in the regulatory approach of using flexible, diverse strategies to maintain or restore core cooling, containment, and spent fuel pool cooling.

agency is conducting internal outreach to increase NRC staff's knowledge of POANHI.

NRC's Fiscal Year 2022–2026 Strategic Plan calls for ensuring that licensees have measures to address the potential for increased risks from climate change. The strategic plan also promotes risk-informed decision-making to support NRC's strategic objective of providing quality licensing and oversight of nuclear facilities. Moreover, *GAO's Standards for Internal Control in the Federal Government* state that management should identify, analyze, and respond to risks related to achieving defined objectives.[56] These standards also call for agency management to use quality information to achieve their objectives.

Assessing its current processes would help NRC to determine whether they adequately address the potential for increased risks to nuclear power plants from climate change. Specifically, identifying gaps in its processes and developing a plan to address them, including by using climate projections data or augmenting POANHI, would help ensure that NRC adopts a comprehensive approach for assessing risks and fulfills its mission to protect public health and safety.

NRC officials told us that they use historical data in licensing and oversight processes rather than climate projections data, in part because regulations require NRC to use available historical data to assess the safety of the reactor site and design and they believe these data are reliable and sufficient for developing an adequate margin of safety for plants.[57] According to NRC officials, using site-specific climate projections

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[56]GAO-14-704G. Risk assessment is the identification and analysis of risks related to achieving defined objectives to form a basis for developing responses to these risks. Our prior work has shown that assessing risks includes assessing both the likelihood of an event occurring and the effect the event would have. Agency leaders and subject matter experts should assess each risk by assigning the likelihood of the event's occurrence and the potential effect if the event occurs. GAO, *Enterprise Risk Management: Selected Agencies' Experiences Illustrate Good Practices in Managing Risk*, GAO-17-63 (Washington, D.C.: Dec. 1, 2016).

[57]See, e.g., 10 C.F.R. § 100.20(c) (requiring NRC to consider for initial licensing of new reactors the seismology, meteorology, geology, and hydrology of the site and to estimate the "maximum probable flood" using historical data). See also 10 C.F.R. § 60.2 (defining "design bases" to include using severe natural events estimates based on historical and physical data); and 10 C.F.R. Part 50, Appendix A, General Design for Nuclear Power Plants, Criterion 2—*Design Bases for Protection Against Natural Phenomena* (requiring the design bases for the reactor's safety structures, systems, and components to consider the "most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated," among other factors).

data for extreme hazard levels in nuclear power plant design and safety reviews is challenging because of the uncertainty associated with applying these data to specific sites. However, NRC regulations do not preclude NRC from using climate projections data, and new sources of reliable projected climate data are available to NRC. In 2023, the White House Office of Science and Technology Policy issued guidance to federal agencies on selecting and using climate data to assess risks and their potential impacts.[58] This guide provides information on climate models and projections to help federal agencies understand exposure to current and future climate-related hazards and their potential impacts. Without incorporating the best available information into its licensing and oversight processes, it is unclear whether the safety margins for nuclear power plants established during the licensing period—in most cases over 40 years ago—are adequate to address the risks that climate change poses to plants.

## Conclusions

Commercial nuclear power plants in the United States were licensed and built an average of 42 years ago, and weather patterns and climate-related risks to their safety and operations have changed since their construction. Climate change is expected to exacerbate natural hazards—such as heat, drought, wildfires, flooding, hurricanes, sea level rise, and extreme cold weather events—that can affect nuclear power plant safety and operations in various ways. Some of these effects are already occurring, and many are expected to continue to worsen.

However, NRC does not use climate projections data to identify and assess risk as part of the safety reviews it conducts or the probabilistic risk assessments it reviews during the initial licensing process. NRC has also not fully developed POANHI, which the agency relies on to identify and assess changes in natural hazard risks, including climate change.

NRC has the opportunity to consider climate risks more fully and, in doing so, to better fulfill its mission to protect public health and safety.

[58]Office of Science and Technology Policy, *Selecting Climate Information to Use in Climate Risk and Impact Assessments: Guide for Federal Agency Climate Adaptation Planners*, (Washington, D.C.: March 2023). Although climate projections data and guidance are available to federal agencies, we previously recommended that the federal government, through the Executive Office of the President, make authoritative climate data and information accessible and assist in translating that information for decision makers. GAO, *High-Risk Series: Efforts Made to Achieve Progress Need to Be Maintained and Expanded to Fully Address All Areas,* GAO-23-106203 (Washington, D.C.: April 20, 2023) and *Climate Information: A National System Could Help Federal, State, Local, and Private Sector Decision Makers Use Climate Information,* GAO-16-37 (Washington, D.C.: Nov. 23, 2015).

Specifically, assessing whether its licensing and oversight processes adequately consider climate risks to nuclear power plants and developing and implementing a plan to address any gaps identified would help the agency do so. As NRC makes licensing, license renewal, and oversight decisions, adopting an approach that incorporates the best available information on climate risks and ways that those risks may affect nuclear plants, would provide greater assurance that licensees have adequate measures to address risks from climate change.

## Recommendations for Executive Action

We are making the following three recommendations to NRC:

The Chair of the NRC should direct NRC staff to assess whether its licensing and oversight processes adequately address the potential for increased risks to nuclear power plants from climate change. (Recommendation 1)

The Chair of the NRC should direct NRC staff to develop, finalize, and implement a plan to address any gaps identified in its assessment of existing processes. (Recommendation 2)

The Chair of the NRC should direct NRC staff to develop and finalize guidance on incorporating climate projections data into relevant processes, including what sources of climate projections data to use and when and how to use climate projections data. (Recommendation 3)

## Agency Comments and Our Evaluation

We provided a draft of this report for review and comment to NRC.

In its written comments, reproduced in appendix IV, NRC stated that the three recommendations are consistent with actions that are either underway or under development. In addition, NRC stated that the layers of conservatism and defense-in-depth incorporated into NRC's processes provide reasonable assurance regarding any plausible natural hazard and combinations at a site for the licensed operational lifetime of the reactor, including those that could result from climate change. As we noted in our report, NRC has not conducted an assessment to demonstrate that the safety margins for nuclear power plants established during the licensing period are adequate to address the risks that climate change poses to plants. According to the NCA, many of the climate conditions and impacts experienced in the United States today are unprecedented for thousands of years. Across all regions of the United States, extremes, including heat, drought, flooding, wildfire, and hurricanes, are becoming more frequent and/or severe, with a cascade of effects in every part of the country. We continue to believe that NRC cannot fully consider potential climate change effects on plants without using the best available information—including climate projections data—in its licensing and oversight processes.

NRC also provided technical comments, which we incorporated, as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Chair of the NRC, and other interested parties. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-3841 or ruscof@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix V.

Frank Rusco
Director, Natural Resources and Environment

# Appendix I: Objectives, Scope, and Methodology

This report examines (1) how climate change is expected to affect nuclear power plants and (2) actions the Nuclear Regulatory Commission (NRC) has taken to address the risks to nuclear power plants from climate change.

To address both objectives, we interviewed officials from NRC headquarters, all four NRC regional offices, and two nuclear power plants. We also interviewed officials from the Department of Energy—including the Office of Nuclear Energy and the Idaho National Laboratory—the Department of Homeland Security, the Federal Energy Regulatory Commission, and the National Oceanic and Atmospheric Administration (NOAA). We also interviewed nine stakeholders knowledgeable about nuclear power plant safety and operations, climate change, and resilience measures. These included stakeholders from three industry groups, four nongovernmental organizations, and two academic institutions. We identified stakeholders using snowball sampling.[1] Views from selected stakeholders cannot be generalized to all stakeholders.

We conducted site visits to two nuclear power plants—Palo Verde Nuclear Generating Station in Buckeye, Arizona, and Turkey Point Nuclear Generating Station in Homestead, Florida. We toured the power plants and interviewed plant staff and NRC resident inspectors at each site. To answer both objectives, we chose these sites for in-person visits based on factors including exposure to distinct natural hazards, regional diversity, reactor type, licensee size, and agency resources. Findings from selected site visits are not generalizable to all sites.

To address how climate change is expected to affect nuclear power plants, we reviewed prior GAO reports and sources of climate change information (including the fourth and fifth National Climate Assessments (NCA)), completed a literature review, and conducted data analysis.[2] To conduct the literature review of articles and reports related to the effects of selected hazards and climate change on nuclear power plants, we searched a variety of scholarly, trade, and news databases, such as Ei

[1]In snowball sampling, the methodology begins with an initial list of contacts and asks each person interviewed to refer the interviewer to additional cognizant persons. The group of referred contacts (or “snowball”) grows larger and then narrows as a group of individuals are identified frequently.

[2]Few supporting sources distinguish between the impact of selected natural hazards on operating versus shutdown nuclear power plants. As a result, we most often do not make this distinction.

Encompass LIT, Geobase, Inspec, the National Technical Information Service, ProQuest Environmental Science Professional, and Scopus using relevant keywords (e.g., “nuclear power,” “climate change,” “risk,” and “extreme weather”) for articles and other documents published since 2012. The results yielded 107 potentially relevant articles and other documents published from January 2012 through January 2023. To determine which articles were relevant to our scope, one analyst reviewed the articles’ abstracts and determined whether the articles were in scope using professional judgment based on their knowledge of the engagement’s scope. A second analyst reviewed the first analyst’s determinations, and the two came to a consensus on which articles were in scope. Using this method, we selected 56 articles and other documents for further review. Reviewing them for relevance, we ultimately identified and used 36 articles to support findings in our report.

To conduct our data analysis, we identified national-level data sets from relevant federal agencies for six of the seven natural hazards identified by the NCA, and our review of literature, as likely to be exacerbated by climate change in the United States. The six hazards are heat, cold, wildfires, flooding, storm surge from hurricanes, and sea level rise.[3] For heat and cold, we used climate projections data that incorporate emission scenarios to project future exposure to those hazards.[4] For wildfires, flooding, and hurricane storm surge, we used climate data that show current conditions based on past conditions (which do not incorporate climate projections).[5] For sea level rise, we used data for coastal regions and sea level rise projections from an interagency report covering sea level rise scenarios to identify coastal nuclear power plants and projected

[3]To identify the best available federal-level hazard data, we relied on interviews with agency officials and prior GAO reports. We did not analyze drought data because we were unable to identify national-level geospatial data that was both relevant to nuclear power plants and sufficiently reliable for our purposes.

[4]To analyze projected exposure to heat and cold hazards, we used NCA data on the projected exposure to maximum and minimum temperatures in the midcentury (i.e., 2036–2065), using both a low and high emission scenario for projected climate change.

[5]To analyze flood exposure, we used 2023 data from the Federal Emergency Management Agency that categorizes flood exposure into high, moderate, minimal or other, and unknown flood hazard categories. To analyze exposure to hurricane storm surge, we used NOAA data on storm surge exposure from Categories 1, 4, and 5 hurricanes. To analyze exposure to wildfires, we used 2023 data from the U.S. Forest Service on wildfire hazard potential.

sea level rise in their respective regions.[6] In this report, we refer to these hazards collectively as selected natural hazards that may be exacerbated by climate change.

For our national-level data from federal agencies, we used data we determined to be the most appropriate to represent selected natural hazards.[7] Data sources for each of the hazards we analyzed are, as follows:

- **Heat and cold.** To analyze projected exposure to heat and cold, we used data from the fourth NCA on the projected exposure to maximum temperatures in the midcentury (i.e., 2036–2065).[8]
- **Wildfire.** To analyze exposure to wildfire hazard potential, we used 2023 data from the U.S. Forest Service's Wildfire Hazard Potential Map. For reporting purposes, we grouped wildfire hazard potential into the following three categories: no/low, moderate, and high/very high.[9]
- **Flooding.** To analyze exposure to flood hazards, we used 2023 data from the Federal Emergency Management Agency's National Flood Hazard Layer. For reporting purposes, we grouped flood hazard

[6]W. V. Sweet, B. D. Hamlington, R. E. Kopp, C. P. Weaver, P. L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A. S. Genz, J. P. Krasting, E. Larour, D. Marcy, J. J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K. D. White, and C. Zuzak, *Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines*, NOAA Technical Report NOS 01 (Silver Spring, MD: February 2022).

[7]Data sources were chosen based on use in prior GAO reports, review of the NCA, and interviews with federal agencies responsible for collecting and reporting on data related to the selected natural hazards.

[8]The fifth NCA was released on November 14, 2023, after we had obtained and analyzed the hazard data sets from the fourth NCA. We reviewed relevant sections from the fifth NCA and did not identify major differences in the predicted or projected trends for the selected natural hazards.

[9]We combined layers of "high" and "very high" wildfire hazard potentials, which correspond to areas at the 85th percentile or greater for wildfire hazard potential. The no/low category includes plants that are in areas that are not covered by the "moderate," "high," or "very high" wildfire potential layers.

zones into the following three categories: no/low, moderate, and high.[10]

- **Hurricane storm surge.** To analyze exposure to various levels of hurricane storm surge, we used data from NOAA's Sea, Lake, and Overland Surges from Hurricanes model. We used a range of categories from the data, including no exposure to hurricanes, and Categories 1, 4, and 5 hurricanes.[11]
- **Sea level rise.** To analyze potential exposure to sea level rise in 2050, we used data from an interagency report covering sea level rise scenarios to illustrate regional climate projections for sea level rise in coastal regions. The data include two types of estimates–observation-based extrapolations and regionalized global mean sea level scenarios. NOAA officials recommended using these projections for our analysis of sea level rise data.

To identify nuclear power plant locations, we used nuclear power plant location data from NRC.[12] We used a 0.5-mile radius around the plant coordinates provided by NRC as a proxy for approximate plant size. We based the size of the radius on approximations we made for an average U.S. nuclear power plant.[13]

See appendix II for further discussion of these data sources.

[10]No/low corresponds to areas with minimal, unknown, or other flood hazards, including areas with reduced risk because of levees as well as areas with flood hazard based on future conditions, such as the future implementation of land-use plans. Moderate flood hazard zones correspond to a 500-year floodplain, which indicates between 0.2 percent and 1 percent annual chance of flooding. High flood hazard zones correspond to a 100-year floodplain, which indicates a 1 percent or higher annual chance of flooding.

[11]In our analysis, we used data on storm surge from Category 1 hurricanes (the lowest possible category) and for Categories 4 and 5 hurricanes (the highest possible categories) to show a range of climate change effects.

[12]In March of 2023, we obtained NRC nuclear power plant coordinates for all 54 operating nuclear power plants. In July 2023, we obtained NRC nuclear power plant coordinates for the 21 nuclear power plants that have shut down and have spent nuclear fuel stored onsite in spent fuel pools or in dry cask storage. NRC provided coordinates, including a latitude and longitude value for each plant. In addition, NRC's location data file contained other identifying plant information including operating status, license number, and reactor type.

[13]We requested average plant size from NRC, but NRC was unable to provide these data. Instead, we approximated the size of a typical nuclear power plant using DOE documentation on nuclear power plants.

Using hazard and nuclear power plant location data, we analyzed natural hazard exposure in the areas around nuclear power plants. In our analysis, we included operating plants and plants at various stages of decommissioning, including those in the process of decommissioning and those already shut down, with spent nuclear fuel stored onsite. We did not include experimental or test reactors in our analysis.

For certain hazards, we analyzed exposure to a range of intensities. For example, we analyzed nuclear power plant exposure to storm surge from the weakest (Category 1) and strongest (Category 5) hurricanes, as modeled by NOAA.

To analyze whether nuclear plants are located in areas that may be affected by heat, cold, wildfire, flooding, and hurricane storm surge, we used MapInfo mapping software to determine whether the nuclear power plant locations were located in areas with exposure to the selected hazards. Exposure indicates that a facility is located in an area that may be affected by a selected hazard. If the plant overlapped with multiple hazard layers, the layer representing the highest level of exposure was reported. For example, in our report, we coded a plant whose locations showed exposure to both layers for Category 1 and Category 5 storm surge data as having exposure to Category 5 storm surge.

We assessed the reliability of the fourth NCA climate projections data we used to analyze heat and cold exposure by (1) interviewing NOAA officials knowledgeable about the data and (2) reviewing existing information about the data and system that produced them.

To assess the reliability of the Federal Emergency Management Agency's National Flood Hazard Layer, NOAA's data on Sea, Lake, and Overland Surges from Hurricanes, and the U.S. Forest Service's Wildfire Hazard Potential data, we reviewed prior GAO data reliability assessments for reports using the same data.[14] Then, through interviews and email correspondence with NOAA, the Federal Emergency Management Agency, and U.S. Forest Service officials, we ensured that these data remained appropriate and reliable, considering any subsequent updates or changes made to the data.

[14]GAO, *Chemical Accident Prevention: EPA Should Ensure Regulated Facilities Consider Risks from Climate Change*, GAO-22-104494 (Washington, D.C.: Feb. 28, 2022) and GAO, *Superfund: EPA Should Take Additional Actions to Manage Risks from Climate Change,* GAO-20-73 (Washington, D.C.: Oct. 18, 2019).

To assess the reliability and appropriate use of sea level rise data for use in our analysis, we reviewed regional sea level rise data in an interagency report covering sea level rise scenarios and interviewed NOAA officials knowledgeable about sea level rise data.

To assess the reliability of NRC's data on nuclear power plant locations, we communicated with NRC staff about data accuracy and conducted limited data testing.[15] As a result of the steps described above, we found the data from the NCA, the Federal Emergency Management Agency, NOAA, the U.S. Forest Service, and NRC to be sufficiently reliable for the purpose of our reporting objectives.

To examine NRC's actions to address risks to nuclear power plants from climate change, we conducted interviews and reviewed relevant agency documents. We interviewed officials from NRC headquarters, all four NRC regional offices, and two nuclear power plants. During our two nuclear power plant site visits, we interviewed plant operator staff as well as NRC's resident inspectors to assess whether NRC processes to mitigate the risks of natural hazards and extreme weather at those plants adequately consider climate change risks. We also observed an NRC safety evaluation review to understand the extent to which NRC incorporates considerations of climate change risks when determining whether and under what conditions to license a nuclear power plant.[16] We reviewed relevant documents consisting of the following: relevant laws and regulations, agency documents (including guidance on probabilistic risk assessments and NRC's 2022–2026 Strategic Plan), two NRC office instructions, NRC's inspection manual on adverse weather protection, and other documents.[17] We compared NRC's actions against requirements to identify any relevant gaps. We also reviewed GAO's

[15]Specifically, we inputted a selection of NRC's location data into mapping software to ensure NRC's latitude and longitude location data for nuclear power plants correctly corresponded to plant names and identifying information provided by NRC. Also, we compared the plant operating status of selected plants in NRC's dataset with public information to ensure the operating status of plants matched.

[16]This safety evaluation review was for Turkey Point's Units 6 and 7, which were granted an operating license under 10 C.F.R. Part 52 but have not been built, according to NRC officials.

[17]NRC, *Strategic Plan Fiscal Years 2022–2026,* NUREG-1614, Vol. 8 (Washington, D.C.: April 2022). See also, NRC, *Inspection Manual: Adverse Weather Protection,* Inspection Procedure 71111, Attachment 01 (Washington, D.C.: Jan. 1, 2018).

*Standards for Internal Control in the Federal Government* and compared NRC's actions against those standards.[18]

We conducted this performance audit from November 2022 to April 2024 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

[18]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: Sept. 10, 2014).

# Appendix II: Available Federal Data on Heat, Cold, Wildfires, Flooding, Storm Surge, and Sea Level Rise

This appendix provides information on data sources we used to analyze potential exposure of nuclear power plants to selected natural hazards—including heat, cold, wildfires, flooding, storm surge from hurricanes, and sea level rise. We include information, when available, on the data source name, description, purpose, update frequency, and limitations.

## National Climate Assessment Heat and Cold Climate Projections Data

The U.S. Global Change Research Program posts climate projections data on its website so that authors and other users can access their data.[1] The variables we used for heat and cold are part of a suite of variables intended to provide users insights into the effects of climate change on different variables under multiple emission scenarios.[2]

We analyzed and reported on the following heat or cold variables from the fourth National Climate Assessment (NCA):[3]

- projected change in maximum daily temperature;

[1]NOAA's Technical Support Unit and the Scripps Institute of Oceanography were involved in creating these data. Together, these stakeholders contributed to creating 100 variables derived through statistical downscaling—a process used to take climate model data, which are typically at a low resolution, and produce more detailed data relevant to a specific location or region. Climate projections have limitations that include uncertainties in emissions, natural variability, and differences in scientific models. "Emission uncertainty" refers to a climate projection's reliance on emission scenarios reliant on assumptions about future emissions, changes in population, energy use, and technology. "Natural variability" refers to unpredictable climate events like volcanic eruptions. Scientific models refer to the way processes are understood and incorporated. For example, any change in the scientific understanding of cloud properties and ocean circulation can affect projections of future climate. In this report, we refer to these data as NCA data.

[2]Climate projections are based on emissions scenarios. These scenarios are produced using a range of future assumptions about underlying socioeconomic conditions, such as population and global gross domestic product projections. The climate projections data from the fourth NCA enable users to analyze projected exposure to temperature, precipitation, and other related variables by using a range of emission scenarios and time periods. Four scenarios are available, including historical climate (averages based on the 1976–2005 climate), lower (averages based on NCA assumptions for intermediate-low sea level rise, lower population, and lower development land use), higher (averages based on intermediate sea level rise, higher population, and higher development land use), and the upper bound (averages based on extreme sea level rise, higher population, and higher development land use). All four scenarios base their future projections on historical climate data for 1976–2005. These scenarios are available for three time periods, which include the early 21st Century (2016–2045), mid-21st Century (2036–2065), and late 21st Century (2070–2099).

[3]The fifth NCA became available in November 2023, after we had obtained and analyzed heat and cold data from the fourth NCA.

- projected change in the annual days with a maximum temperature greater than the 99th percentile;
- projected change in the annual number of days with a maximum temperature greater than 115 degrees Fahrenheit;
- projected change in annual highest maximum temperature averaged over a 5-day period; and
- projected change in the annual number of days with a maximum temperature lower than the 1st percentile.[4]

## U.S. Forest Service Wildfire Hazard Potential Data

The U.S. Forest Service maps wildfire hazard potential based on landscape conditions and other observations. We previously reported that the primary intended use of the wildfire hazard potential map is to identify priority areas for hazardous fuels treatments from a broad, national- to regional-scale perspective. The data do not explicitly show wildfire threat or risk.[5]

The U.S. Forest Service maps an index of wildfire hazard potential for the contiguous United States based on, among other factors, annual burn probabilities and potential intensity of large fires. The U.S. Forest Service categorizes the wildfire hazard potential index into five classes: very low, low, moderate, high, and very high. The U.S. Forest Service designates as “high” those areas with wildfire hazard potential index from the 85th to the 95th percentiles, and as “very high” those areas above the 95th percentile. The U.S. Forest Service also categorizes some areas as non-burnable (including agricultural lands, developed lands, and water).

As we previously reported, according to the U.S. Forest Service, areas with higher levels of wildfire hazard potential have fuels that are more likely to burn with high intensity under certain weather conditions. However, areas with moderate, low, and very low wildfire hazard potential

[4]We selected temperature data using the projected change by the midcentury time frame under both a low and high emission scenario to show the range of potential projected change to selected natural hazards. The midcentury time frame was selected because it captures potential hazard effects during the period in which nuclear power plants are likely to remain operational. Other available variables include the average daily temperature and maximum 1- or 5-day precipitation. In this report, we refer to these data as NCA data.

[5]The objective of the wildfire hazard potential map is to depict the relative potential for wildfire that would be difficult for suppression resources to contain. The U.S. Forest Service’s Wildfire Hazard Potential map is available at https://doi.org/10.2737/RDS-2015-0047-4.

may still experience wildfires, particularly near areas with higher wildfire hazard potential.

We used 2023 wildfire hazard potential data. These data incorporated methodological changes to the fire simulation modeling to better represent probabilistic components of wildfire hazard for the fuel and climate conditions as they exist today, according to U.S. Forest Service officials we interviewed. For our analysis, we combined the high and very high wildfire hazard potential categories; we did not identify the number of facilities in each of these categories separately.

## Federal Emergency Management Agency Flood Hazard Data

The Federal Emergency Management Agency's National Flood Hazard Layer provides data on the most current coastal and riverine flooding hazard data.[6] Among other uses, the flood hazard data are used for flood insurance ratings and floodplain management. The National Flood Hazard Layer identifies areas with the highest risk of flooding, with a 1 percent or higher annual chance of flooding.[7] In some locations, the National Flood Hazard Layer also identifies areas with a 0.2 percent or higher annual chance of flooding, which the Federal Emergency Management Agency considers moderate flood hazards, and other flood hazards.[8] The National Flood Hazard Layer also identifies areas with minimal flood hazards, including those with less than 0.2 percent annual chance of flooding, and unknown flood hazards, including areas the Federal Emergency Management Agency has not assessed for flood hazards.

[6]Riverine flooding is flooding related to or caused by a river, stream, or tributary overflowing its banks because of excessive rainfall, snowmelt, or ice. The Federal Emergency Management Agency provides a tool for viewing, downloading, and printing flood maps for specific locations. The Federal Emergency Management Agency's flood hazard maps are available at https://www.fema.gov/flood-maps/national-flood-hazard-layer. Federal law requires the Federal Emergency Management Agency to assess the need to revise and update the nation's flood maps once every 5 years or more often as the Administrator determines necessary. 42 U.S.C. § 4101(e).

[7]These areas are known as Special Flood Hazard Areas. Under federal law, in communities that participate in the National Flood Insurance Program, homeowners are required to purchase flood insurance for properties located in Special Flood Hazard Areas that are secured by mortgages from federally regulated lenders. 42 U.S.C. § 4012a(b)(1).

[8]Other flood hazards include areas with reduced risk because of levees, as well as areas with flood hazard based on future conditions, for example, if land use plans were implemented.

## National Oceanic and Atmospheric Administration Storm Surge Hazard Data

The National Oceanic and Atmospheric Administration (NOAA) provides estimates of hurricane storm surge using a model called Sea, Lake, and Overland Surges from Hurricanes.[9] Estimates for storm surge are available for coastal areas in the eastern United States from Texas to Maine as well as in Hawaii, Puerto Rico, and the U.S. Virgin Islands. As of November 2023, storm surge data for coastal areas in the western United States were only available for Southern California.

The model accounts for specific shorelines by incorporating bay and river configurations, water depths, bridges, roads, levees, and other physical features. It estimates the maximum extent of storm surge at high tide by modeling hypothetical hurricanes under different storm conditions, such as landfall location, storm trajectory, and forward speed.

NOAA models storm surge for Category 1 through Category 5 hurricanes for the Atlantic coast south of the North Carolina-Virginia border, the Gulf of Mexico, Puerto Rico, and the U.S. Virgin Islands; and Category 1 through Category 4 hurricanes for the Atlantic coast north of the North Carolina-Virginia border and Hawaii.[10] As we previously reported, the model is to be used for educational purposes and to increase awareness of storm surge hazards at a city or community level. According to NOAA's website, the agency updates the model for portions of the shoreline each year to account for, among other changes, new data and the addition of flood protection devices, such as levees. The model does not account for future conditions such as erosion, subsidence (i.e., the sinking of an area of land), construction, or sea level rise.

## 2022 Interagency Sea Level Rise Technical Report Sea Level Rise Data

The 2022 Interagency Sea Level Rise Technical Report provides observation-based extrapolations and model-based global mean sea level scenarios as two distinct estimates of future sea level rise. Observation-based extrapolations use observed changes in sea level rise to estimate

[9]According to NOAA, "storm surge" is an abnormal rise of water generated by a storm, over and above the predicted tides. Storm surge is produced by water being pushed toward the shore by the force of the storm's winds. NOAA's storm surge hazard maps are available at https://www.nhc.noaa.gov/nationalsurge/.

[10]We previously reported that NOAA does not estimate storm surge for Category 5 hurricanes in areas where such hurricanes have not historically made landfall, such as areas north of the North Carolina-Virginia border.

the trajectory of sea level rise.[11] Model-based-global mean sea level scenarios use emission scenarios to estimate future sea level rise. The 2022 Interagency Sea Level Rise Technical Report provides both types of estimates for sea level rise in 2050 (relative to a baseline of the year 2000) for eight coastal regions of the United States. Formed by analyzing aggregated tide gauge data, the regional boundary data that NOAA provided our team include the Northeast (Maine to Virginia), the Southeast (North Carolina to the east coast of Florida), the Eastern Gulf (west coast of Florida to Mississippi), the Western Gulf (Louisiana to Texas), the Southwest (California), the Northwest (Oregon to Washington), the Hawaiian Islands, and the Caribbean.

The 2022 Interagency Sea Level Rise Technical Report providing the sea level rise estimates and coastal regions is intended to help inform federal agencies, Tribes, state and local governments, and stakeholders in coastal communities about current and future sea level rise.[12] The two primary limitations that the report discusses for the sea level rise estimates we use include process uncertainty and emission uncertainty. Process uncertainty refers to uncertainty about the impact of emissions on ice sheet loss, ocean expansion, and local ocean dynamics. Emission uncertainty refers to the uncertain amount of greenhouse gas emissions that will enter the atmosphere, trap heat, and affect temperature and sea level rise.

[11]The observation-based extrapolations are intended to serve as a comparison with the model-based-global mean sea level scenarios.

[12]W. V. Sweet, B. D. Hamlington, R. E. Kopp, C. P. Weaver, P. L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A. S. Genz, J. P. Krasting, E. Larour, D. Marcy, J. J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K. D. White, and C. Zuzak, *2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines*, NOAA Technical Report NOS 01 (Silver Spring, MD: February 2022).

# Appendix III: Nuclear Power Plant Exposure to Selected Natural Hazards

Table 1 shows the exposure of areas around operating nuclear power plant locations to six current or projected natural hazards: flooding, hurricane storm surge, wildfire, sea level rise, heat, and cold. Data for flooding, hurricane storm surge, and wildfire are current and based on historical observation data. Data for sea level rise and heat and cold temperature variables are climate projections data, which incorporate emission scenarios. For more information about the data sources used, see appendix II.

Table 1: Potential Exposure to Current and Future Hazards at Operating Nuclear Power Plants

| Plant[a] | State | Flood hazard level[b] | Hurricane storm surge level[c] | Wildfire potential level[d] | Projected regional sea level rise in 2050, low and high emission scenarios (feet)[e] | Projected change in max. daily temp., low and high emission scenarios (°Fahrenheit)[f] | Projected change in max. temp. exceeding historical highs, low and high emission scenarios (days/year)[g] | Projected change in max. temp. over 115°F, low and high emission scenarios (days/ year)[h] | Projected change in 5-day max. temp., low and high emission scenarios, (°Fahrenheit)[i] | Projected change in max. temp. below historical lows, low and high emission scenarios (days/ year)[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Browns Ferry** | AL | High | No exposure | None/ low | N/A | 3.74, 4.61°F | 21.07, 29.35 days | 0.01, 0.05 days | 5.05, 6.32°F | -1.86, -2.18 days |
| **Joseph M. Farley** | AL | High | No exposure | Moderate | 1.0, 1.7 ft. | 3.53, 4.33°F | 19.79, 28.87 days | 0.01, 0.02 days | 4.33, 5.44°F | -1.88, -2.27 days |
| **Arkansas Nuclear One** | AR | High | No exposure | Moderate | N/A | 3.90, 4.85°F | 14.15, 20.63 days | 0.09, 0.17 days | 4.94, 6.10°F | -2.01, -2.25 days |
| **Palo Verde** | AZ | Moderate | No exposure | None/ low | N/A | 3.64, 4.73°F | 16.66, 24.67 days | 15.09, 22.64 days | 3.82, 4.85°F | -2.34, -2.72 days |
| **SAFER Phoenix[k]** | AZ | High | No exposure | High/ very high | N/A | 3.59, 4.66°F | 19.21, 28.16 days | 12.86, 19.86 days | 4.31, 5.32°F | -2.09, -2.52 days |
| **Diablo Canyon** | CA | High | No exposure | High/ very high | 0.5, 1.2 ft. | 2.59, 3.27°F | 5.14, 7.10 days | 0, 0 days | 3.56, 4.35°F | -2.49, -2.82 days |
| **Millstone** | CT | High | Category 4 | None/ low | 1.2, 1.8 ft. | 3.38, 4.32°F | 8.28, 12.78 days | 0, 0 days | 3.52, 4.76°F | -2.37, -2.77 days |
| **St. Lucie** | FL | High | Category 5 | Moderate | 0.9, 1.6 ft. | 3.05, 3.99°F | 37.60, 60.07 days | 0, 0 days | 3.52, 4.60°F | -1.52, -2.05 days |
| **Turkey Point** | FL | High | Category 5 | High/ very high | 0.9, 1.6 ft. | 2.91, 3.75°F | 54.28, 79.80 days | 0, 0 days | 3.11, 3.94°F | -1.99, -2.40 days |
| **Edwin I. Hatch** | GA | High | No exposure | High/ very high | 0.9, 1.6 ft. | 3.39, 4.22°F | 20.62, 30.21 days | 0, 0.01 days | 4.38, 5.56°F | -1.78, -2.25 days |

| Plant[a] | State | Flood hazard level[b] | Hurricane storm surge level[c] | Wildfire potential level[d] | Projected regional sea level rise in 2050, low and high emission scenarios (feet)[e] | Projected change in max. daily temp., low and high emission scenarios (°Fahrenheit)[f] | Projected change in max. temp. exceeding historical highs, low and high emission scenarios (days/year)[g] | Projected change in max. temp. over 115°F, low and high emission scenarios (days/ year)[h] | Projected change in 5-day max. temp., low and high emission scenarios, (°Fahrenheit)[i] | Projected change in max. temp. below historical lows, low and high emission scenarios (days/ year)[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Vogtle** | GA | No/low | No exposure | High/ very high | 0.9, 1.6 ft. | 3.54, 4.38°F | 16.23, 22.88 days | 0.01, 0.01 days | 4.30, 5.41°F | -2.02, -2.41 days |
| **Braidwood** | IL | No/low | No exposure | None/ low | N/A | 4.26, 5.35°F | 16.66, 24.74 days | 0.01, 0.01 days | 5.06, 6.57°F | -2.48, -2.76 days |
| **Byron** | IL | No/low | No exposure | None/ low | N/A | 4.37, 5.46°F | 15.92, 24.51 days | 0, 0 days | 5.26, 6.88°F | -2.61, -2.84 days |
| **Clinton** | IL | High | No exposure | None/ low | N/A | 4.35, 5.35°F | 19.12, 26.98 days | 0.05, 0.03 days | 5.50, 6.87°F | -2.41, -2.74 days |
| **Dresden** | IL | High | No exposure | None/ low | N/A | 4.27, 5.38°F | 17.00, 25.26 days | 0.01, 0.01 days | 5.08, 6.61°F | -2.52, -2.80 days |
| **LaSalle** | IL | No/low | No exposure | None/ low | N/A | 4.28, 5.40°F | 16.67, 24.88 days | 0.02, 0.01 days | 5.21, 6.79°F | -2.47, -2.77 days |
| **Quad Cities** | IL | High | No exposure | None/ low | N/A | 4.20, 5.22°F | 17.12, 25.92 days | 0.01, 0 days | 5.20, 6.73°F | -2.45, -2.70 days |
| **Wolf Creek** | KS | High | No exposure | None/ low | N/A | 3.91, 4.91°F | 11.36, 16.85 days | 0.15, 0.22 days | 4.92, 6.16°F | -1.87, -2.26 days |
| **River Bend** | LA | No/low | No exposure | None/ low | 1.6, 2.3 ft. | 3.09, 3.91°F | 29.25, 41.28 days | 0, 0 days | 3.85, 4.88°F | -1.33, -1.70 days |
| **Waterford** | LA | No/low | Category 5 | None/ low | 1.6, 2.3 ft. | 2.88, 3.59°F | 22.43, 33.67 days | 0, 0 days | 3.14, 4.04°F | -1.70, -2.04 days |
| **Calvert Cliffs** | MD | High | Category 4 | Moderate | 1.2, 1.8 ft. | 3.62, 4.58°F | 16.21, 24.27 days | 0, 0 days | 4.75, 6.22°F | -2.32, -2.61 days |

| Plant[a] | State | Flood hazard level[b] | Hurricane storm surge level[c] | Wildfire potential level[d] | Projected regional sea level rise in 2050, low and high emission scenarios (feet)[e] | Projected change in max. daily temp., low and high emission scenarios (°Fahrenheit)[f] | Projected change in max. temp. exceeding historical highs, low and high emission scenarios (days/year)[g] | Projected change in max. temp. over 115°F, low and high emission scenarios (days/ year)[h] | Projected change in 5-day max. temp., low and high emission scenarios, (°Fahrenheit)[i] | Projected change in max. temp. below historical lows, low and high emission scenarios (days/ year)[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Donald C. Cook** | MI | High | No exposure | None/ low | N/A | 4.25, 5.43°F | 16.75, 25.52 days | 0, 0 days | 5.23, 6.85°F | -2.67, -2.97 days |
| **Fermi** | MI | High | No exposure | None/ low | N/A | 4.18, 5.29°F | 15.12, 23.04 days | 0, 0 days | 5.29, 7.01°F | -2.84, -3.09 days |
| **Monticello** | MN | High | No exposure | Moderate | N/A | 4.36, 5.41°F | 14.72, 22.40 days | 0, 0 days | 5.27, 6.87°F | -2.72, -2.96 days |
| **Prairie Island** | MN | High | No exposure | None/ low | N/A | 4.44, 5.51°F | 14.28, 22.42 days | 0, 0 days | 4.86, 6.45°F | -2.78, -3.00 days |
| **Callaway** | MO | No/low | No exposure | None/ low | N/A | 4.34, 5.33°F | 15.36, 23.26 days | 0.15, 0.22 days | 5.71, 7.11°F | -2.31, -2.54 days |
| **Grand Gulf** | MS | High | No exposure | None/ low | 1.6, 2.3 ft. | 3.72, 4.59°F | 24.81, 34.84 days | 0, 0.01 days | 4.30, 5.46°F | -1.93, -2.18 days |
| **Brunswick** | NC | High | Category 5 | High/ very high | 0.9, 1.6 ft. | 2.67, 3.39°F | 12.00, 18.35 days | 0, 0 days | 3.02, 3.91°F | -1.94, -2.28 days |
| **McGuire** | NC | High | No exposure | High/ very high | N/A | 3.89, 4.82°F | 17.41, 24.70 days | 0, 0.02 days | 4.64, 5.91°F | -2.07, -2.36 days |
| **Shearon Harris** | NC | High | No exposure | High/ very high | 0.9, 1.6 ft. | 3.79, 4.73°F | 17.66, 25.38 days | 0, 0.01 days | 4.47, 5.72°F | -2.05, -2.37 days |
| **Cooper** | NE | High | No exposure | High/ very high | N/A | 4.32, 5.32°F | 12.21, 18.53 days | 0.05, 0.09 days | 5.09, 6.55°F | -2.26, -2.46 days |
| **Seabrook** | NH | High | Category 4 | None/ low | 1.2, 1.8 ft. | 3.72, 4.77°F | 9.24, 13.56 days | 0, 0 days | 3.89, 5.18°F | -2.72, -3.07 days |

| Plant[a] | State | Flood hazard level[b] | Hurricane storm surge level[c] | Wildfire potential level[d] | Projected regional sea level rise in 2050, low and high emission scenarios (feet)[e] | Projected change in max. daily temp., low and high emission scenarios (°Fahrenheit)[f] | Projected change in max. temp. exceeding historical highs, low and high emission scenarios (days/year)[g] | Projected change in max. temp. over 115°F, low and high emission scenarios (days/ year)[h] | Projected change in 5-day max. temp., low and high emission scenarios, (°Fahrenheit)[i] | Projected change in max. temp. below historical lows, low and high emission scenarios (days/ year)[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hope Creek** | NJ | High | Category 4 | None/ low | 1.2, 1.8 ft. | 3.74, 4.79°F | 12.70, 19.86 days | 0, 0 days | 4.24, 5.71°F | -2.63, -2.95 days |
| **Salem** | NJ | High | Category 4 | None/ low | 1.2, 1.8 ft. | 3.74, 4.79°F | 12.70, 19.86 days | 0, 0 days | 4.24, 5.71°F | -2.63, -2.95 days |
| **James A. FitzPatrick** | NY | High | No exposure | None/ low | N/A | 4.06, 5.16°F | 14.59, 21.08 days | 0, 0 days | 4.87, 6.44°F | -2.65, -3.06 days |
| **Nine Mile Point** | NY | High | No exposure | None/ low | N/A | 4.06, 5.16°F | 14.59, 21.08 days | 0, 0 days | 4.87, 6.44°F | -2.65, -3.06 days |
| **R. E. Ginna** | NY | No/low | No exposure | High/ very high | N/A | 4.39, 5.53°F | 14.43, 20.97 days | 0, 0.01 days | 4.98, 6.72°F | -2.84, -3.15 days |
| **Davis-Besse** | OH | High | No exposure | None/ low | N/A | 4.06, 5.08°F | 15.18, 22.48 days | 0, 0 days | 4.93, 6.46°F | -2.71, -2.98 days |
| **Perry** | OH | High | No exposure | None/ low | N/A | 4.27, 5.41°F | 15.04, 23.08 days | 0, 0 days | 4.82, 6.35°F | -2.82, -3.07 days |
| **Beaver Valley** | PA | High | No exposure | None/ low | N/A | 3.76, 4.79°F | 16.38, 24.97 days | 0, 0 days | 4.84, 6.54°F | -2.55, -2.87 days |
| **Limerick** | PA | High | No exposure | None/ low | 1.2, 1.8 ft. | 3.88, 4.91°F | 13.22, 20.69 days | 0, 0 days | 4.96, 6.66°F | -2.57, -2.87 days |
| **Peach Bottom** | PA | High | No exposure | None/ low | 1.2, 1.8 ft. | 4.06, 5.08°F | 16.27, 24.13 days | 0, 0 days | 5.20, 6.79°F | -2.56, -2.89 days |
| **Susquehanna** | PA | Moderate | No exposure | Moderate | 1.2, 1.8 ft. | 4.23, 5.27°F | 15.05, 21.82 days | 0, 0.02 days | 5.58, 7.13°F | -2.69, -3.00 days |

| Plant[a] | State | Flood hazard level[b] | Hurricane storm surge level[c] | Wildfire potential level[d] | Projected regional sea level rise in 2050, low and high emission scenarios (feet)[e] | Projected change in max. daily temp., low and high emission scenarios (°Fahrenheit)[f] | Projected change in max. temp. exceeding historical highs, low and high emission scenarios (days/year)[g] | Projected change in max. temp. over 115°F, low and high emission scenarios (days/ year)[h] | Projected change in 5-day max. temp., low and high emission scenarios, (°Fahrenheit)[i] | Projected change in max. temp. below historical lows, low and high emission scenarios (days/ year)[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Catawba** | SC | High | No exposure | High/ very high | N/A | 4.00, 4.96°F | 18.27, 25.53 days | 0, 0.03 days | 4.73, 6.02°F | -2.05, -2.30 days |
| **H. B. Robinson** | SC | High | No exposure | High/ very high | 0.9, 1.6 ft. | 3.57, 4.44°F | 15.03, 21.81 days | 0, 0.01 days | 4.39, 5.59°F | -1.94, -2.29 days |
| **Oconee** | SC | High | No exposure | Moderate | N/A | 3.66, 4.54°F | 19.32, 26.96 days | 0, 0.03 days | 4.86, 6.22°F | -1.56, -1.89 days |
| **Virgil C. Summer** | SC | High | No exposure | Moderate | 0.9, 1.6 ft. | 3.55, 4.50°F | 15.91, 22.53 days | 0.01, 0.05 days | 4.50, 5.72°F | -1.71, -2.12 days |
| **SAFER Memphis**[k] | TN | No/low | No exposure | None/ low | N/A | 3.99, 4.85°F | 21.63, 31.04 days | 0.01, 0.04 days | 5.09, 6.41°F | -1.98, -2.24 days |
| **Sequoyah** | TN | High | No exposure | Moderate | N/A | 3.70, 4.55°F | 19.20, 26.92 days | 0, 0.01 days | 4.99, 6.30°F | -1.68, -2.04 days |
| **Watts Bar** | TN | High | No exposure | Moderate | N/A | 3.70, 4.59°F | 18.75, 26.76 days | 0, 0.01 days | 4.78, 6.04°F | -1.90, -2.22 days |
| **Comanche Peak** | TX | High | No exposure | Moderate | N/A | 3.69, 4.67°F | 14.75, 21.52 days | 0.18, 0.62 days | 4.07, 5.42°F | -1.89, -2.15 days |
| **South Texas Project** | TX | No/low | Category 5 | None/ low | 1.6, 2.3 ft. | 2.93, 3.74°F | 22.77, 34.60 days | 0, 0 days | 3.16, 3.99°F | -1.62, -1.90 days |
| **North Anna** | VA | High | No exposure | Moderate | 1.2, 1.8 ft. | 3.82, 4.83°F | 18.28, 26.64 days | 0.01, 0.02 days | 4.95, 6.43°F | -2.20, -2.55 days |
| **Surry** | VA | High | Category 4 | None/ low | 1.2, 1.8 ft. | 3.47, 4.40°F | 13.85, 21.08 days | 0, 0 days | 3.96, 5.17°F | -2.36, -2.68 days |

| Plant[a] | State | Flood hazard level[b] | Hurricane storm surge level[c] | Wildfire potential level[d] | Projected regional sea level rise in 2050, low and high emission scenarios (feet)[e] | Projected change in max. daily temp., low and high emission scenarios (°Fahrenheit)[f] | Projected change in max. temp. exceeding historical highs, low and high emission scenarios (days/year)[g] | Projected change in max. temp. over 115°F, low and high emission scenarios (days/ year)[h] | Projected change in 5-day max. temp., low and high emission scenarios, (°Fahrenheit)[i] | Projected change in max. temp. below historical lows, low and high emission scenarios (days/ year)[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Columbia** | WA | No/low | No exposure | High/ very high | N/A | 3.90, 4.87°F | 9.56, 14.05 days | 0.01, 0.06 days | 4.15, 5.29°F | -1.64, -1.88 days |
| **Point Beach** | WI | High | No exposure | None/ low | N/A | 3.91, 4.93°F | 10.01, 15.74 days | 0, 0 days | 4.58, 6.13°F | -2.48, -2.78 days |

Source: GAO analysis of data from the fourth National Climate Assessment (NCA), U.S. Forest Service, National Oceanic and Atmospheric Administration (NOAA), the 2022 Interagency Sea Level Rise Technical Report, the Federal Emergency Management Agency, and the Nuclear Regulatory Commission (NRC). I GAO-24-106326

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[k]The nuclear power industry operates two Strategic Alliance for FLEX Emergency Response (SAFER) centers that maintain emergency equipment that can be provided to plants as a backup to a plant's onsite primary backup equipment.

Table 2 shows the exposure of areas around shutdown nuclear power plant locations to six current or projected natural hazards: flooding, hurricane storm surge, wildfire, sea level rise, heat, and cold.[1] Data for flooding, hurricane storm surge, and wildfire are current data and based on historical observation data. Data for sea level rise and heat and cold temperature variables are climate projections data, which incorporate emission scenarios. For more information about the data sources used, see appendix II.

[1]We included plants at various stages of decommissioning, including those in the process of decommissioning and those already decommissioned, with spent nuclear fuel stored onsite. We refer to these as shutdown plants because they are no longer operational.

**Table 2: Potential Exposure to Current and Future Hazards at Shutdown Nuclear Power Plants**

| Plant[a] | State | Flood hazard level[b] | Hurricane storm surge level[c] | Wildfire potential level[d] | Projected regional sea level rise in 2050, low and high emission scenarios (feet)[e] | Projected change in max. daily temp., low and high emission scenarios (°Fahrenheit)[f] | Projected change in max. temp. exceeding historical highs, low and high emission scenarios (days/ year)[g] | Projected change in max. temp. over 115°F, low and high emission scenarios (days/ year)[h] | Projected change in 5-day max. temp., low and high emission scenarios (°Fahrenheit)[i] | Projected change in max. temp. below historical lows, low and high emission scenarios(days/ year)[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Humboldt Bay** | CA | High | No exposure | Moderate | 0.5, 1.2 ft. | 2.65, 3.43°F | 8.70, 14.32 days | 0, 0 days | 3.22, 4.20°F | -2.36, -2.68 days |
| **Rancho Seco** | CA | High | No exposure | Moderate | 0.5, 1.2 ft. | 3.35, 4.26°F | 10.78, 15.07 days | 0.12, 0.26 days | 4.29, 5.35°F | -2.28, -2.65 days |
| **San Onofre** | CA | High | Category 1 | High/ very high | 0.5, 1.2 ft. | 2.52, 3.34°F | 6.59, 9.92 days | 0, 0 days | 3.10, 3.93°F | -2.66, -3.01 days |
| **Fort Saint Vrain** | CO | No/low | No exposure | Moderate | N/A | 4.43, 5.55°F | 20.00, 27.98 days | 0, 0 days | 5.07, 6.48°F | -1.43, -1.83 days |
| **Haddam Neck** | CT | High | Category 4 | Moderate | 1.2, 1.8 ft. | 3.64, 4.69°F | 9.65, 15.07 days | 0, 0 days | 3.86, 5.24°F | -2.42, -2.80 days |
| **Crystal River** | FL | High | Category 5 | High/ very high | 1.0, 1.7 ft. | 3.01, 3.87°F | 34.35, 52.84 days | 0, 0 days | 3.24, 4.22°F | -1.76, -2.22 days |
| **Duane Arnold** | IA | High | No exposure | None/ low | N/A | 4.50, 5.55°F | 17.40, 26.03 days | 0.01, 0.02 days | 5.47, 7.04°F | -2.60, -2.80 days |
| **Zion** | IL | High | No exposure | None/ low | N/A | 4.18, 5.25°F | 13.44, 20.26 days | 0.01, 0.01 days | 5.20, 6.80°F | -2.41, -2.65 days |
| **Pilgrim** | MA | High | Category 4 | Moderate | 1.2, 1.8 ft. | 3.23, 4.12°F | 7.35, 10.76 days | 0, 0 days | 3.53, 4.60°F | -2.06, -2.44 days |
| **Yankee Rowe** | MA | No/low | No exposure | None/ low | 1.2, 1.8 ft. | 4.24, 5.52°F | 11.92, 18.63 days | 0, 0 days | 4.82, 6.74°F | -2.73, -3.07 days |

| Plant[a] | State | Flood hazard level[b] | Hurricane storm surge level[c] | Wildfire potential level[d] | Projected regional sea level rise in 2050, low and high emission scenarios (feet)[e] | Projected change in max. daily temp., low and high emission scenarios (°Fahrenheit)[f] | Projected change in max. temp. exceeding historical highs, low and high emission scenarios (days/ year)[g] | Projected change in max. temp. over 115°F, low and high emission scenarios (days/ year)[h] | Projected change in 5-day max. temp., low and high emission scenarios (°Fahrenheit)[i] | Projected change in max. temp. below historical lows, low and high emission scenarios(days/ year)[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Maine Yankee** | ME | High | Category 4 | None/ low | 1.2, 1.8 ft. | 3.74, 4.85°F | 9.87, 14.50 days | 0, 0 days | 4.09, 5.41°F | -2.58, -2.9 days |
| **Big Rock Point** | MI | High | No exposure | None/ low | N/A | 4.22, 5.39°F | 11.06, 17.29 days | 0, 0 days | 4.13, 5.71°F | -3.02, -3.28 days |
| **Palisades** | MI | High | No exposure | None/ low | N/A | 3.84, 4.92°F | 13.75, 21.03 days | 0, 0 days | 4.35, 5.78°F | -2.61, -2.99 days |
| **Fort Calhoun** | NE | High | No exposure | Moderate | N/A | 4.26, 5.32°F | 13.67, 20.69 days | 0.01, 0.01 days | 4.78, 6.15°F | -2.32, -2.58 days |
| **Oyster Creek** | NJ | High | Category 4 | High/ very high | 1.2, 1.8 ft. | 3.60, 4.54°F | 9.99, 14.93 days | 0, 0 days | 4.33, 5.65°F | -2.51, -2.81 days |
| **Indian Point** | NY | High | Category 4 | High/ very high | 1.2, 1.8 ft. | 3.78, 4.84°F | 12.33, 18.84 days | 0, 0 days | 4.78, 6.39°F | -2.63, -3.00 days |
| **Trojan** | OR | High | No exposure | Moderate | 0.3, 1 ft. | 3.44, 4.37°F | 6.64, 10.03 days | 0, 0 days | 4.19, 5.32°F | -1.96, -2.22 days |
| **Three Mile Island** | PA | High | No exposure | None/ low | 1.2, 1.8 ft. | 4.14, 5.21°F | 14.66, 21.37 days | 0.01, 0.05 days | 5.68, 7.31°F | -2.78, -3.05 days |
| **Vermont Yankee** | VT | High | No exposure | None/ low | 1.2, 1.8 ft. | 3.77, 4.89°F | 13.48, 21.03 days | 0, 0 days | 4.80, 6.64°F | -2.48, -2.84 days |
| **Kewaunee** | WI | No/low | No exposure | None/ low | N/A | 3.92, 4.96°F | 9.50, 14.96 days | 0, 0 days | 4.38, 5.92°F | -2.59, -2.88 days |
| **Lacrosse** | WI | High | No exposure | None/ low | N/A | 4.31, 5.38°F | 17.34, 26.24 days | 0, 0 days | 5.30, 6.96°F | -2.58, -2.79 days |

Source: GAO analysis of data from the fourth National Climate Assessment (NCA), U.S. Forest Service, National Oceanic and Atmospheric Administration (NOAA), the 2022 Interagency Sea Level Rise Technical Report, the Federal Emergency Management Agency, and the Nuclear Regulatory Commission (NRC). I GAO-24-106326

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# Appendix IV: Comments from the Nuclear Regulatory Commission

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 7, 2024

Frank Rusco, Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION COMMENTS ON DRAFT GOVERNMENT ACCOUNTABILITY OFFICE REPORT GAO-24-106326, "NUCLEAR POWER PLANTS: NRC SHOULD TAKE ACTIONS TO FULLY CONSIDER THE POTENTIAL EFFECTS OF CLIMATE CHANGE"

Dear Mr. Rusco:

Thank you for the opportunity to review and comment on the U.S. Government Accountability Office (GAO) draft report GAO-24-106326, "Nuclear Power Plants: NRC Should Take Actions to Fully Consider the Potential Effects of Climate Change," which the U.S. Nuclear Regulatory Commission (NRC) received on February 6, 2024.

The NRC appreciates the constructive engagement we have had with the GAO throughout the audit and the GAO's thoroughness in seeking to understand the NRC's regulatory framework related to external hazards, particularly given the complexity of the detailed processes and programs that the NRC uses to support its safety mission.

We are in general agreement with the findings. The three recommendations in the draft report are very broad but are consistent with actions that are either underway or under development. The NRC considers this report to be a fair characterization of its regulatory structure, processes, and strengths. However, considering the description of the conservatisms, safety margins, and defense-in-depth policies described in the report, the NRC does not agree with the conclusion that the agency does not address the impacts of climate change. In effect, the layers of conservatism and defense in depth incorporated into NRC's processes provide reasonable assurance regarding any plausible natural hazard and combinations at a site for the licensed operational lifetime of the reactor, including those that could result from climate change. Specifically, the processes, tools, methods, models, data, and additional margins provide reasonable assurance of the ability to withstand or mitigate projected changes in natural hazards.

It is also important to note that the NRC's mission is focused on nuclear safety; as such, we cannot impose requirements that would increase energy resilience or require consideration of potential future climate impacts without a sufficient nuclear safety justification. This is an important distinction since the predominant concerns expressed often in the draft report are that a licensee's operations may be disrupted more frequently by climate change and that the NRC should more fully consider future climate projections. The NRC is focused on nuclear safety and any potential increase in the risk of a radiological release, consistent with the NRC's mandate.

We note there was no focus during the audit and no mention in the report of the NRC's proactive approach to safety reviews to support the licensing of new reactors. This is a significant contribution by the NRC to climate resilience; specifically, the NRC is licensing safe new energy sources that are an alternative to fossil-fuel-based plants. As noted in the enclosure, we would recommend a brief reference to the NRC's contributions to climate resilience via the proactive planning and implementation of new and advanced reactor licensing and license renewals.

If you have any questions concerning the staff's comments, please contact John Jolicoeur. Mr. Jolicoeur can be reached at (301) 415-1642 or by email to John.Jolicoeur@nrc.gov.

Sincerely,

Signed by Furstenau, Raymond
on 03/07/24

Ray V. Furstenau
Acting Executive Director for Operations

# Appendix V: GAO Contact and Staff Acknowledgments

## GAO Contact

Frank Rusco, at (202) 512-3841 or ruscof@gao.gov

## Staff Acknowledgments

In addition to the contact named above, Janice Ceperich (Assistant Director), Marissa Dondoe (Analyst-in-Charge), Bethany Benitez, Colleen Candrl, Breanne Cave, Lilia Chaidez, John Delicath, Cindy Gilbert, Claire McLellan, John Mingus, Katrina Pekar-Carpenter, Dan C. Royer, Wesley Sholtes, John Tanis, Joseph Dean Thompson, Linda Tsang, and Kristen Watts made significant contributions to this report.

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