Nuclear News

March 2021

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23rd Annual Reference Section

Fukushima
10 YEARS ON


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Energy
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Cherry trees still blossom on the Fukushima Daiichi campus. For more about the revitalization of Fukushima, check out Leaders on page 12.

March 2021
Volume 64, Number 3

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On the cover: Water tanks cover land at Fukushima Daiichi, some of which once contained forest.


Dave
DIGITAL
TRANSFORMATION

Nuclear Notes

An ANS president remembers Fukushima

It's been 10 years since one of the largest earthquakes in recorded history—measuring 9.0 magnitude—occurred off the east coast of northern Japan. The earthquake on March 11, 2011, generated a major tsunami that flooded parts of the country, causing nearly 20,000 deaths and disrupting electricity, gas, and water supplies; telecommunications; and railway service. The electricity disruptions severely affected the six-unit Fukushima Daiichi nuclear power plant, causing a loss of all on-site and off-site power and leading to a release of radioactive material from the reactors. Three reactor cores largely melted in the first three days after the accident, and a fourth unit was deeply damaged. The accident was rated 7 (the highest rating) on the INES scale, due to high radioactive releases over days four through six, eventually up to a total of some 940 PBq (iodine-131 equivalent).

Within days, the American Nuclear Society commissioned a Special Committee on Fukushima to provide a concise explanation of what had happened during the accident and to offer recommendations based on lessons learned from a study of the event. About a year later, the Special Committee's report was officially released (and is available online at fukushima.ans.org).

Joe Colvin, president emeritus of the Nuclear Energy Institute, was ANS president at the time of the accident, and he remembers the difficulty in getting accurate information about the events. Tokyo Electric Power Company, the owner/operator of Fukushima Daiichi, was guarded in providing thorough updates. "I was on the phone with the Institute of Nuclear Power Operations and NEI the day after the tsunami trying to get a handle on what [ANS and the U.S. nuclear community] were going to do, how we were going to do it, and how to get the information flowing," he said. ANS and NEI were tasked mainly with communicating with U.S. media, while INPO and the Electric Power Research Institute dealt with regulatory and accident mitigation and other types of emergency preparedness issues.

Colvin noted that the events at Fukushima were flashed before the eyes of the world constantly by the media. Unit 1's hydrogen explosion, caught on film, and the way it was broadcast repeatedly created fear and anxiety in the public. When then-chairman of the NRC Gregory Jaczko appeared before Congress and said basically that Fukushima was going to be another Chernobyl, it created an even greater media circus.

Members of the ANS Special Committee, especially cochair Dale Klein, and other ANS members, such as Margaret Harding (see page 128), were in contact with the media to offer reliable facts. "They were trying to provide some confidence in what the public needed to hear," Colvin said, adding, "We got a lot of feedback from ANS members that we really had to get out there and correct the misinformation."

Another challenge was providing assurance about the safety of U.S. plants. "Japan was operating our technology—the General Electric boiling water reactors," Colvin said. "Because of Fukushima, there were a lot of questions from the media about the plants' safety. ANS members who were involved in some way with U.S. plants were very active in providing information to local media in their area. There was a lot of activity going on. It was difficult to coordinate, but I think overall that ANS and its members did a good job without having been prepared for that kind of event."

The accident at Fukushima prompted a new look at safety protocol at all nuclear power plants, and the World Association of Nuclear Operators collected the data from every country's nuclear fleet. After these events unfolded, it was realized that TEPCO and some utilities had not been fully open with information about their programs and regulatory systems. "It proved to be an introspective look for WANO and the safety of the plants and how the nuclear industry was going to deal with this situation from the international, worldwide viewpoint," said Colvin. TEPCO has since become more transparent with sharing information, but not completely, perhaps because of cultural reasons. Still, regarding communication of plant information on a worldwide basis, "The result was positive in the end," Colvin said.

Please enjoy the rest of this issue, which also has our 23rd annual reference guide, featuring an up-to-date world list of nuclear power plants; maps showing worldwide plant locations; and tables with information on U.S. plant license renewals.

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Letters

Got something to say?
Email the Editor at rmichal@ans.org.

Don't forget books on fusion

I read with interest the January issue with the theme of fusion. I regret, however, that no mention was made of books on the subject. I have authored *Fusion Reactor Physics: Principles and Technology*, published in 1975 by the Ann Arbor Science publishers, and *Fusion Energy in Space Propulsion*, published in 1995 by the American Institute of Aeronautics and Astronautics as volume 167 in the Progress in Aeronautics and Astronautics series. I would welcome the mention of any additional publications on fusion.

Terry Kammash
Ann Arbor, Mich.

Good job, *NN*

Thank you for the January print copy of *Nuclear News* focused on fusion. It was well prepared and I enjoyed reading it.

Nermin Uckan
Former editor, ANS journal
Fusion Science & Technology
Oak Ridge, Tenn.

Nuclear's role in advancing diversity

Thanks so much for your wonderful article on the new ANS diversity award in January's *Nuclear News* (p. 106). It was just great.

One minor clarification for future reference. We generally use the term "first in the Southeast" rather than "first in the South" when discussing the Oak Ridge desegregation. That is because a number of segregated public schools in the North and West went forward with desegregation in the fall of 1954—months before the Atomic Energy Commission mandate to Oak Ridge. This group includes a couple of school systems in western Arkansas and Texas.

Yet, from Tennessee southward (in what some call the "old South"), the Jim Crow culture refused to give even an inch to the 1954 Supreme Court ruling. Public school systems fought against desegregation with a great passion.

It is interesting to note that back in 1955, Tennessee's state constitution actually prohibited teaching "mixed classes." Teachers and school administrators who broke this constitutional requirement risked significant legal penalties as well as personal physical harm from Jim Crow.

Black parents at the time had to have (what they called) "survival talks" with their young sons before entering the all-white schools. Their sons were reminded to always move off the sidewalk when a white person approached and never, ever look at a white girl. Imagine having to tell your children that before they went to school—just for their survival!

That was the unfortunate (and dangerous) reality of Jim Crow in the Southeast. It is also the reason that nuclear industry leadership in civil rights was so pivotal for our country.

Thanks again for your wonderful article. Really appreciate your efforts.

Martin McBride
Oak Ridge, Tenn.

P.S.—I believe my ANS membership goes back at least to the 1980s. I fondly remember how packed with stories of new nuclear power plants issues of *Nuclear News* were back then. Those stories tailed off as the deep damage to our industry's public image from the 1979 Three Mile Island accident became clear. I also vaguely recall being a student ANS member in the early 1970s.

The memory of the ANS psychology back then—the great excitement and pride—seems remarkably different from the reality of today with the uncertainty over nuclear's future. Many thanks for carrying the flag for us!

Editor's reply: Thanks to the three ANS members who submitted letters for this month's issue. Regarding publications on fusion, *NN* keeps an eye out for all new books—fission or fusion—but we surely miss some. If you have any suggestions, please send them in to nucnews@ans.org.

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>
> **-Alicia Raftery**
>
> Nuclear Engineer

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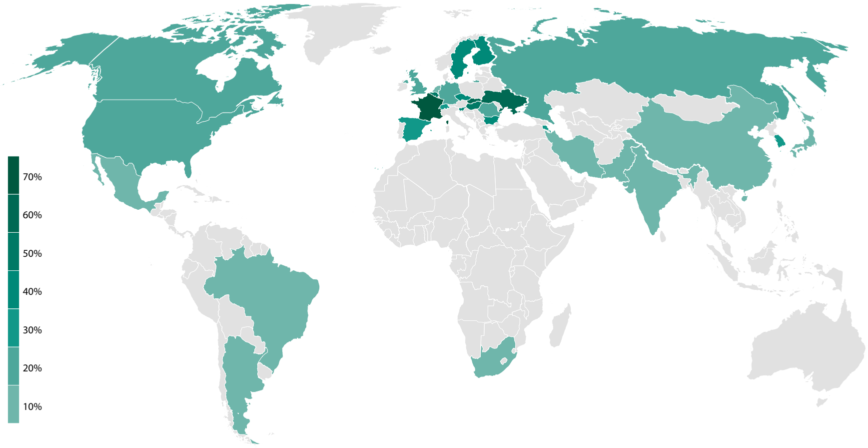
ATOMS AROUND THE WORLD

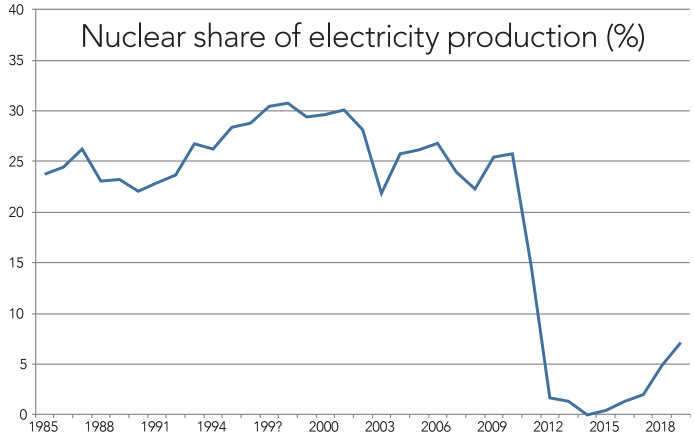
Nuclear power . . . what does it look like? Fuel pellets or pebbles? A hyperboloid cooling tower? Watery depths in Cherenkov blue? All this and more. When it comes to visualizing nuclear's power on a global scale, though, data may draw the best picture.

NUCLEAR'S SHARE

Nuclear energy has generated clean electricity around the world for decades, and its share of total electricity generation varies widely from country to country, as this representation of 2019 data shows. France is on top with a total of 70.6 percent of its electricity generated by nuclear power.

Data Sources: International Atomic Energy Agency PRIS and Our World in Data, based on BP Statistical Review of World Energy and Ember (2021)





AND IN JAPAN . . .

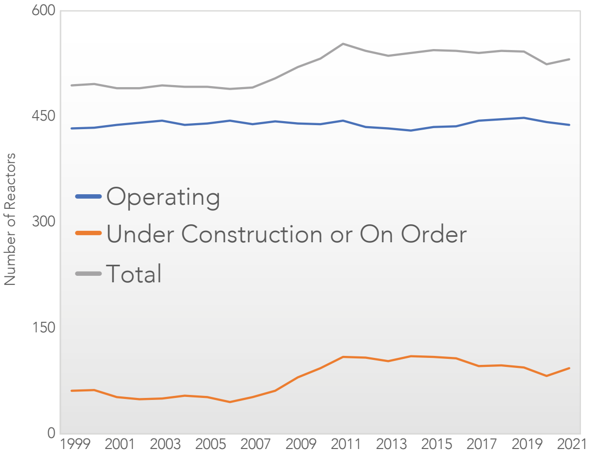
Nuclear energy's share of electricity generation plummeted dramatically following the Fukushima Daiichi accident.

Data Source: Our World in Data, based on BP Statistical Review of World Energy and Ember (2021)

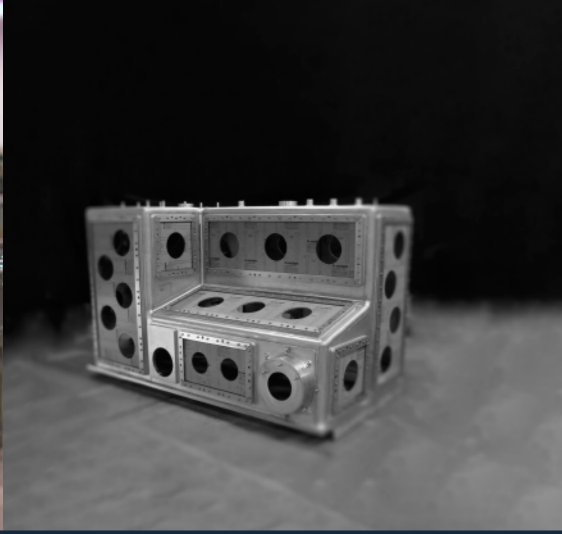
TRACKING ANNUAL STATS

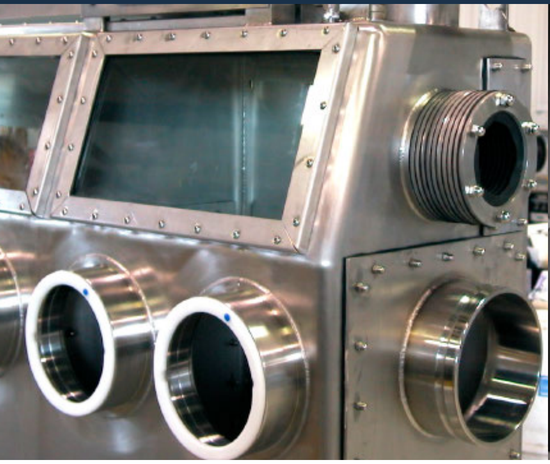
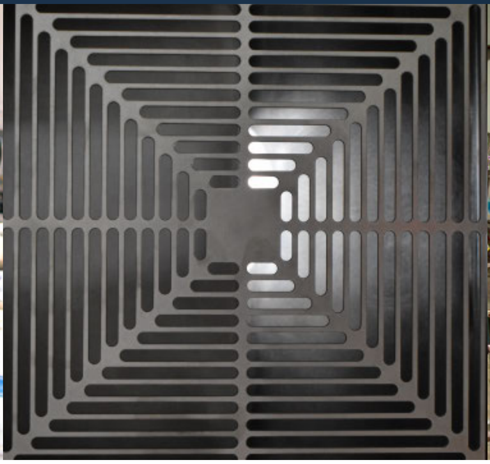
As we assembled this 23rd Annual *Nuclear News* Reference Issue, we took a moment to compare year-end stats on the total number of operating reactors and forthcoming reactors (those under construction or with firm build commitments).

What did we learn? Despite numerous shutdowns and startups, the number of operating reactors worldwide has been remarkably consistent over 23 years, with a low of 430 in 2014 and a high of 448 in 2019, and a mean of 439.3. The number of reactors planned or under construction more than doubled in five years—from 45 in 2006 to 109 in 2011—before the year-over-year increase in planned capacity leveled off. If operators hadn't accelerated shutdowns and canceled new builds following Fukushima, we could be looking at a very different set of curves.








Safely decommissioning Fukushima Daiichi and revitalizing Fukushima

By Akira Ono

The mission of Tokyo Electric Power Company Holdings (TEPCO), and my personal mission, is to safely decommission the damaged Fukushima Daiichi nuclear power station and thereby contribute to the revitalization of Fukushima.

In performing this important work, we are guided by the principle of balancing the recovery of Fukushima with the decommissioning of the Fukushima Daiichi nuclear power station, doing everything possible to mitigate the risks as we progress. Since the accident on March 11, 2011, we have stabilized the site and alleviated many of its crisis aspects.

Most significantly, we have been making efforts to improve the working environment by reducing the contamination on the site due to the accident. About 4,000 workers are currently engaged at Fukushima Daiichi. The average monthly radiation dose for those workers has been reduced from 21.55 mSv (2,155 mrem) immediately following the accident to 0.3 mSv (30 mrem).

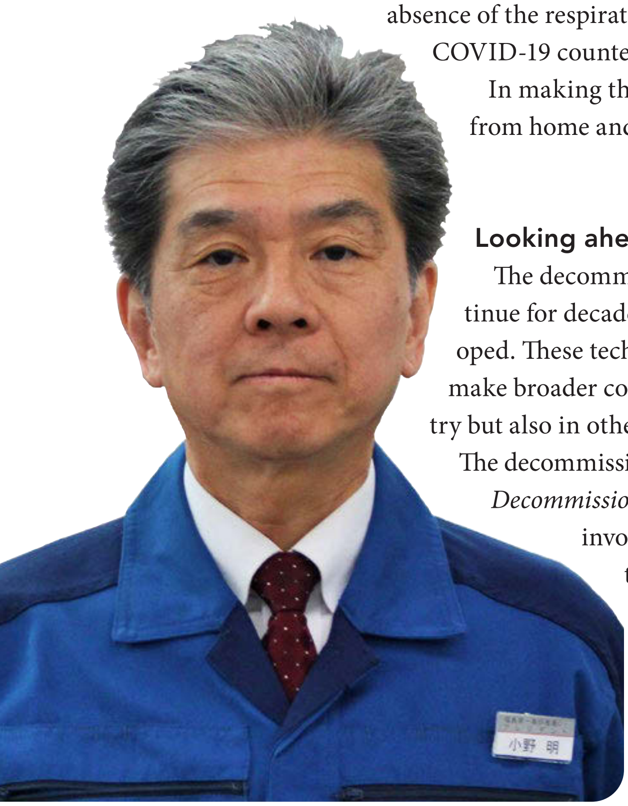
On about 96 percent of the site, workers are no longer required to wear coveralls or full-face masks. This greatly contributes to safety, as communication among workers is greatly enhanced by the absence of the respirator masks. Of course, they are required to wear less restrictive masks as a COVID-19 countermeasure.

In making this progress, we have received a great deal of technical and personal support from home and abroad, for which I am sincerely grateful.

Looking ahead

The decommissioning of Fukushima Daiichi is without precedent. The work will continue for decades, and new technologies and processes will have to be continuously developed. These technologies and the knowledge gained from our work have the potential to make broader contributions to the world's future development not only in the nuclear industry but also in other industries. We have already begun sharing that knowledge widely.

The decommissioning work at Fukushima Daiichi is guided by the *Mid-and-Long-Term Decommissioning Action Plan*, created by TEPCO to identify the main work processes involved in decommissioning as a whole in order to achieve the goals laid out in the government's Mid-and-Long-Term Roadmap and the risk-reduction map produced by the Nuclear Regulatory Authority. The Fukushima Daiichi Decontamination and Decommissioning Engineering Company has been reorganized to carry out that action plan, which is organized into four main areas, in addition to continuous improvement on the working environment.



Akira Ono is chief decommissioning officer of Tokyo Electric Power Company Holdings and president of the Fukushima Daiichi Decontamination and Decommissioning Engineering Company.

Contaminated water management

Managing water on the site requires a multilayered approach that includes the diversion of as much water as possible. For water that does become contaminated, successful management requires containment, treatment,

Cherry trees blossoming at the Fukushima Daiichi nuclear power station. Most trees had to be removed to make room for water storage tanks, but the cherry trees, an important symbol of renewal, were saved by a special order. Photo: TEPCO

and storage. Most contaminated water on the site has been treated at least once by the site's multi-nuclide removal equipment (the Advanced Liquid Processing System) to remove most nuclides and is being safely stored on-site. Currently, about 1.2 million cubic meters of treated water is being stored on-site in more than 1,000 tanks. TEPCO is providing information to the public through our Treated Water Portal Site (www4.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html) and by other means.

Fuel removal

The removal of fuel assemblies stored in the spent fuel pools requires that we first clear rubble generated by the accident and reduce high radiation levels. Fuel assembly removal was completed at Unit 4, which was not operating at the time of the accident, in December 2014. Fuel removal is currently underway at Unit 3 and is expected to be completed by the end of March 2021. Fuel removal from the spent fuel pools at the remaining units is planned for completion by 2031.

Fuel debris retrieval

At the time of the 2011 accident, the fuel powering the active units melted and resolidified in different ways in each of the three reactors. Retrieving that solidified fuel debris is the pivotal, as well as the most challenging, subject of decommissioning. Currently, we are determining its condition and location and developing technologies for its safe retrieval. Those activities include visual investigations inside the primary containment vessels and preparations for the first small-scale trial retrieval at Unit 2, using a robotic arm being developed in cooperation with the United Kingdom. Following the trial retrieval, the scale of retrieval is expected to increase gradually as more experience is gained.

Waste management

Solid waste—such as rubble, used protective gear, and felled trees—has been safely stored and reduced in volume through incineration, etc. Efforts to determine other methods of processing and disposing of solid waste are continuing.

On the 10th anniversary

As we move forward with this unprecedented decommissioning challenge, the key is to inspire the spirit in our human resources to meet that challenge, as well as to learn from the experience we gain each day in our fieldwork. In addition, in order to make progress safely and steadily, the trust and confidence not only of the local communities and parties concerned but also of the broader public are essential. We pledge to continue to provide as much information as possible, at home and abroad, to be worthy of that trust. We will observe March 11 this year, the 10th anniversary of the accident, as a time to reflect, but even more important, as an occasion to rededicate ourselves to the work ahead. ⊠

Spotlight On . . .

Post-Fukushima safety enhancements

ANS flooding and seismic consensus standards assist the NRC and DOE in buttressing nuclear facility safety policies.

By Leah Parks, Carl Mazzola, Jim Xu, and Brent Gutierrez

March 11 will mark the 10-year anniversary of the Fukushima Daiichi event, when a 45-foot tsunami, caused by the 9.0-magnitude Great Tohoku Earthquake, significantly damaged the reactors at Japan's Fukushima Daiichi nuclear power plant. In response to this event, the U.S. Nuclear Regulatory Commission took actions to evaluate and mitigate beyond-design-basis events, including a new requirement for the staging of so-called Flex equipment, as well as changes to containment venting and improvements to emergency preparedness. The U.S. Department of Energy also addressed beyond-design-basis events in its documented safety analyses.

In 2019, the NRC promulgated the new rule, 10 CFR 50.155, *Mitigation of Beyond-Design-Basis Events* (*Federal Register*, August 9, 2019), to establish regulatory requirements for nuclear power reactor applicants and licensees to mitigate beyond-design-basis events. A detailed description of the post-Fukushima safety enhancements, which is beyond the scope of this article, is available on the NRC public website.

Following the accident, the NRC requested that licensees of operating reactors reanalyze potential flooding and seismic effects using updated information and state-of-the-art methodologies, which resulted in changes to operating plans and procedures intended to protect certain plant structures, systems, and components important to safety. The enhancements include seismic and flooding protection features to address potential impacts from natural disasters. The DOE updated its facility safety and natural phenomena hazards design guides (NPHs), which include DOE O 420.1C, *Facility Safety*, and DOE-STD-1020, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*. It has also issued a handbook (DOE-HDBK-1220) that includes these enhancements.

Concurrent with NRC and DOE regulatory changes, the American Nuclear Society's Environmental and Siting Consensus Committee (ESCC) initiated several working group activities to revise existing standards and to develop new standards related to flooding and seismic evaluations.

Review of ANS ESCC standards in response to Fukushima Daiichi

A thorough review of several ESCC consensus standards projects was initiated in the post-Fukushima lessons-learned period. Revisions to many of these standards have been published and have been endorsed in NRC regulatory guidance and DOE guides or are being considered for endorsement in revisions to the regulatory guidance. Some standards projects are still under development, while others have been completed. Descriptions* of the revised flood and seismic event standards are presented on pages 16–17.

Japan map:
FreeVectorMaps.com

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*The descriptions of the standards are taken directly from the ANS Standards store website (techstreet.com/ans).

ESCC is also pursuing the development of a new standard, ANS-2.34, *Characterization and Probabilistic Analysis of Volcanic Hazards*. ANS-2.34 is proposed to provide criteria and guidance for performing a probabilistic volcanic hazard analysis for the design and construction of nuclear facilities. Although the probability of a lahar affecting a nuclear power plant or a DOE nonnuclear reactor facility is extremely low, the ashfall downwind from a volcanic eruption, similar to the 1980 Mount St. Helens event, can severely impact the integrity of safety-related heating, ventilation, and air-conditioning systems. The standard is expected to be relevant to DOE facilities that may be near volcanic hazards and is less relevant to nuclear power plants because of the siting requirements in 10 CFR Part 100.

The table on pages 18–19 provides a summary of how the ESCC standards relate to relevant NRC regulatory guides and DOE directives or standards.

All ANS standards are living documents with sunset provisions that necessitate the need for reaffirmation or revision prior to the sunset date. Accordingly, working groups remain active to initiate these processes to keep the standards current. Moreover, flood and seismic events continue to occur, revising the baseline data bases and leading to changes in frequency, return period, and magnitude, while methodologies constantly improve to reduce aleatory and epistemic uncertainties. All of these factors need to be considered in future revisions to such standards to make them relevant for future regulatory actions and policy decisions. The ESCC interfaces with governmental and nongovernmental organizations that record and study these NPHs and invites key individuals to participate on its working groups to ensure appropriate expertise is available. The ESCC is also in contact with NRC and DOE representatives to evaluate the need to revise a standard and/or develop a new standard.

The ESCC is one of eight consensus committees of the ANS Standards Committee that oversee more than 100 national standards and standards development projects. These other consensus committees provide the same support to the NRC and the DOE in technical areas beyond the scope of this article. ⊠

Leah Parks is a systems performance analyst at the NRC. Carl Mazzola is a senior scientist with 50 years of experience in environmental management, risk management, chemical safety, nuclear safety, and emergency management and is chair of the ESCC. Jim Xu is a senior level advisor for seismic and geotechnical engineering with the NRC and is chair of the ESCC Seismic Subcommittee. Brent Gutierrez is the director of the Performance Assurance Division at the DOE Savannah River Operations Office and is vice chair of the ESCC Seismic Subcommittee.

Legal basis for NRC and DOE use of voluntary consensus standards

The National Technology Transfer and Advancement Act (NTTAA) of 1995 (Public Law 104-113) directed federal agencies to use technical standards developed by voluntary consensus standards bodies. The NTTAA also directed the National Institute of Standards and Technology to develop a plan for implementing the provisions of the act dealing with standards conformity. The Office of Management and Budget's Circular A-119, *Federal Participation in the Development and Use of Voluntary Consensus Standards and Conformity Assessment*, effective February 19, 1998, was issued to provide policy guidance to federal agencies.

OMB Circular A-119, revised in 2016, promotes agency participation in standards bodies to support the creation of standards that are usable by federal agencies and minimize reliance on government-unique standards where an existing standard would meet the federal government's objective. This circular defines use as "incorporation of a standard in whole, in part, or by reference in regulation." Management Directive 6.5, *NRC Participation in the Development and Use of Consensus Standards*, provides direction for implementing the NTTAA and OMB Circular A-119.

Standards may be directly incorporated into NRC regulations or endorsed in guidance. If the standard has not been incorporated into regulations or endorsed in a regulatory guide, licensees and applicants may use the standard if appropriately justified and consistent with current regulatory practice and applicable NRC requirements. For more information on the NRC policy governing standards activities, visit the NRC public website.

The DOE generally adopts voluntary consensus standards in their entirety as it did in the revisions of DOE-STD-1020 and the development of DOE-HDBK-1220.

Spotlight On continues

Revised flood and seismic event standards

ANSI/ANS-2.2–2016 (R2020),* *Earthquake Instrumentation Criteria for Nuclear Power Plants*, specifies the required earthquake instrumentation at the site and on Seismic Category I structures of light-water–cooled, land-based nuclear power plants. It may be used for guidance at other types of nuclear facilities. It was the first consensus standard to establish a comprehensive implementation process and criteria for earthquake instrumentation at the nuclear facilities. This standard provides guidance on locations and procedures for placing seismic instrumentations in both free-field and in structures that can collect ground motion data after an earthquake to allow for an effective assessment of the seismic effect on critical structures and components, therefore supporting safety evaluations for decision-making for shutdown and restart of the facility.

ANSI/ANS-2.10–2017, *Criteria for the Handling and Initial Evaluation of Records from Nuclear Power Plant Seismic Instrumentation*, provides criteria for the timely retrieval and the subsequent processing, handling, and storage of data obtained from nuclear power plant and non-power nuclear facility strong-motion analog and digital seismic instrumentation. Nuclear power plant seismic instrumentation requirements are specified in ANSI/ANS-2.2–2016 (R2020). Non-power nuclear facility seismic instrumentation, if required, is specified in facility-specific regulations, standards, and/or guidance documents.

This standard provides a systematic process for the treatment of data recorded on the earthquake instrumentation in accordance with criteria of ANSI/ANS-2.2–2016 (R2020). The current version of this standard was expanded to include digital data that would be expected for the deployment of new earthquake instrumentation at nuclear facilities. It significantly enhances the ability for the critical assessment of earthquake damages to safety-related structures and components and allows the plant operator to make informed decisions for the facility following an earthquake event. The latter topic is addressed in ANSI/ANS-2.23–2016 (R2020).

Both ANS-2.2 and ANS-2.10 were designed to provide data support for ANSI/ANS-2.23–2016 (R2020), which establishes criteria for the plant response to an earthquake event. These three standards together enhance seismic evaluations. The principal function of the seismic instrumentation covered in this standard is to address issues that have a significant bearing on safety or mitigate the consequences of accidents that could result in potential off-site exposures. This standard does not address weak-motion instrumentation installed in some non-power nuclear facilities to measure small-magnitude ground accelerations or velocities.

ANSI/ANS-2.23–2016 (R2020), *Nuclear Power Plant Response to an Earthquake*, describes actions that the nuclear power plant owner or operator shall take to prepare for and respond to a felt earthquake at the plant, including the need for plant shutdown; actions to determine the readiness of the plant to resume operation; and those evaluations necessary to verify the long-term integrity of safety-related and important structures, systems, and components. It also includes a consensus definition of operating basis earthquake exceedance, beyond which U.S. regulations require plant shutdown. Application of this revised standard provides a comprehensive, balanced plan for the response of a nuclear power plant to an earthquake.

This version of the standard was developed in response to the Fukushima event, as well as insights gleaned from the Mineral, Virginia, earthquake of 2011. Lessons learned from the Fukushima and Virginia events provided the key driver for the methodology used for developing ANS-2.23, which implements a comprehensive and graded approach to the plant response and safety assessment following an earthquake event. The enhancements to this standard, together with ANS-2.2 and ANS-2.10, contribute to the improved seismic safety for the operation of nuclear facilities in the United States.

ANSI/ANS-2.26–2004 (R2017), *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design*, provides (1) criteria for selecting the seismic design category (SDC) for nuclear facility structures, systems, and components (SSC) to achieve earthquake safety and (2) criteria and guidelines for selecting limit states for these SSCs to govern their seismic design. The limit states are selected to ensure the desired safety performance in an earthquake. The SDCs used in this standard are not the same as the SDCs referred to in the International Building Code.

Note that ANS-2.26 was reaffirmed in 2017. This standard is currently being revised to incorporate lessons learned from the Fukushima accident and to use, as appropriate, a more risk-informed and performance-based approach to SSC categorizations.

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*"R" stands for "reaffirmed"; the American National Standards Institute requires that standards developed by the ANS Standards Committee undergo maintenance within five years of ANSI approval and that formal action be promptly initiated to revise, reaffirm, or withdraw them.

ANSI/ANS-2.27–2020, *Criteria for Investigations of Nuclear Facility Sites for Seismic Hazard Assessments*, provides criteria and guidelines for conducting geological, seismological, geophysical, and geotechnical investigations needed to provide information to support the following:

1. seismic source characterization input to a probabilistic seismic hazard analysis (PSHA)
2. evaluation of tectonic permanent ground deformation hazard using probabilistic fault displacement hazard analysis for surface-faulting sources and probabilistic tectonic deformation hazard analysis for blind fault sources
3. site response analysis input to PSHAs
4. nontectonic, earthquake-induced ground failure hazard
5. foundation stability

This standard provides criteria for siting investigations in support of performing a PSHA in accordance with ANSI/ANS-2.29. The current version incorporates lessons learned from the NRC Near Term Task Force activities related to the seismic reevaluation of operating reactors in the United States.

ANSI/ANS-2.29–2020, *Probabilistic Seismic Hazard Analysis*, provides guidance for performing a PSHA for developing design and safety evaluation criteria for nuclear facilities. Criteria provided in this standard address various aspects of conducting PSHAs, including the following:

1. purpose, objective, and process
2. detailed requirements
3. PSHA framework
4. seismic source model
5. ground motion model
6. site effects
7. implementation of PSHA for seismic design and seismic probabilistic risk assessment
8. documentation
9. quality assurance

This standard embraces the Senior Seismic Hazard Analysis Committee's approach to achieving an adequate representation of the center, body, and range of technically defensible interpretations of the complete set of data, models, and methods used in a comprehensive PSHA. It incorporates lessons learned from the Fukushima event by providing guidance on all levels of PSHA studies that can be used for site-specific ground motion response spectra for the siting and design of nuclear facilities.

ANSI/ANS-2.30–2015 (R2020), *Criteria for Assessing Tectonic Surface Fault Rupture and Deformation at Nuclear Facilities*, provides criteria and guidelines for assessing permanent ground deformation (PGD) hazard due to tectonic surface fault rupture and deformation at nuclear facilities. Specifically, the purpose of this standard is to provide an outline of procedures and methods for performing probabilistic fault displacement hazard analysis for surface rupture hazard and probabilistic tectonic deformation hazard analysis for surface deformation due to displacements along blind (buried) faults. Probabilistic approaches for assessing surface fault displacement and tectonic deformation hazard are relatively new; thus, criteria and guidelines have not been defined previously. PGD due to fault rupture is a potential hazard for nuclear facilities founded across or near a fault. In this standard, only coseismic PGD hazard related to movement on crustal faults is addressed. Deformation in the form of creep or afterslip and uplift and subsidence during subduction zone earthquakes is not addressed. Non-tectonic deformation, as described in Section 5.1, is not addressed in this standard.

Methods to investigate and characterize surface fault displacement and tectonic deformation hazards have advanced significantly, justifying a new standard. Specifically, it is possible to quantify the expected PGD from surface or near-surface fault rupture due to advances in geologic, geomorphic, and paleoseismic techniques used to identify and quantify the location, rate, and amount of Quaternary deformation, as well as empirical observations of PGD resulting from historical earthquakes.

ANSI/ANS-2.8–2019, *Probabilistic Evaluation of External Flood Hazards for Nuclear Facilities*, establishes a probabilistic approach to evaluating external flood hazards at nuclear facilities. This standard, however, does not prescribe the design basis or acceptable level of risk for a specific external flood hazard or set of flood hazards. The criterion for an acceptable level of risk for a nuclear facility is made by the applicable authority or regulatory body.

Tables continue on pages 18–19

Relation of ESCC standards to NRC regulatory guides and DOE directives or standards

ANSI/ANS Standard	Related NRC Regulatory Guide
ANSI/ANS-2.2–2016 (R2020) ***Earthquake Instrumentation Criteria for Nuclear Power Plants***	RG 1.12, Rev. 3, *Nuclear Power Plant Instrumentation for Earthquakes* (October 2017) RG 1.13, Rev. 2, *Spent Fuel Storage Facility Design Basis* (March 2007)
ANSI/ANS-2.8–2019 ***Probabilistic Evaluation of External Flood Hazards for Nuclear Facilities***	RG 1.59, Rev. 2, *Design Basis Floods for Nuclear Power Plants* (August 1977)
ANSI/ANS-2.10–2017 ***Criteria for the Handling and Initial Evaluation of Records from Nuclear Power Plant Seismic Instrumentation***	RG 1.166, Rev. 1, *Pre-Earthquake Planning, Shutdown and Restart of a Nuclear Power Plant Following an Earthquake* (February 2020)
ANSI/ANS-2.23–2016 (R2020) ***Nuclear Power Plant Response to an Earthquake***	RG 1.166, Rev. 1, *Pre-Earthquake Planning, Shutdown and Restart of a Nuclear Power Plant Following an Earthquake* (February 2020)
ANSI/ANS-2.26–2004 (R2017) ***Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design***	RG 1.29, Rev. 5, *Seismic Design Classification for Nuclear Power Plants* (July 2016)
ANSI/ANS-2.27–2020 ***Criteria for Investigations of Nuclear Facility Sites for Seismic Hazard Assessments***	RG 1.208, *A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion* (March 2007)
ANSI/ANS-2.29–2020 ***Probabilistic Seismic Hazard Analysis***	RG 1.208, *A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion* (March 2007)
ANSI/ANS-2.30–2015 (R2020) ***Criteria for Assessing Tectonic Surface Fault Rupture and Deformation at Nuclear Facilities***	There are no relevant NRC RGs. Related topics are addressed in *NRC Standard Review Plan* (SRP, NUREG-0800), Section 2.5.3, “Surface Deformation.”
ANS-2.34 (New Project) ***Characterization and Probabilistic Analysis of Volcanic Hazards***	Draft RG-4028, Proposed New RG 4.26, *Volcanic Hazards Assessment for Proposed New Nuclear Power Reactor Sites* (March 2020)

Status of Revision to RG and Endorsement of the Standard	Related DOE Standards and Handbooks
ANSI/ANS-2.2–2016 (R2020) is listed as a reference in RG 1.12 under "Related Guidance." RG 1.12 states that ANSI/ANS-2.2–2016 (R2020) provides an acceptable method for the placement of seismic sensors for various nuclear power plant design configurations. RG 1.13 references ANSI/ANS-2.2–2016 (R2020), ANSI/ANS-2.10–2017, and ANSI/ANS-2.23–2016 (R2020).	
RG 1.59 is currently under revision (Draft RG 1290) and is expected to be released for public comment this fiscal year. Rev. 3 of RG 1.59 focuses primarily on deterministic methods and references the 1992 version of ANSI/ANS-2.8. Note that the 1995 *Final Policy Statement on the Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities* states, "Application of PRA represents an extension and enhancement of traditional regulation rather than a separate and different technology." A separate RG is under consideration for development on probabilistic flood hazard analysis. The NRC will evaluate the endorsement of ANSI/ANS-2.8–2019, as appropriate, while developing the guide. JLD-ISG-2013-01, *Guidance for Assessment of Flooding Hazards Due to Dam Failure*	DOE-STD-1020–2016, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities* DOE-HDBK-1220, *NPH Handbook*
ANSI/ANS-2.10–2017 is endorsed in RG 1.166 Rev. 1.	
The NRC will consider endorsement, as appropriate, in a future revision to RG 1.29.	DOE-STD-1020–2016, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities* DOE-HDBK-1220, *NPH Handbook*
The NRC staff will consider endorsement, as appropriate, when revising RG 1.208.	DOE-STD-1020-2016, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities* DOE-HDBK-1220, *NPH Handbook*
The NRC staff will consider endorsement, as appropriate, when revising RG 1.208.	DOE-STD-1020-2016, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities* DOE-HDBK-1220, *NPH Handbook*
	DOE-HDBK-1220, *NPH Handbook*
	DOE-STD-1020-2016, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities* DOE-HDBK-1220, *NPH Handbook*

ANS staff, members recall chaotic time following Fukushima accident

Margaret Harding hadn't planned on being "the public voice of ANS" in the days following the Fukushima accident. But a timely call from a reporter lurking on an ANS listserv led to more interview requests. Soon Harding was on the media front lines, battling the misinformation being spread in the wake of Fukushima. "I got involved somewhat by chance," said Harding, an ANS member since 2003 and president and chief executive officer of 4 Factor Consulting. "Matt Wald, then a reporter for the *New York Times*, contacted me, then quoted me in an article. The rest, as they say, is history."

Harding received the ANS Special Award for excellence in media and communications in 2012 for her efforts in the days after the accident. But she wasn't the only ANS member pressed into duty: ANS staff was also heavily involved. The Society's leadership at the time created a coordinated ANS response that connected nuclear experts with media outlets and helped offset the false information swirling around.

"Fukushima was a global incident, and some channels were carrying constant coverage for the first few days," said Laura Scheele, the current communications director for the Versatile Test Reactor who at the time was the ANS communications and public policy specialist. "There was a notable lack of scientifically credible experts in nuclear energy available to media. Given the intense media interest, which correspondingly affects policymaker and public interest, combined with the passion of ANS members, ANS [couldn't help but respond] to the accident."

ANS leadership also leveraged ANS member

Recalling Fukushima continues on page 24

Michael Corradini addresses the media during the rollout of the ANS Special Committee on Fukushima report, which was released one year after the 2011 accident.

Calming fears about low-dose radiation

During my time as vice president and president of ANS, I have been advocating for a new approach to implementing dose limits across the nuclear industry. A lack of understanding and an unfounded fear of radiation has resulted in widespread efforts to minimize dose, rather than to optimize radiation protection in a holistic sense. I want to put the "reasonably" back into ALARA ("as low as reasonably achievable"). Such a paradigm shift, from minimization to optimization, while easily said, equates to a major cultural change spanning international government agencies, industry, nongovernmental organizations, professional societies, and even academia. It is essential to have the active participation of all stakeholders in a transparent process to effect such a change. This process will not only lead us toward a more level playing field for nuclear, it will also greatly impact public perception of nuclear and radiological technology.

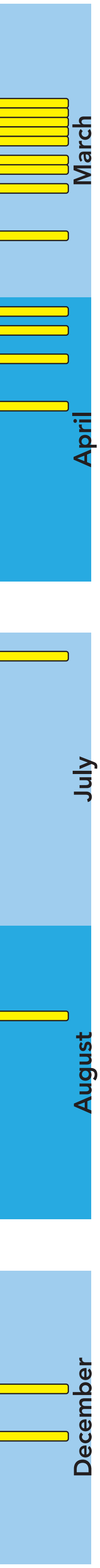
In this issue of *Nuclear News*, we recognize the 10-year anniversary of the Fukushima accident. One of the biggest lessons learned from the accident response was that the evacuation of 100,000 people to avoid relatively low radiation doses was demonstrated to be far riskier than the radiation exposure itself. The projected dose range without evacuation was 1,000–5,000 mrem/yr, which is commensurate with the radiation worker dose limit recommended by the National Council on Radiation Protection and Measurements of 5,000 mrem/yr. This limit is also below the levels at which there are statistically significant observed increases in cancer incidence. The evacuation itself reportedly resulted in an estimated 2,300 deaths and high levels of persistent fear, anxiety, and depression among evacuees. Inconsistent communications about the risks to the affected populations exacerbated the fear (another lesson learned). Was the evacuation reasonable?

Did you hear about the evacuation of a New Jersey high school in January over a radiation scare? A student received a Geiger counter as a Christmas gift (a kindred spirit!) and took it to school, along with a small piece of antique orange Fiestaware. Soon after, the school was evacuated, and local police, firefighters, and a hazardous materials team showed up. Does this response seem reasonable? The decision to evacuate or not during the Fukushima accident may have been different in a culture of holistic risk protection optimization rather than dose minimization. But what about the high school evacuation? I suggest that the incident was more a result of public perception.

The radiation protection optimization culture change will take decades and many, many participants, but each ANS member can influence public understanding and opinion, starting right now. Change the way you talk about nuclear from citing its safety statistics to touting its many benefits. Learn how to effectively communicate the risks of nuclear outside of our nuclear echo chamber. Introduce the Navigating Nuclear (navigatingnuclear.com) curriculum to your local schools and serve as a resource for teachers and students alike. Display your nuclear credentials with pride and open yourself to conversations with those who have different views.—*Mary Lou Dunzik-Gougar (president@ans.org)*

Nuclear Trending continues

A Fukushima Daiichi timeline



March 11, 2011—At 2:46 p.m. Japan time, a magnitude 9.0 earthquake strikes off Honshu island. Fukushima Daiichi Units 1, 2, and 3 automatically shut down. Units 4, 5, and 6 were offline for maintenance. An hour later, a 46-foot tsunami hits, overflowing the 19-foot seawall, flooding the plant and disabling most generators. Most emergency core cooling systems fail.

March 12, 2011—Emergency backup battery for Unit 3 runs out, and the fuel rods are exposed. Some steam is released into the air.

March 13, 2011—The situation at Unit 1 is declared an INES level 4. Core damage begins in Unit 3. Unit 2 is thought to be stable.

March 14, 2011—A major explosion in a Unit 3 building damages the cooling system for Unit 2, triggering core damage in that unit. An INES level 5 is issued.

March 15, 2011—An explosion severely damages reactor 4. Another explosion takes place in Unit 3. A fire starts in Unit 4.

March 17, 2011—Work begins to hook up an external power source to all six units. Helicopters are brought in to drop water on spent fuel pools in Units 3 and 4.

March 18, 2011—Thirty fire engines arrive and begin spraying water on the afflicted reactors.

March 20, 2011—Power is successfully connected to Unit 2. A generator providing power for Units 5 and 6 is repaired, allowing them both to be brought to a cold shutdown state.

March 25, 2011—A breach in Unit 3's containment vessel is suspected. The U.S. Navy sends a barge with 500,000 gallons of fresh water to the scene.

April 2, 2011—Contaminated water from Unit 2 is found to be flowing into the sea.

April 4, 2011—TEPCO begins funneling radioactive water from storage tanks into the Pacific Ocean.

April 7, 2011—A magnitude 7.1 aftershock strikes and workers are evacuated, but no additional damage is done to the plant.

April 12, 2011—The INES level of the incident is raised to 7—the same level as Chernobyl.

July 3, 2011—Contaminated water is no longer being generated. Recycled water is being used for cooling.

August 10, 2011—A new closed circulation cooling system is completed.

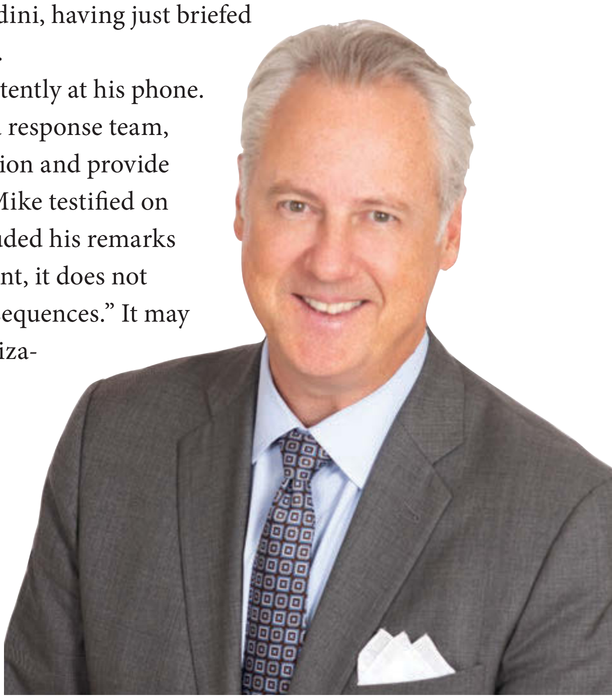
December 15, 2011—A timetable for decommissioning the reactors is announced, with an anticipated end date of 2052.

December 20, 2011—The U.S. Nuclear Regulatory Commission confirms that the reactors are now stable.

Timeline information acquired from various sources.

Communication lessons learned from Fukushima

It is hard to believe that this month marks the 10-year anniversary of the Fukushima accident. If I close my eyes, I can recall exactly where I was when I first heard the news—standing in a hallway in the Russell Senate Office Building with soon-to-be ANS president Mike Corradini, having just briefed Capitol Hill staff on the role of universities in the U.S. nuclear R&D enterprise.



"There's something happening in Japan," I recall him saying, as he looked intently at his phone.

The next two weeks are a bit of a blur. The Society created a makeshift media response team, and we did our collective best to wrap our heads around an unthinkable situation and provide factual, trustworthy information to the media and the public. A month later, Mike testified on behalf of ANS before the House Energy and Commerce Committee. He concluded his remarks by saying, "While radioactive materials have been released into the environment, it does not appear, based on current data, that there will be widespread public health consequences." It may seem obvious today, but at the time, I don't recall any other authority or organization willing to go that far on the record. It was a bold statement.

Ten years on, I wonder just how well the communication lessons we learned from Fukushima hold up in today's world. If the unthinkable happens now, or even something "internationally unimaginable," are we prepared to respond effectively as a community?

I think on the whole, the answer is yes. The barriers to entering a media circus are certainly lower today. In 2011, going on TV meant traveling to a studio. Now, anyone with a fast Internet connection, a decent webcam, and some claim to knowledge of the topic can appear on CNN or Fox News. Some things won't have changed; the perpetual challenge of obtaining reliable information about an adverse event in a timely fashion amid the fog of war comes to mind.

Then there are areas that need some more work. We still lack a consensus on an approach for talking about radiation exposure with the general public. I can remember during Fukushima, watching an industry spokesperson get sucked into an on-air conversation about "millions of becquerels," and thinking to myself, "We are in a Kobayashi Maru." We must be able to quickly translate an mSv/hr reading into something the average person can relate to, be it Brazil nuts per day, cross-country flights per week, or months living on the International Space Station.

The biggest change, however, is a massive societal shift in the way we humans obtain and process information about the world beyond our senses. We all know it by different names: a post-truth world, identity-protective cognition, "alternative facts," or QAnon. A February 2021 research paper published in the *Proceedings of the National Academy of Sciences* comes to a simple, yet stunningly sweeping conclusion: "People believe that facts are essential for earning the respect of political adversaries, but our research shows that this belief is wrong. . . . In moral and political disagreements, everyday people treat subjective experiences as truer than objective facts." We are definitely not in the Kansas of "providing the public with unbiased technical information" anymore.

We at ANS are in training. Our communications team has held two tabletop crisis communications exercises in the past three months, one on hypothetical nuclear reactor incidents in the United States

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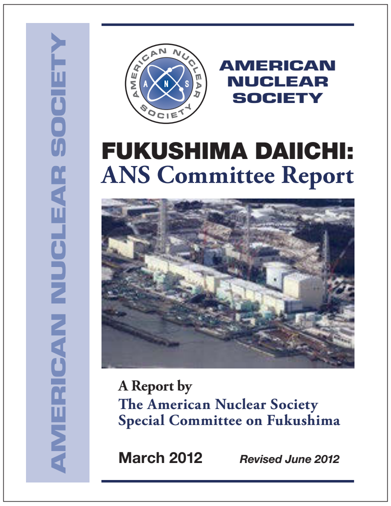
Recalling Fukushima continued from page 20

expertise in other ways. Those efforts included creating the Special Committee on Fukushima, which published a detailed report on the one-year anniversary of the accident. The committee was cochaired by Dale Klein, a former chairman of the Nuclear Regulatory Commission, and Michael Corradini, who served as ANS vice president/president-elect (2011–2012) and then president (2012–2013).



AMERICAN NUCLEAR SOCIETY

AMERICAN
NUCLEAR
SOCIETY

FUKUSHIMA DAIICHI:
ANS Committee Report

A Report by
The American Nuclear Society
Special Committee on Fukushima

March 2012 *Revised June 2012*

"ANS represents the professional aspects of nuclear engineering, nuclear science, and radiation technology," said Klein, an ANS Fellow and professor in the Mechanical Engineering Department at the University of Texas. "As a professional society, ANS has the responsibility and the duty to provide information to its members and the public at large. As members, we agree to a code of professional ethics, and it was our duty to address this [accident]."

Among its other efforts, the Society established the Japan Relief Fund, which supported nuclear workers at Fukushima; produced a member-reviewed FAQ on the health risks of radiation from the incident to U.S. residents; and wrote a letter to then-president Barack Obama urging restraint in immediate responses to the accident. Corradini also testified on behalf of ANS in front of Congress in April 2011.

"ANS needed to be involved because it could act as an objective, arms-length group of professionals that would present the facts to the public," said Corradini, a distinguished professor emeritus in the Engineering Department at the University of Wisconsin. "We were not part of the federal government, the industry, nor a regulator. It was my view that we would be trusted by the public and provide the facts and associated analysis about what occurred and what were the implications."

The full Special Committee report is available at fukushima.ans.org. The report was also the focus of an ANS webinar on March 2 titled "*Nuclear News* Presents: A Look Back at the Fukushima Daiichi Accident." The webinar featured Corradini, Klein, and other panelists and can be viewed free on demand at ans.org/webinars/archive.

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and internationally, and the other on potential radiological dispersion scenarios, and has identified several technical experts from across the nuclear disciplines. We've also created a crisis response webpage that, when activated, will allow us to quickly disseminate information to members, media, and the public, but only after it has been vetted by a team of experts from different backgrounds. We will be in "basic training" a little longer, but the ANS team is committed to being mission ready in the very near future.

Ten years on, I remain grateful to all those ANS members who answered the call in 2011 (too many to name—you know who you are).—*Craig Piercy, Executive Director/CEO (cpiercy@ans.org)*

A Decade of Support - Contributing to the Fukushima Cleanup Effort

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NUCLEAR SOLUTIONS

Veolia Nuclear Solutions is a market-leading technology provider for the most challenging nuclear & hazardous waste challenges.

Our Immediate Response

In March 2011, in the early days after the Japan Earthquake & Tsunami, the chief concern was the removal of cesium and other isotopes from millions of cubic meters of highly contaminated water at the Fukushima site. Designed and delivered in 8 weeks, our Ion Specific Media System (ISMS) processed over 115 million gallons of contaminated water and removed 10 million curies of cesium – more than 70% of the radioactivity on site.

Bespoke Solutions to Tackle the Toughest Challenges

The Group has continued to support the Fukushima cleanup effort throughout the past decade by designing and delivering innovative solutions. This includes the delivery of two ion-exchange at-tank mobile water treatment solutions to remove strontium-contaminated water as well as customized remote-handling systems to inspect, repair, and ultimately retrieve fuel debris from the damaged reactors.

Continued Support of an Essential Cleanup Mission

Our experts, based in the US, France, UK, and Japan, will support the ongoing decommissioning & dismantling mission at Fukushima for many years to come. In addition to our fit-for-purpose solutions to tackle some of the most difficult waste handling projects, our team is evaluating the use of patent protected treatment options - such as vitrification - to treat nuclear waste inventories and thus allowing for a safe, reliable, and low-life-cycle management cost solution for long-term waste disposal.

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To get more information on Veolia's nuclear capabilities in the U.S,
contact Amanda Gilmore: **amanda.gilmore@vnsfs.com**

Resourcing the world

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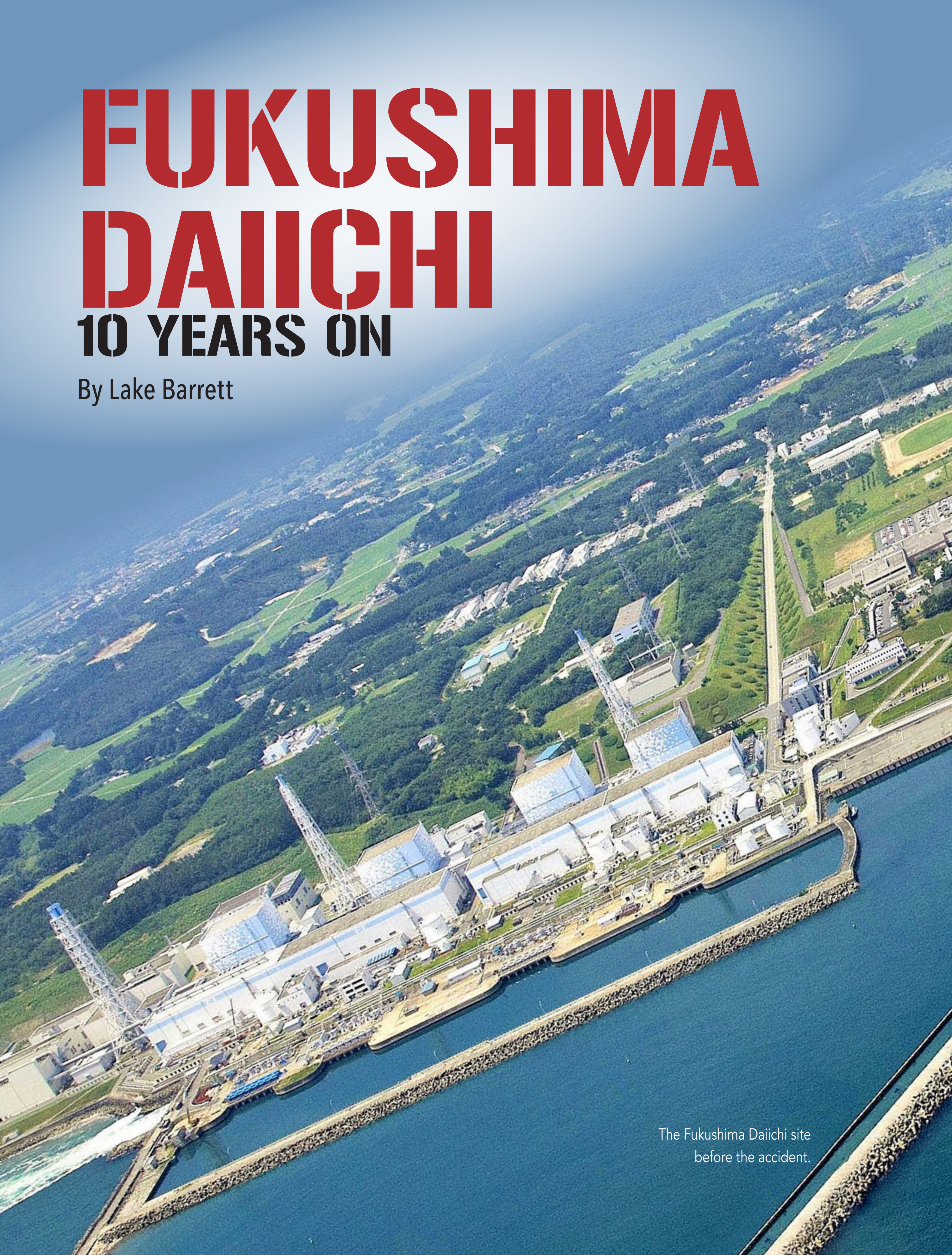
FUKUSHIMA DAIICHI

10 YEARS ON

By Lake Barrett



The Fukushima Daiichi site before the accident.

It was a rather normal day back on March 11, 2011, at the Fukushima Daiichi nuclear plant before 2:45 p.m. That was the time when the Great Tohoku Earthquake struck, followed by a massive tsunami that caused three reactor meltdowns and forever changed the nuclear power industry in Japan and worldwide. Now, 10 years later, much has been learned and done to improve nuclear safety, and despite many challenges, significant progress is being made to decontaminate and defuel the extensively damaged Fukushima Daiichi reactor site. This is a summary of what happened, progress to date, current situation, and the outlook for the future there.

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The accident on-site

Tokyo Electric Power Company's (TEPCO's) Fukushima Daiichi facility had for many years been the largest nuclear power station in the world, with its six 1970s vintage General Electric boiling water reactors. Unit 1, a 460-MWe BWR 3, was commissioned in 1971; Units 2, 3, 4, and 5 were 750-MWe BWR 4s; and Unit 6 was a 1,100-MWe BWR 5 that was finished in 1979. On March 11, 2011, Units 1, 2, and 3 were at full power, and Units 4, 5, and 6 were shut down and undergoing springtime maintenance. The Unit 4 reactor vessel was defueled, with all spent fuel in its spent fuel pool. All the units were well maintained and had been upgraded to the extent required under Japanese regulations of that time.

The earthquake, one of the largest ever recorded in human history, and the following tsunami were well beyond projections. The initial huge seismic shocks were slightly beyond the site seismic design bases; however, all the reactors successfully scrammed and were experiencing an as-designed safe shutdown sequence without any significant safety system damage or problems. All off-site power connections were lost due to transmission system failures, but the site's 13 emergency diesel generators started powering all safety systems as designed. So, despite the great earthquake shock, the reactors were being safely shut down in a controlled manner.


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Immediately following the initial seismic shocks, the Japan Meteorological Agency issued a tsunami warning for a 3-meter-high wave. Being in a major outage situation, there were approximately 6,000 workers on-site, and evacuations were initiated from the lower plant areas. Initially, there was not much concern about a tsunami, as the site's tsunami protection design had been upgraded from 3 meters to 6.2 meters, and most vital equipment was located at the 10-meter elevation level.

However, approximately 45 minutes after the initial seismic shock, a series of tsunami waves hit the site, flooding it up to the 15-meter level (Fig. 1) and disabling 12 of the 13 emergency diesel power supplies and most of the emergency DC power for Units 1, 2, and 3. The massive flooding created a beyond-station blackout situation, with virtually all emergency AC and DC power systems lost. Reactor buildings were flooded with seawater (Fig. 2), tanks were washed away, control rooms were dark, virtually all instrumentation was lost, and electronic communications were nonexistent (Fig. 3). As core cooling was uncertain, a major emergency condition was declared and off-site emergency plans were initiated, followed by a series of public evacuations as the situation deteriorated.

The operators struggled to restore safety instrumentation and to find ways to inject water into the reactor vessels to cool the cores. They creatively scavenged batteries, including those from vehicles in the parking lots, to restore vital instrumentation, such as reactor water levels and pressures (Fig. 4).

The functionality of the Unit 1 emergency core cooling isolation condensers was very difficult to determine because of the uncertainty of containment isolation valve positions due to the sporadic AC and DC power loss sequencing. However, some of the isolation condenser valves were in the closed position, which resulted in the loss of core cooling, core metallic component oxidation, core melting, reactor vessel breach, primary containment overpressure and leakage, and high radiation levels that evening.

Operators were able to keep the Unit 2 and 3 high-pressure turbine-driven reactor core isolation cooling (RCIC) pumps and the Unit 2 high-pressure coolant injection (HPCI) pumps operating to inject water into the reactor vessels from the torus wet well for several days. These variable RCIC and HPCI injections helped delay the overheating of the Unit 2 and 3 cores; however, since there was no available ultimate heat sink for the torus wet wells, the containment pressures and temperatures continued to rise, making low-pressure injection difficult.

For all three units, operators made heroic efforts by entering extremely high-radiation areas inside of the dark, flooded reactor buildings to manually open valves to vent the containments to reduce pressures to allow low-pressure water injection. These venting efforts were only partially successful.

Many courageous attempts were made to reestablish core cooling by pulling temporary electrical cables, manually carrying batteries and portable air compressors to operate valves, installing new ultimate heat sink seawater pumps, and utilizing fire engines to inject fresh water (Fig. 5) and then seawater when freshwater supplies were exhausted. Efforts to cool the reactor vessel cores of shut-down Units 5 and 6, all six reactor spent fuel pools, and the large common spent fuel pool were successful, but the cores of Units 1, 2, and 3 could not be saved.

Despite these great operator efforts, the cores in Units 1, 2, and 3 overheated and melted. Fuel cladding and other metals oxidized, creating exothermic hydrogen gas, which breached the reactor vessels and overpressurized the primary containments, causing leakage such that explosive hydrogen gas and radioactive fission products entered the reactor buildings. The Unit 1 and 3 reactor buildings' upper floors were

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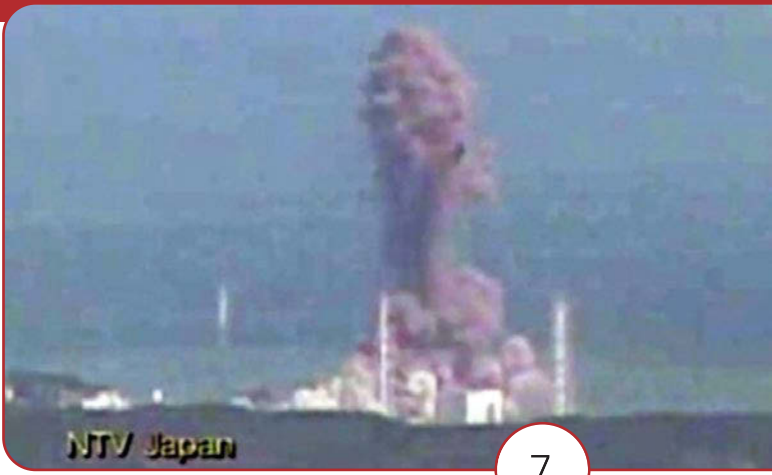

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destroyed by internal hydrogen gas explosions (Figs. 6 and 7). Hydrogen gas also backflowed from the Unit 3 ventilation system into the Unit 4 reactor building, causing an explosion on the upper floors of that building as well. No explosion occurred in the Unit 2 reactor building because the shock wave from the Unit 1 hydrogen explosion dislodged the Unit 2 reactor building blowout panel, dispersing the hydrogen gas generated by the Unit 2 core oxidation into the atmosphere before it could explode. However, airborne fission products vented to the environment along with the heated steam (Fig. 8).

Fission products escaping from the three units, primarily cesium and iodine, created extremely high radiation levels on the site, hampering on-site mitigation efforts. On-site gamma radiation levels were in the sievert per hour range (100 rem/hr) in many areas, making emergency work difficult and dangerous.

During the immediately following days and weeks, TEPCO amassed a large skilled team to establish control over the site. Seawater had to be injected by fire trucks during the first week and then new freshwater supplies were brought in for improved injection cooling. Extensive airborne mitigation

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efforts were made to minimize off-site releases (Fig. 9). Special water injection pumping systems were created to ensure that all spent fuel pools were flooded (Fig. 10). Silt fences were installed to mitigate fission products, primarily cesium, from flowing into the ocean from building basements that were filled with contaminated water flowing from the severely damaged reactor buildings (Fig. 11). Further information is provided in the ANS special Fukushima report at fukushima.ans.org.

Containment of highly contaminated water leaking from the reactor building basements into the turbine building basements and then to the seawater intake structures via a maze of underground tunnels was a major early challenge. Some of the underground pipe tunnels allowed direct leakage into the sea (Fig 12).

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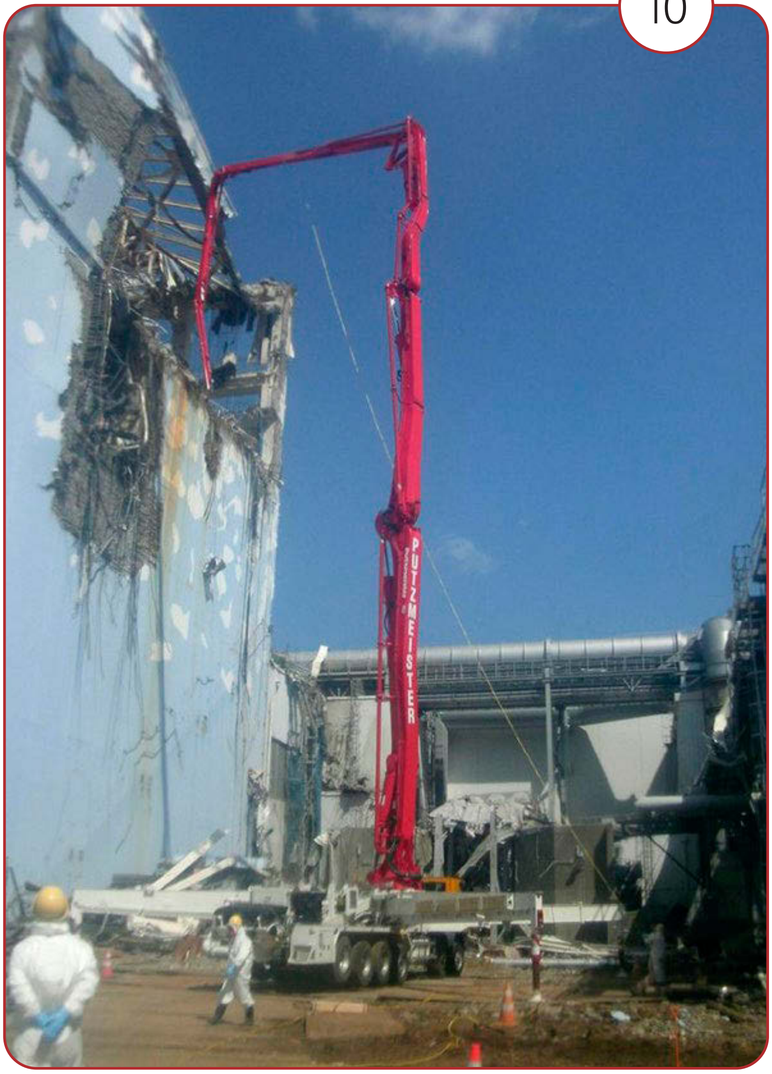

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Early efforts were made to minimize such leakage with concrete sealing (Fig. 13) and the installation of special tank capacity (Fig. 14). New storage capacities for high volumes of very radioactive wastewater were created by quickly preparing the basements of radwaste and incinerator buildings to become de facto contaminated water storage tanks. Zeolite bags were placed in submerged areas to minimize cesium mobility and to minimize sea contamination (Fig. 15).

After the first several weeks, the site was stabilized, with core debris cooling established and with airborne and water containment/mitigation efforts proceeding. A comprehensive personnel radiation protection system was put in place to support an on-site workforce of approximately 5,000 workers, with many outside support people constantly coming and going.

A major early priority was the creation of cesium removal water systems to allow the recycling of highly radioactive water from the melted fuel debris cooling water injection. TEPCO engaged Kurion to develop a zeolite cesium adsorption water processing technology similar to that used for processing highly radioactive water in the Three Mile Island (TMI) accident cleanup 40 years ago. Through effective teamwork, this new processing system was designed, constructed, transported, installed, and safely operated within a three-month period. With subsequent improvements, this system is still in use today (Fig. 16).

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Given the importance of cesium removal, TEPCO also developed other redundant and diverse systems. Areva (now Orano) developed and operated a less successful cesium precipitation removal system, and Toshiba also developed a slightly different follow-on zeolite adsorption system called SARRY. The SARRY system, like the Kurion system, has been improved over the years and still operates today (Fig. 17). The Areva cesium precipitation system was discontinued due the complexities of having to manage extremely high levels of radioactive cesium sludges in its receiving tank. TEPCO currently has a major engineering effort to develop robotic equipment to remove and solidify this high-gamma (in the range of tens of Sv/hr (1,000+ rem/hr) sludge. A lesson learned has been that the waste management aspects of these special highly radioactive systems need to be constantly considered in all stages of design, construction, operation, and decommissioning.

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The accident off-site

The core melting and containment leakages caused considerable radioactive releases off-site. During the early phases of the accident, the winds were blowing toward the Pacific Ocean, so there was little impact (Fig. 18). However, later cesium releases were blown westward toward the mainland, causing extensive land contamination (Fig. 19). Early evacuations prior to these releases protected the public. Extensive Japanese and World Health Organization studies have concluded that there were no radiation fatalities, and no observable increases in cancer above the natural variation in baseline rates are anticipated

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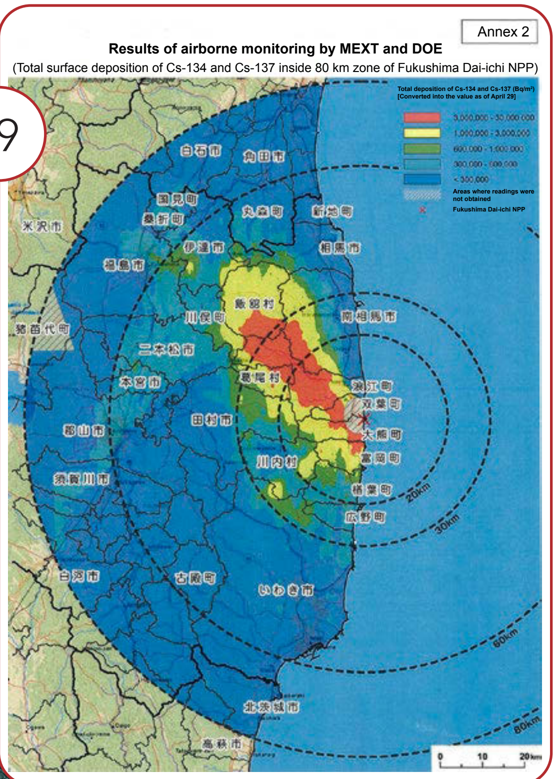

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(who.int/publications/i/item/9789241505130). Unfortunately, the psychosocial effects of the initial evacuation of approximately 160,000 people have been significant (niph.go.jp/journal/data/67-1/201867010007.pdf).

The off-site contamination of Cs-137 requires extensive land and building decontamination and new solid radwaste management capabilities. The Ministry of the Environment, working with Fukushima Prefecture and townships, is financing the reconstruction of earthquake and tsunami damages and decontamination efforts to allow people to return to their homes. Much progress has been made, with most of the evacuation areas now released for people to return to their homes. However, repopulation is a challenge, as many are not returning due to their having moved forward with their lives in other places and the psychosocial feelings about returning. This situation is certainly made more difficult by unrelated Japanese cultural changes that are simultaneously taking place. There is a decreasing overall national population and a desire of young people to live in metropolitan areas, which the Fukushima Daiichi area is not.


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A by-product of the off-site decontamination work has been the accumulation of large volumes of low-level cesium-contaminated soils in fabric bags. Gamma radiation levels were reduced to “able-to-return levels” by removing the top 5 cm (2 inches) of soil. Altogether, this has resulted in up to 20 million 1-cubic-meter fabric bags that require storage somewhere (Fig. 20). Progress has been made to negotiate for temporary storage in an annular ring around the Fukushima Daiichi site for the time being, and transfers are currently taking place to special lined, capped storage trenches (Fig. 21).

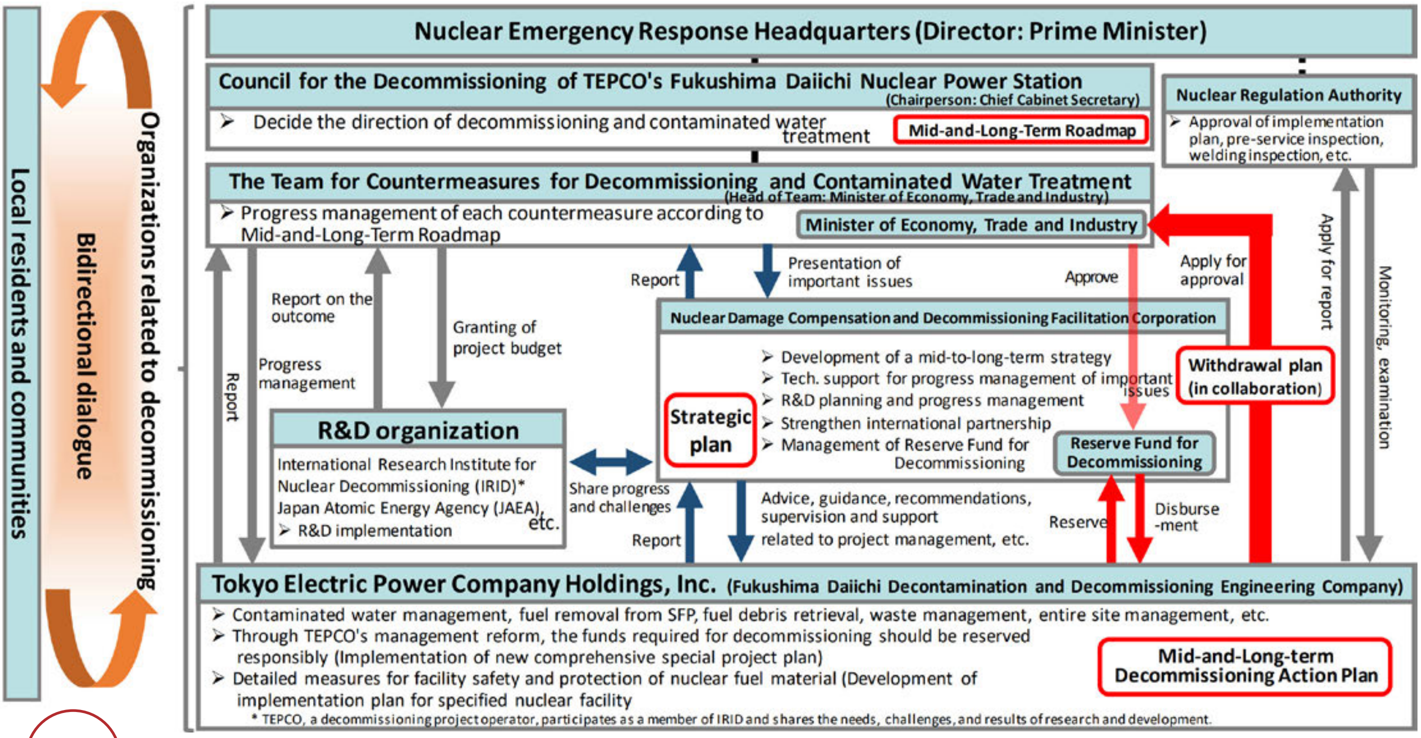
Management adjustments

After the first several months, it became clear that the on-site and off-site recovery from the accident was going to require a coordinated major national and international effort. Similar to the United States’ response to the TMI-2 accident, TEPCO, the Japanese government, the Fukushima prefectural government, and the nuclear industry organized to meet the challenge at Fukushima and across the entire Japanese nuclear complex. These changes focused on not just the on-site and off-site Fukushima Daiichi accident recovery but on ensuring safe nuclear energy across Japan and globally as well.

Japanese laws were changed, and a stronger independent regulator, the Japan Nuclear Regulatory Authority (NRA; nsr.go.jp/english/index.html), was created to ensure reactor safety. Utilities committed billions of dollars to improve safety to restart nuclear reactors. The Japanese nuclear industry followed the post-TMI example of establishing its own safety organization, the Japan Nuclear Safety Institute (genanshin.jp/english/), which is modeled after the Institute of Nuclear Power Operations. Thanks to these and other improvements, nuclear power remains an important, although lesser, component of Japan’s clean energy needs for the future.

For decontamination of the off-site area, the Ministry of the Environment is working with Fukushima Prefecture to accomplish that task with extensive government and TEPCO support. Further information is located here: josen.env.go.jp/en/decontamination/.

The extensive Fukushima Daiichi on-site decontamination and decommissioning (D&D) activities



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remain the responsibility of TEPCO, with substantial government support. A new comprehensive structure of organizations under the leadership of the Ministry of Economy, Trade, and Industry (METI) has been set up to ensure proper financing and support for on-site D&D.

While TEPCO remains the owner of the site, it has set up within TEPCO Holdings a new D&D implementing organization called the Fukushima Daiichi Decontamination and Decommissioning Engineering Company (FDEC) to focus on Fukushima. This concept is similar to what the United States set up to achieve D&D success at TMI.

METI established a new technology research association composed of 17 organizations (currently, 18), the International Research Institute for Nuclear Decommissioning (IRID), to coordinate national and international resources to develop new remote D&D technologies that can be used at Fukushima and elsewhere. The Japan Atomic Energy Agency is also a major supporting resource for D&D and safety technologies and the advanced scientific D&D work at Fukushima.

To ensure overall integration, financing, and policy guidance, METI established the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF) to focus on the Fukushima D&D program. The NDF, on behalf of the Japanese government, provides financial support, policy guidance, and coordination for the Fukushima recovery. Further information is on the NDF website (dd.ndf.go.jp/eindex.html). Figure 22 shows the interrelationship of these organizations within Japan to safely accomplish the Fukushima D&D recovery effort.

Reactor safety lessons

As with the TMI accident 40 years ago, the Fukushima accident has yielded a wealth of reactor safety lessons that are being internationally captured and acted upon to make nuclear power safer. Here in the United States, the nuclear industry and the Nuclear Regulatory Commission did major generic and site-specific reviews to ensure and improve safety for all U.S. reactors, with many safety enhancements made, e.g., implementation of a flexible and diverse strategy (FLEX) to address virtually any possible reactor safety challenges. Further information on FLEX is provided here: nrc.gov/docs/ML1222/ML12221A205.pdf.

The Department of Energy's Office of Nuclear Energy has a program that allows nuclear safety and operation experts from industry, academia, and the national laboratories to work closely with their Japanese and other international colleagues to extract data from the ongoing characterization and cleanup efforts to learn and gain design and operational insights to further enhance safety for existing and future reactors. These insights are used to update guidance for severe accident prevention, mitigation, and emergency planning. A status report on this work is provided at the anl.gov site here: publications.anl.gov/anlpubs/2019/09/154944.pdf.

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The D&D approach

Once the site was stabilized after 2011, the long process to safely contain radioactive materials by removing them from damaged, undesigned conditions and placing them in controlled, engineered configurations began. The general approach and schedule for achieving this is presented in the METI-issued 30–40-year plan called the Fukushima D&D Roadmap (meti.go.jp/english/earthquake/nuclear/decommissioning/). Additional further information is provided in the supporting NDF strategic plan with annual updates (dd.ndf.go.jp/en/strategic-plan/index2020.html).

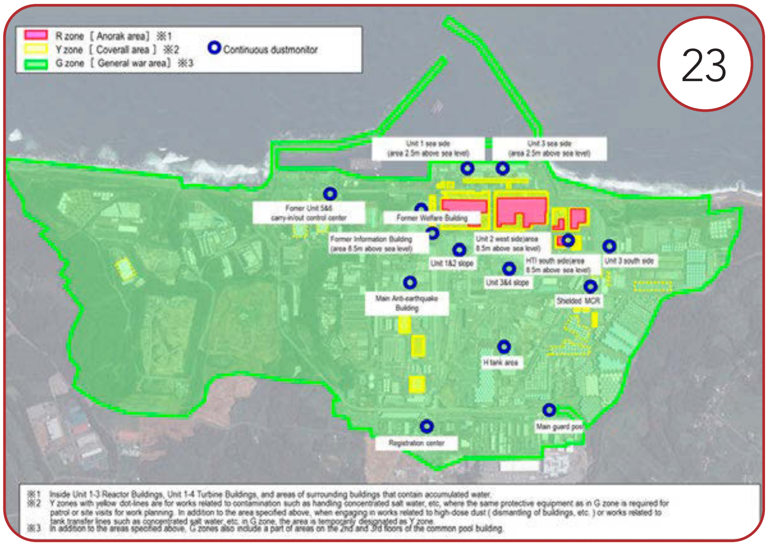
In general, the D&D approach is to proceed along the major areas below. Much progress has been made over the past 10 years in each of these areas. Here are some of the major accomplishments by area:

Maintain worker safety and improve working conditions

- The site has been significantly decontaminated, allowing over 90 percent of the area to be accessed with normal work clothing (Fig. 23). Only the highly contaminated reactor and turbine buildings and some waste management facilities require respirators and special protective clothing.
- A very comprehensive radiation protection and occupational worker safety program is fully in place.
- New on-site buildings have been constructed to support tradesmen and engineering functions.

Reduce site radiological risks in a risk-informed manner

- A detailed site-wide risk analysis has been performed for all risk areas, and work prioritization is risk-informed (Fig. 24).
- The Unit 1 explosion damaged the seismic braces near the top of Unit 1/2 100-meter-high exhaust stack. The stack internals were highly radioactive due to primary containment venting, as determined by surveys and drone investigation into the stack. The top 50 meters of the stack were remotely cut and removed in sections last year (Fig. 25).



※1 Inside Unit 1-3 Reactor Buildings, Unit 1-4 Turbine Buildings, and areas of surrounding buildings that contain accumulated water.
※2 Y zones with yellow dot-lines are for works related to contamination such as handing concentrated salt water, etc, where the same protective equipment as in G zone is required for patrol or site visits for work planning. In addition to the area specified above, when engaging in works related to high-dose dust (dismantling of buildings, etc.) or works related to tank transfer lines such as concentrated salt water, etc. in G zone, the area is temporarily designated as Y zone.
※3 In addition to the areas specified above, G zones also include a part of areas on the 2nd and 3rd floors of the common pool building.

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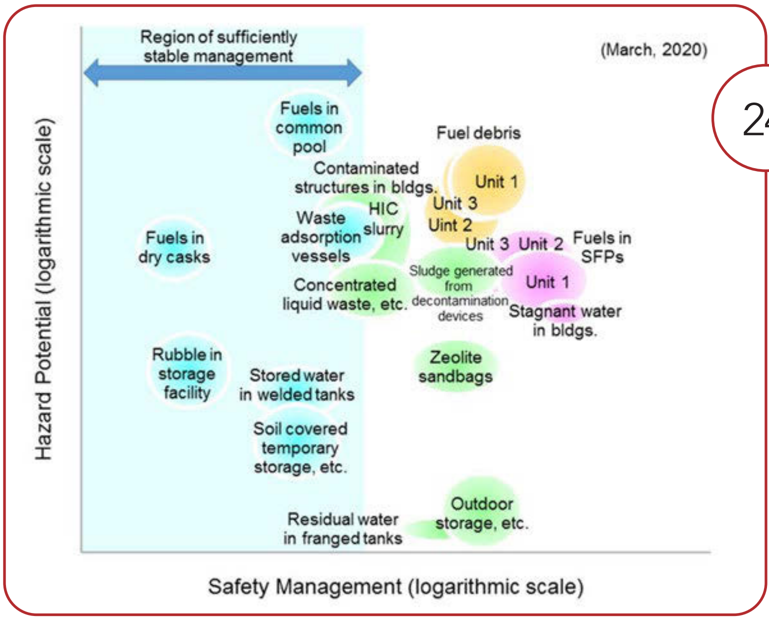

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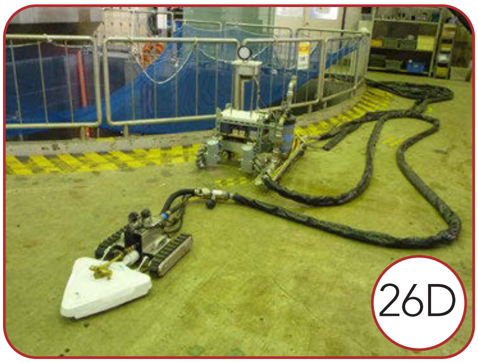

■ Remote decontamination activities continue daily in contaminated buildings to reduce radiation and contamination. An example of progress is shown in Fig. 26A, with a robotic crawler to remove and collect radioactive sludges. Figures 26B and 26C are examples of a debris-clearing robot and a vacuuming robot, and 26D is a floor-washing robot working in the Unit 2 reactor building.

Control and minimize airborne releases

■ As the decontamination and deconstruction of damaged and contaminated building structures proceeds, there is always a risk of activities creating cesium radioactive dusts that may enter the air and spread. An extensive active airborne monitoring array is being operated, and specific activities are closely monitored. When necessary, large, remotely constructed temporary enclosures are built, such as the Unit 1 reactor building enclosure (Fig. 27). When work access is needed, panels can be removed with airborne mitigation actions (e.g., water sprays) taken as necessary (Fig. 28).

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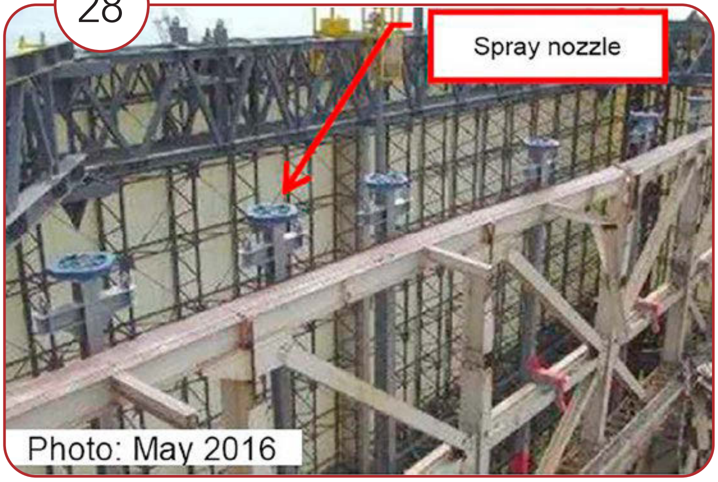

Photo: May 2016

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Decontaminate and temporarily store radioactive waters

- The continuous injection of recycled water into the three damaged cores over the past 10 years has required the constant processing of highly contaminated cesium and strontium wastewater from the basement floors. The initial gross cesium removal systems, Kurion and SARRY, have processed over 2.4 million tons of water, removing over 99.99 percent of cesium. To date, these systems have discharged over 1,000 highly radioactive zeolite adsorption vessels (Fig. 29), which are stored on-site.
- After the gross cesium removal, gamma levels are reduced to allow salt removal by using primarily reverse osmosis (RO) systems, allowing the purified water to be reinjected onto the tops of the reactor core debris. The RO concentrate stream is high in salts, Sr-90, and other isotopes. Three special advanced liquid waste processing systems (ALPS) have been created to process these concentrates to remove Sr-90 and 62 other isotopes (Fig. 30) to levels well below international standards for a controlled ocean release. Tritium is not removed, but tritium levels are low enough to allow normal dilution to well below international safety and environmental protection standards. To date, these systems have processed over 1.2 million tons of water. Further information is provided here: www4.TEPCO.co.jp/en/decommission/progress/watertreatment/index-e.html.
- Over 1,000 large welded steel tanks (Figs. 31 and 32) have been built that now contain over 1 million tons of processed water awaiting a government decision for

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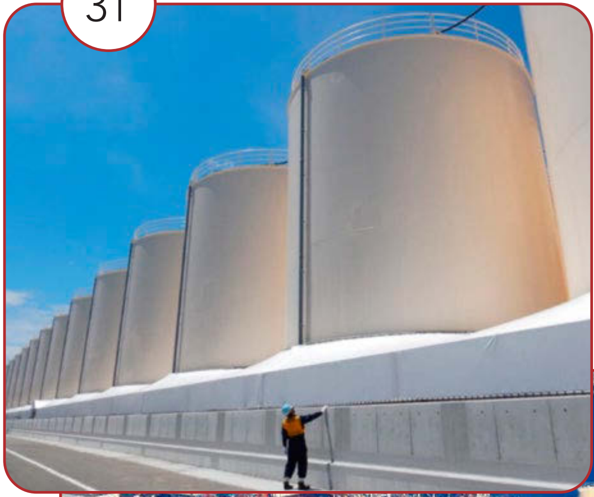

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final disposition. A Japanese study group and many other organizations, including the International Atomic Energy Agency, have recommended a controlled, monitored discharge into the ocean. The Japanese government is currently in a dialog with interested groups (e.g., fishery cooperatives) regarding socioeconomic concerns that might arise from unscientific, emotionally based rumors. A final disposition decision is expected soon. The current planned tank capacity will be full in approximately mid-2022.

Seal and mitigate underground contaminated water sources to control ocean releases

■ During the initial accident phases, there was some fission product contamination that entered the on-site groundwater aquifer from underground structure leaks and rainwater infiltration from surface depositions. To mitigate further ocean contamination, a comprehensive special concrete sealing operation of underground equipment tunnels has taken place. To date, several hundred meters of underground tunnels have been sealed with special sealing concrete.

■ To further prevent underground water flows into the ocean, a 780-meter-long, 30-meter-deep steel seawall has been built (Fig. 33).

■ A 1.5-kilometer-long, 30-meter-deep ice wall has been constructed around the Unit 1–4 reactor and turbine buildings to isolate the contaminated basements and better control groundwater levels (Figs. 34 and 35).

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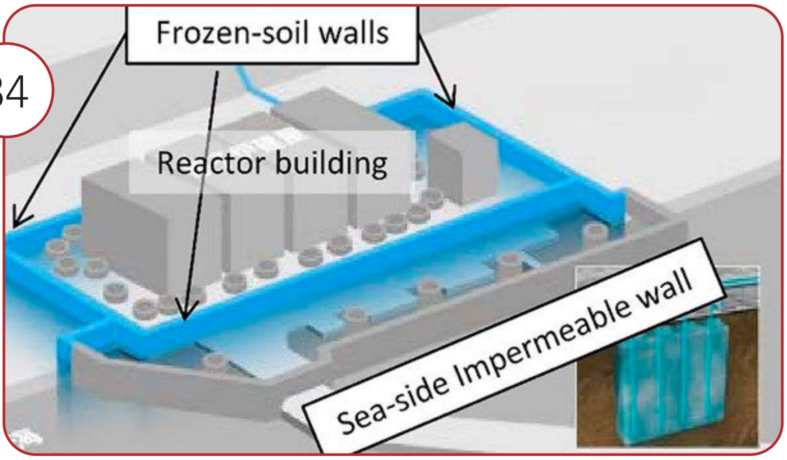

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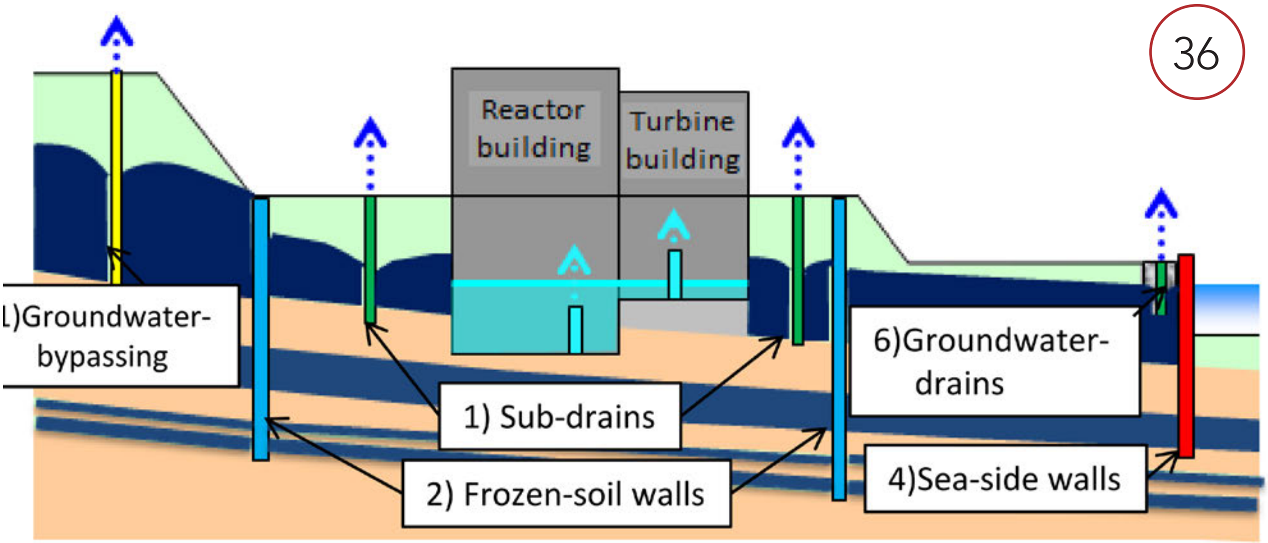

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- A sophisticated subdrain groundwater level pumping system has been built to control groundwater levels within the ice wall boundary to ensure that the groundwater level is always slightly above the reactor building basement water levels, which are being constantly reduced to dry building basements to ensure that there is no radioactive water leakage into the groundwater while minimizing the amount of groundwater flowing into the contaminated building basements. Groundwater and rainwater inflows have been reduced from over 400 tons per day to about 100 tons per day (Fig. 36).
- A line of groundwater bypass intercept pumps has been installed to divert natural groundwater from flowing down from the hillside above the Unit 1–4 reactor buildings to minimize groundwater flows and building intrusion. To date, over 600,000 cubic meters of water have been monitored and released.
- A 20-meter-deep underground wall of apatite/zeolite columns was placed downgradient of an older tank farm of flanged tanks that had leaked water containing significant levels of Sr-90. The purpose is to retard possible Sr-90 groundwater movement toward the ocean (Fig. 37).
- To reduce rainwater infiltration that may transport residual ground surface cesium contamination (from the early accident period) into the aquifer, which flows to the ocean, the site has been extensively covered with asphalt or shotcrete. To date, approximately 1.5 million square meters have been covered (Fig. 38).

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Remove spent fuel from the damaged reactor buildings' spent fuel pools

■ Early on, plans were made to defuel the spent fuel pools in damaged Unit 1–4 reactor buildings. The Unit 4 spent fuel pool had the most spent fuel and had the highest heat load; thus, it had a higher-risk source term. It was also structurally weakened because explosive hydrogen that flowed from Unit 3 via interconnected piping accumulated and exploded on the fourth and fifth floors of Unit 4. In addition, since Unit 4's nuclear fuel was not damaged, the radiation levels there were much lower, so conventional manual pool defueling could take place. The top of the damaged Unit 4 reactor building was removed and a new self-supporting, seismically engineered spent fuel pool defueling building (Fig. 39) containing a new fuel handling machine and cask handling crane was built (Fig. 40). The pool was subsequently emptied of 1,535 nuclear fuel assemblies in 2014.

■ Unit 3 was the next spent fuel pool to be defueled. The highly radioactive Unit 3 reactor building top (Fig. 41) had rubble removed and was remotely decontaminated to allow a new self-supporting defueling structure to be placed over the spent fuel pool. A significant milestone in the process

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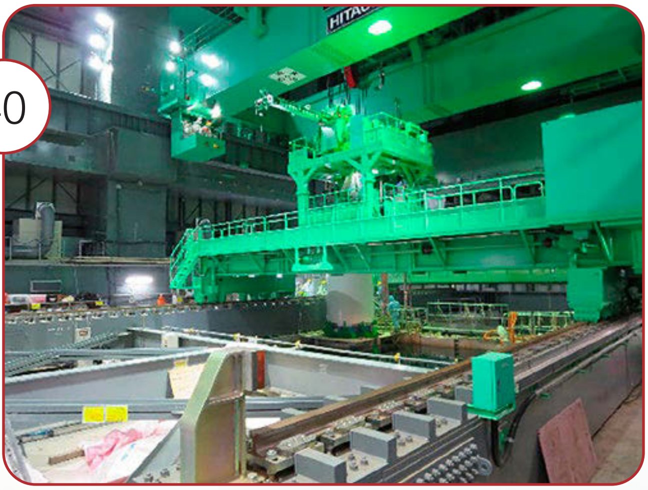

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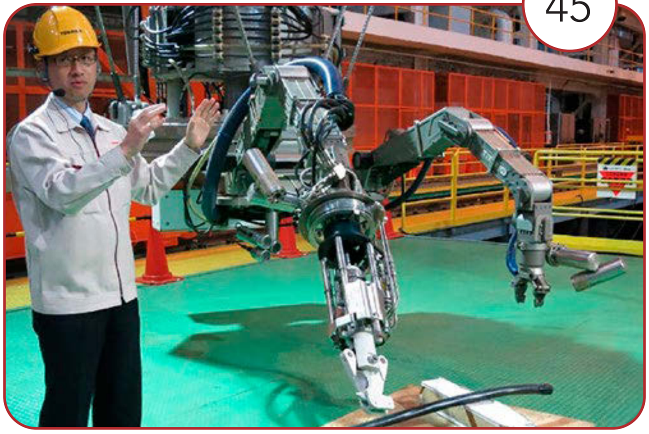

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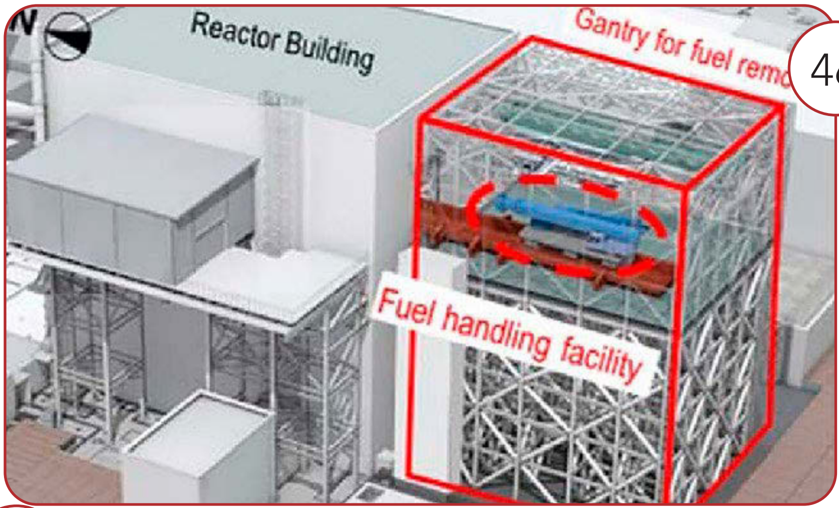

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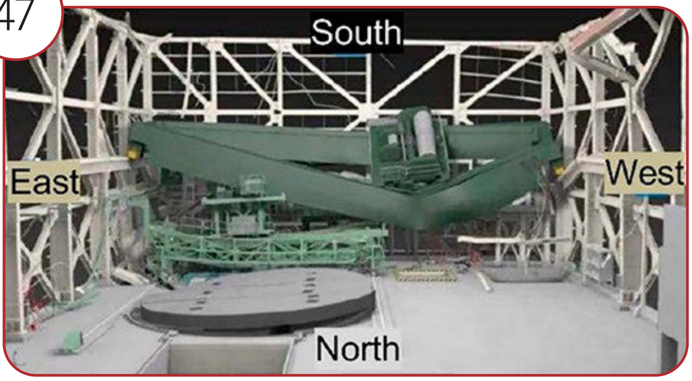

was the lifting of the fallen original fuel handling machine from the top of the spent fuel racks (Fig. 42). A new shield floor was remotely installed, and a new pool defueling building enclosure was built above the existing spent fuel pool (Fig. 43). To perform rubble removal from the tops of the spent fuel racks and to remove the spent fuel assemblies, a new remotely controlled robotic fuel handling machine was installed (Figs. 44 and 45). As of January 22, 510 fuel assemblies have been removed, and the pool is scheduled to be emptied this spring.

- The refueling floor of the Unit 2 reactor building has been remotely accessed, and robots have cleaned the defueling floor. Plans are proceeding to install a new side-entry defueling building (Fig. 46) for special remote/robotic spent fuel defueling machine access. Pool defueling is scheduled to begin in the 2024–2026 timeframe.
- The severely damaged top of the Unit 1 reactor building is being remotely accessed to prepare for spent fuel pool defueling (Fig. 47). The general pool defueling approach is shown in Fig. 48. A special floating concrete shield blanket has been remotely placed on top of the spent fuel pool

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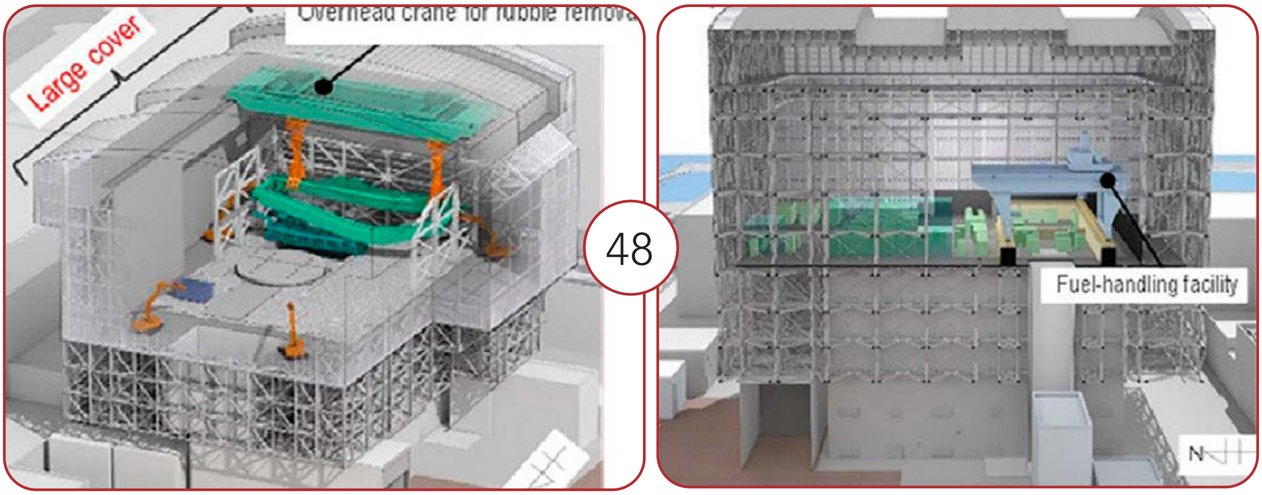

surface to provide a safety barrier for the future remote lift of rubble and heavy objects, such as the original 70-ton crane that is currently over the spent fuel racks. Once the area above the pool is cleared of heavy objects, a remote/robotic defueling machine will be installed. Pool defueling is scheduled for 2027–2028.

Investigate and characterize the internal primary containment vessel (PCV) and core debris conditions

■ Extensive human and robotic surveys and investigations have taken place inside all reactor buildings (but outside of the PCV), and much has been learned.

■ In the Unit 1 reactor building torus room, robotic boats and underwater explorers (Figs. 49A and 49B) have performed visual and sonic measurements to identify PCV leak points, e.g., sand drainpipe leakage, implying that relocated molten core material damaged the PCV liner.

■ Inside the Unit 1 PCV, shape-changing crawler robots have explored internal conditions, taking radiation and physical measurements (Fig. 49C).

■ In Unit 3, an underwater robot, called Sunfish, explored the drywell and swam under the reactor vessel and identified molten core debris (Fig. 49D). Second-generation submarines that can take samples are being developed for further use in Unit 3 (Fig. 49E).

■ In Unit 2, a shape-changing crawler, named Scorpion (Fig. 49F), tried to enter under the pedestal area by traveling down the control rod changing rail but got stuck on hard debris on the rail.

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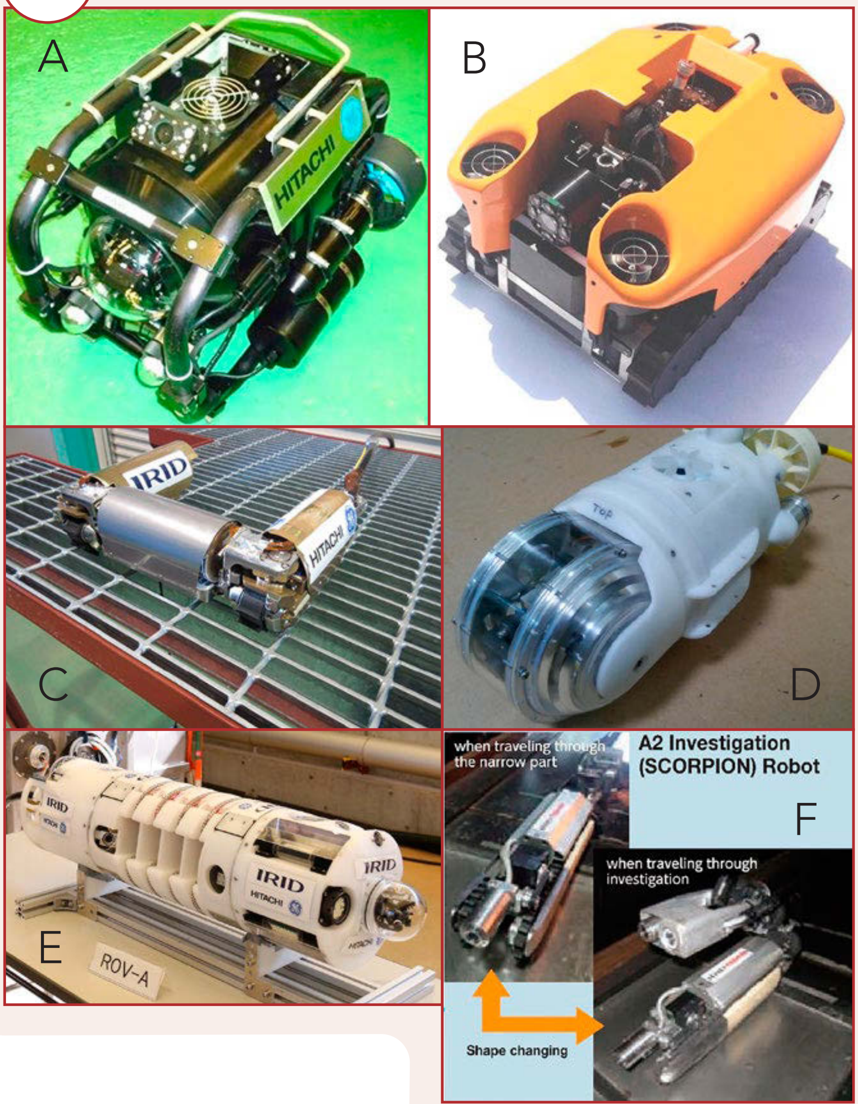

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■ Later, in Unit 2, an extendable, remotely operated pole with a camera, sensors, and movable fingers did explore the pedestal area under the reactor vessel and was able to move small core debris objects. Fuel debris was clearly seen on the basement floor as a fuel assembly lifting handle is clearly visible (Fig. 50). An overall picture of the highly damaged area underneath the failed reactor vessel has been developed (Fig. 51). Note the hole in the floor grating below the apparent reactor vessel breach where the molten core mixture melted through the steel grating.

■ Based on data obtained, coupled with extensive computer modeling, conceptual internal debris projections are being made to guide defueling plans. Figure 52 is a simplified generic projection of internal reactor conditions.

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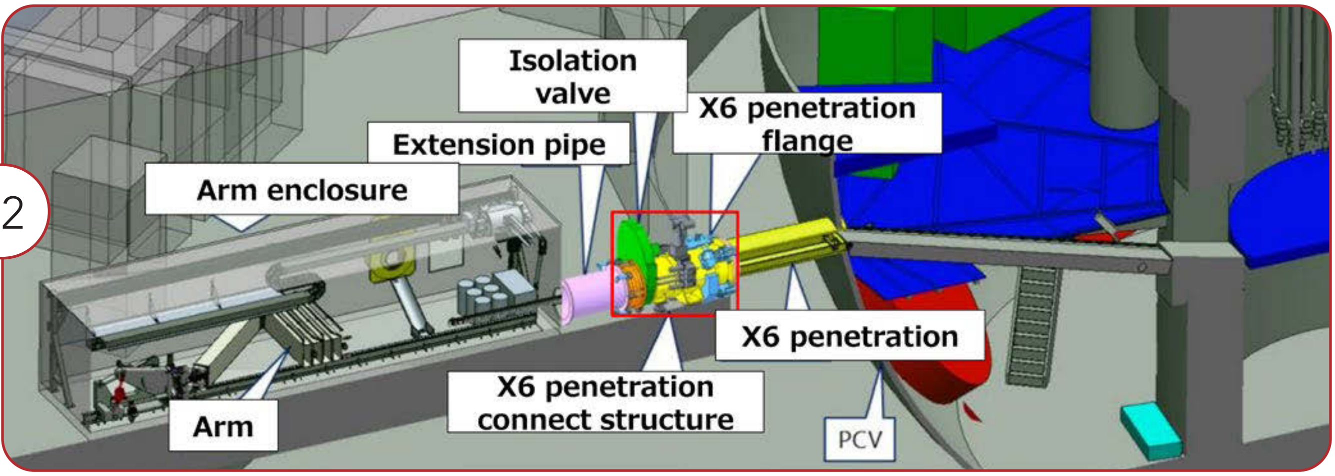

Prepare to defuel and store the damaged core debris

■ FDEC and IRID are currently working to remove the first core debris samples from Unit 2. The plan is to install a hot cell box outside the X-6 penetration that will hold a 22-meter extendable remote arm with end effectors to obtain a sample from the floor (Fig. 53). The 6-ton sampler arm and internal trolley system are shown in Fig. 54. The special arm is under development in the United Kingdom and Japan. Debris sampling is scheduled for later this year, although COVID-19–related delays in the United Kingdom may extend the schedule.

■ FDEC is developing conceptual fuel debris removal plans and designs, and IRID is developing higher-capacity robots for that purpose. Current defueling plans are for side entry as well as top entry options. Given that there are substantial differences and uncertainties concerning the conditions inside the Unit 1–3 PCVs (e.g., water levels and damaged core debris locations), the consideration of multiple defueling options is very appropriate for this stage.

Safely process and store solid waste materials

■ An exceptionally large array of radioactive solid wastes has arisen and will further accumulate over the coming years. A comprehensive on-site storage plan has been developed for the north end of the site. More than 10 major buildings have been built or are planned to be built (Fig. 55), including two large nuclear-grade incinerators to reduce the volume of combustible wastes. The first unit will be used to burn protective clothing and similar materials, and the second will burn the 130,000 cubic meters

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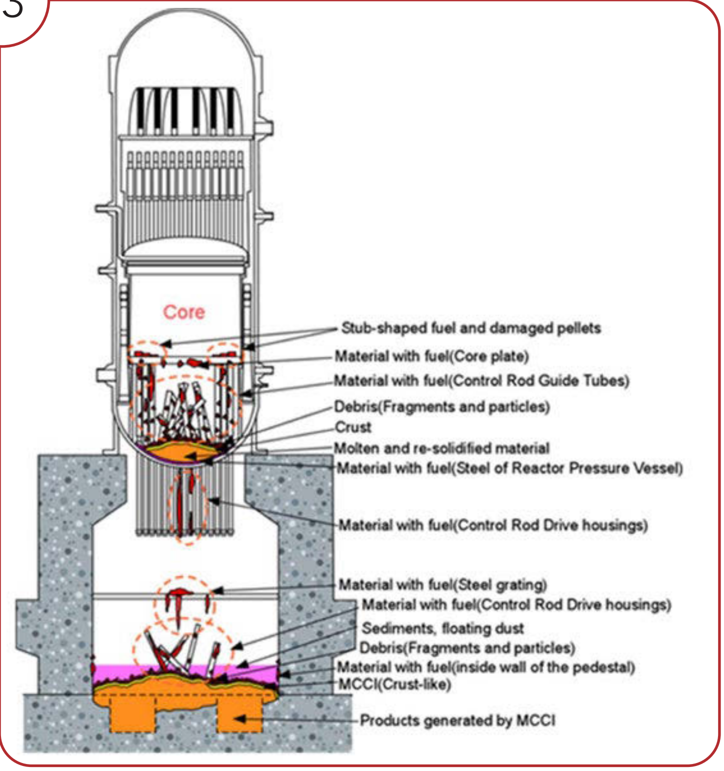

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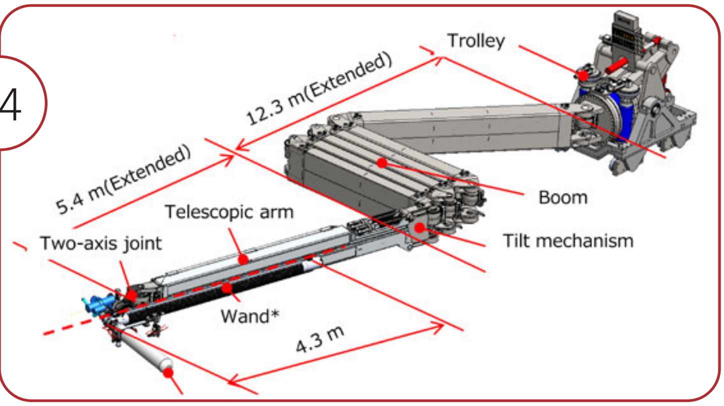

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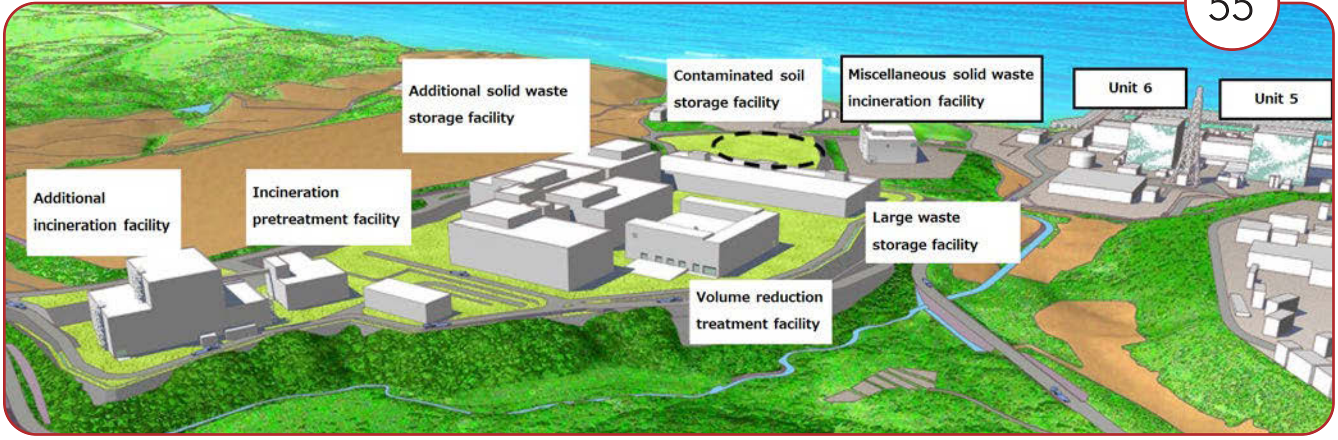

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of trimmed, contaminated trees (Fig. 56) that had to be cut down to make room for the many water storage tanks.

- There had already existed a large amount of spent fuel stored at the site from operations prior to the accident. Most of that fuel is stored in the large common spent fuel pool, but there did exist nine loaded dry storage casks before the accident. During the tsunami, these casks were flooded over with seawater (Fig. 57), but there was no damage to the casks themselves. These and newer spent fuel storage dry casks are being placed in a newly designed spent fuel storage area at a higher elevation on-site.
- The Kurion and SARRY cesium removal systems have generated more than 1,000 highly radioactive shielded spent adsorption containers (Fig. 58). These are stored in a vented condition to control any possible hydrogen gas buildup.
- The operation of the ALPS strontium removal system has generated over 3,500 high-integrity containers that contain highly radioactive Sr-90 sludges, which are kept in shielded concrete vaults (Fig. 59). These are also vented to control hydrogen gas, and a major waste processing project is proceeding to dry these sludges and incinerate their polyethene inner containers to reduce storage volumes and hydrogen gas explosion risks (Fig. 60).

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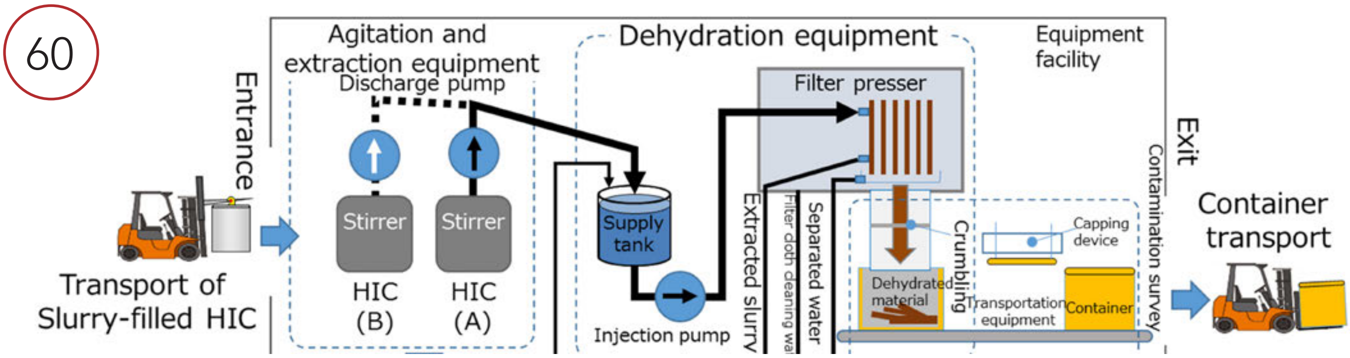


Future challenges and outlook

Much has been accomplished so far, but many difficult tasks and challenges remain. From a technology perspective, developing, installing, operating, and maintaining reliable remotely operated robotic tools to remove the melted core debris from inside the primary containments will be very challenging. Gamma radiation levels are extremely high inside the PCVs such that human entry is not feasible. The FDEC/IRID team are world leaders in state-of-the-art robotics, but the removal of the heterogenous mixtures of melted core material, melted structural materials, corrosion products, and degraded concrete—all located in a physically restricted and hostile radiation, temperature, and chemical environment—is very complex and extremely challenging.

Managing the complex array of radioactive wastes safely will also present continuing significant challenges, as there are so many large volumes of new and different types of wastes with complex radiological, chemical, and physical characteristics.

Time will be a continuing challenge as well, as existing equipment, structures, and buildings slowly degrade over the years. Although a lot of progress has been made, internal robotic core debris exploration/characterization has been relatively slow due to all the necessary development and safety precautions. At the current rate of progress, in my view, it will take many decades to remove most of the melted core debris. Except for the radioactive decay of Cs-134, time is not on the side of reducing the risks, so delays in getting to production defueling is a risk challenge in itself.

Nontechnical sociopolitical challenges are also major factors in achieving success. So far, the Japanese society has been united in supporting D&D progress, but there are growing negative social impacts that can adversely impact technical risk reduction progress. For example, TEPCO has had to spend the equivalent of many billions of dollars storing and managing processed water that contains comparatively low levels of relatively benign tritium. Any other international nuclear facility would have been allowed to have a monitored and controlled ocean release system functioning under existing protective environmental rules years ago. However, the public stigma (often referred to as "harmful rumors") and concern in Japan that there may be an impact on fishery sales has been an exceedingly difficult issue to resolve. It has also been extremely unfortunate that the water release issue has become part of nonrelated historical international tensions in the Pacific region that have no relationship with nuclear (e.g., ongoing historical trade and financial disputes between South Korea and Japan from over 75 years ago).

These complex sociopolitical issues can have a significant negative effect on actual recovery progress because they divert scarce engineering and management time resources from the technical risk reduction needs that already exist, like fuel debris removal. Holding the FDEC technical team back by having to address these socially driven psychological-emotional perception requirements is a major challenge that is very counterproductive and further exacerbates the already challenging technical D&D tasks.

Due to regional social concerns, all waste must be stored on-site, as there are no capable off-site facilities available. Fortunately, the Fukushima Daiichi site is relatively large with good storage elevations. For the near future, once the processed water disposition issue is resolved, there should be room to store all waste and fuel debris materials at the site for many decades. But at some point in the future, off-site long-term storage/disposal facilities will have to be established. As it was for TMI radioactive materials, this will likely become another challenging sociotechnical issue that will have to be addressed.

Another future challenge will be the setting of "how clean is clean enough" standards for decontaminated areas of the site. This will be a delicate social/technical/economic balance that will eventually have to be resolved by the local and regional authorities, TEPCO, and the Japanese government working together.

Despite all these future challenges, the good news is that TEPCO and other Japanese teams are extremely

Photo by The Asahi Shimbun via Getty Images dedicated and focused to safely accomplish the D&D of the Fukushima site. As a Westerner, I am constantly amazed at the organization, personal feelings of responsibility and dedication, and the willingness to perform hard work that is undertaken by all involved to rectify the unfortunate impacts of the reactor accident.

My personal benchmark is that in the aftermath of the TMI-2 accident, we here in the United States learned our lessons, made nuclear energy safer and more productive, and decontaminated and safely removed the melted fuel from inside the damaged Unit 2 reactor. Although the technical damage is more significant at Fukushima, the capabilities today of the Japanese team surpasses what we had available 40 years ago. So, despite the great challenges ahead for Fukushima Daiichi, I am optimistic that Japan, with its international supporters, can achieve the same successful outcome that we did. ⚛

Lake Barrett is a semiretired nuclear engineer who is a senior advisor to TEPCO and IRID. He is a 50-year emeritus ANS member and served as the Nuclear Regulatory Commission's site director for the cleanup of the Three Mile Island accident.

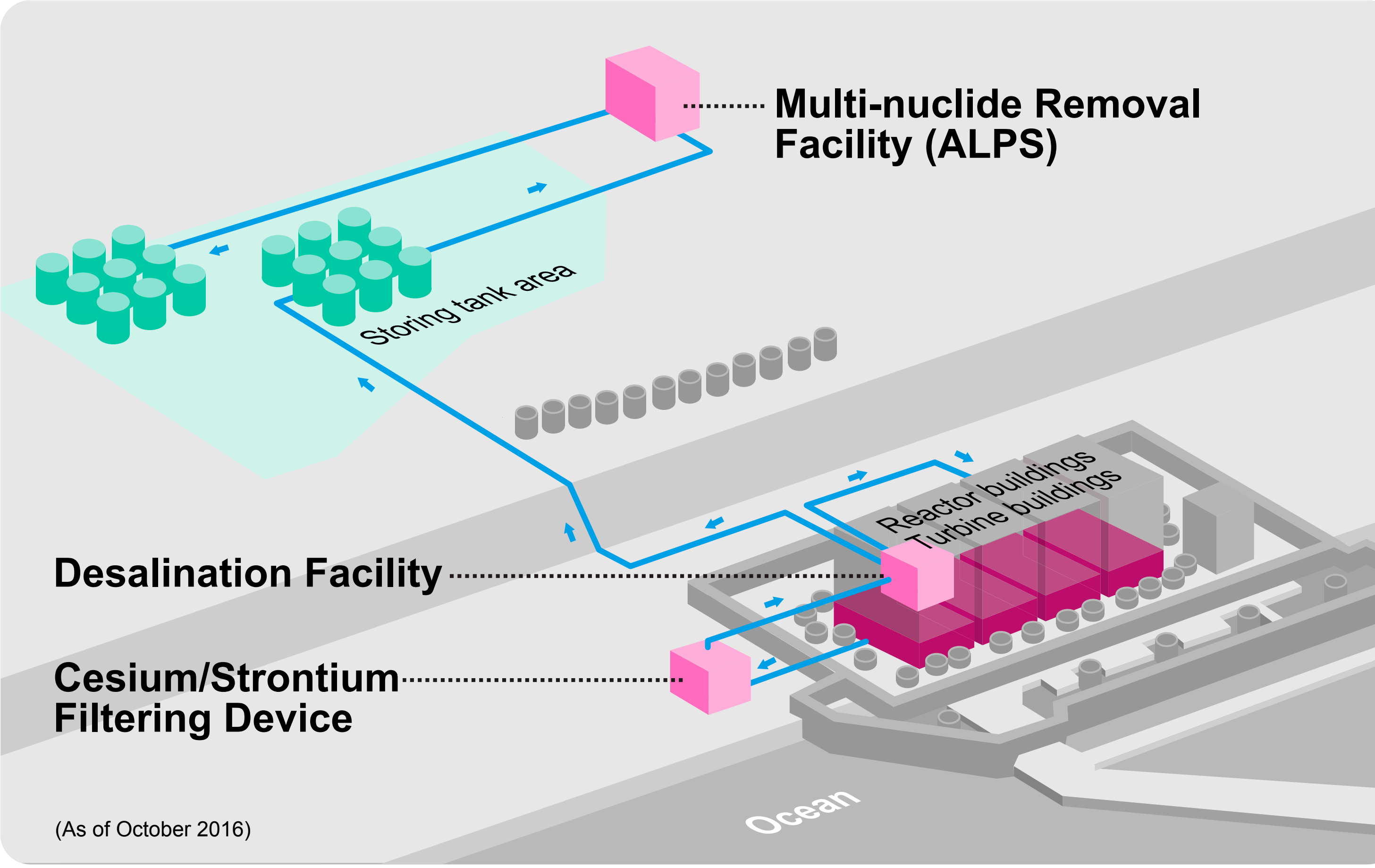
A look at Fukushima Daiichi today.

Advanced liquid waste processing systems

Safely processing Fukushima's wastewater

By John Fabian

The Tokyo Electric Power Company (TEPCO) became a household name a decade ago as the operator of the Fukushima Daiichi nuclear power plant, center of the largest nuclear accident in a generation. Now in 2021, as a result of the continuous mitigation efforts, TEPCO is currently storing 1.2 million cubic meters of treated wastewater—and counting—in more than 1,000 large storage tanks on site. This wastewater has been in the spotlight for the past few years since current projections show that storage capacity will run out by 2022. That spotlight intensified last year when a panel of experts from Japan named the Subcommittee on Handling of the ALPS-Treated Water (ALPS Subcommittee) recommended to the Japanese government that the treated wastewater should be released into the ocean. The ALPS Subcommittee's report states, "The topic of how to handle the treated water is one of the most important decommissioning tasks, which has been discussed since 2013." This issue has plagued the decommissioning and decontamination efforts for the past decade for one simple reason: a failure to effectively communicate about the low risk involved with processing, diluting, and discharging the water over a period of several years.



A depiction of the multiple water treatment facilities on the Fukushima Daiichi site. Image: TEPCO

Background on water treatment at Fukushima

Over the years since the Fukushima accident, TEPCO has had to manage millions of tons of water either from groundwater accumulating in buildings or from the coolant water continuously injected into the three damaged cores. The water requires constant processing to remove contaminants like cesium and strontium, along with other radioactive nuclides. To complete this process, TEPCO uses several water treatment systems: initial cesium removal systems named Kurion and SARRY, which remove 99.99 percent of cesium, followed by a desalination system that purifies the water to be reused as coolant. The waste from the desalination process is then moved to storage tanks to be processed by the advanced liquid waste processing system (ALPS).

These advanced systems remove 62 radionuclides such as cesium-134, cesium-137, strontium-90, and iodine-129 from the highly radioactive water. The process is so effective that the levels of these radionuclides in the water are well below the current international regulatory standards.

Although the ALPS process removes most of the dangerous isotopes, it cannot remove one: tritium. However, tritium is “considered one the of the least harmful radionuclides,” according to the Health Physics Society (HPS). Tritium does produce ionizing radiation as it decays, but the beta particle that is emitted has a very low energy. The HPS fact sheet on tritium states that the beta particles from the hydrogen isotope “can only travel about 6 millimeters (mm) in air. . . . In human tissue, tritium’s beta particle cannot penetrate the typical thickness of the dead layer of skin.”

Tritium levels in the treated storage tank water, according to TEPCO, are at levels higher than regulatory limits allow. However, it is common practice by nuclear power plants all over the world to sufficiently dilute and discharge tritiated water into the environment over a period of time under the strict supervision of regulatory bodies.

Continued

Construction of the ALPS processing facility on the Fukushima Daiichi site in 2013. Photo: TEPCO

ANS member and study director of the ANS Special Committee on the Fukushima Daiichi accident Paul Dickman said that the level of radioactivity is a lot, but “the United States discharges almost double that amount from our nuclear reactor fleet every year, and South Korea annually discharges an amount equal to about 40 percent of the stored tritium at Fukushima.”

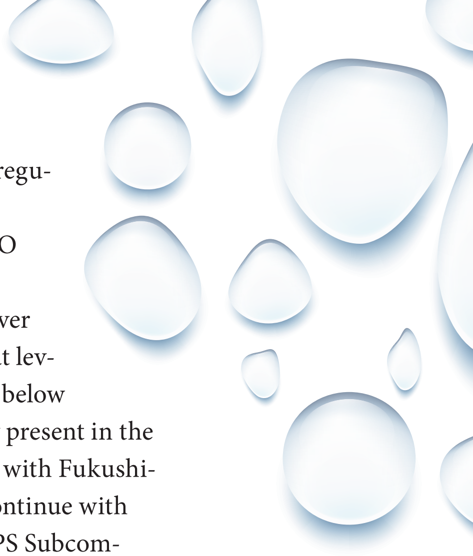
James Conca, an ANS member with a background in geology and radionuclide chemistry and a contributor to *Forbes* and *Nuclear News*, wrote in an article following the issuance of the subcommittee report that “putting this water into the ocean is without doubt the best way to get rid of it. Concentrating it and [storing] it actually causes more of a potential hazard to people and the environment.”

What’s the holdup?

If the water treatment processes lower to well below international regulatory standards the levels of the very dangerous and long-lived radionuclides, leaving only tritium behind (which has been effectively managed since the beginning of nuclear power generation), then why is this still an issue? According to Dickman, the issue stems from a failure to communicate to the general public in understandable language during the early stages of the Fukushima accident. He says, “The legacy of that communications failure remains today and hampers decommissioning operations at the Fukushima site.” The problem was exacerbated by the torrent of misinformation that was propagated by social media and the insatiable demand for immediate and constant updates by the mainstream media.

Since the early days of the accident, TEPCO and the Japanese government have tried to reassure the public that release of tritiated water will not increase the risk of radiation exposure to the public. TEPCO has since set up an online water management portal to update and inform members of the public, and the Japanese government convened the ALPS Subcommittee to review the best ways to dispose of the treated wastewater in a safe manner and how to restore the faith of the public by dealing with “the problem of reputational damage.”

The ALPS Subcommittee report recommends to the Japanese government first to re-treat the water as an extra safety step and then to gradually dilute and release it into the ocean over a period of several years. The report states that this is consistent with international law and current regulatory standards in Japan set prior to the March 2011 accident. The report also notes that if the current recommendations are followed, the release of re-treated water into the ocean will be no more than one one-thousandth of a percent of the exposure to natural radiation per year for a member of the public.



These steps taken by TEPCO and the Japanese government have not held back the antinuclear media frenzy. A steady stream of stories quote mainly from antinuclear groups and state that discharging water will "alter human DNA." These stories have latched on to the idea that carbon-14, a long-lived but low-energy beta emitter, would be released into the oceans. TEPCO has shown in its testing, however, that the levels of C-14 are far lower than current regulatory limits. According to the TEPCO water treatment portal, "The average concentration of C-14 in storage tanks for treated water (tanks analyzed as of the end of June 2020) is 42.4 Bq/liter, which falls below the government's regulatory standard of 2,000 Bq/liter." The range of values in samples was 2.53 Bq/liter to 215 Bq/liter—that is, even the highest concentration in a sample was barely one-tenth of the regulatory limit.

On top of this, adding that TEPCO plans to re-treat and then dilute the wastewater prior to discharging it over a period of several years ensures that levels of any radionuclides will be well below background radiation levels already present in the ocean. The safest option for dealing with Fukushima's wastewater problem is clear: continue with the recommendations from the ALPS Subcommittee (and many other professionals and nongovernmental organizations) to re-treat, dilute, and discharge the treated wastewater.

John Fabian (jfabian@ans.org) is publications director for the American Nuclear Society.

Further reading

This article was written using the following sources, which contain a wealth of additional information related to the Fukushima wastewater situation and its solution. All URLs are current as of the time of writing.

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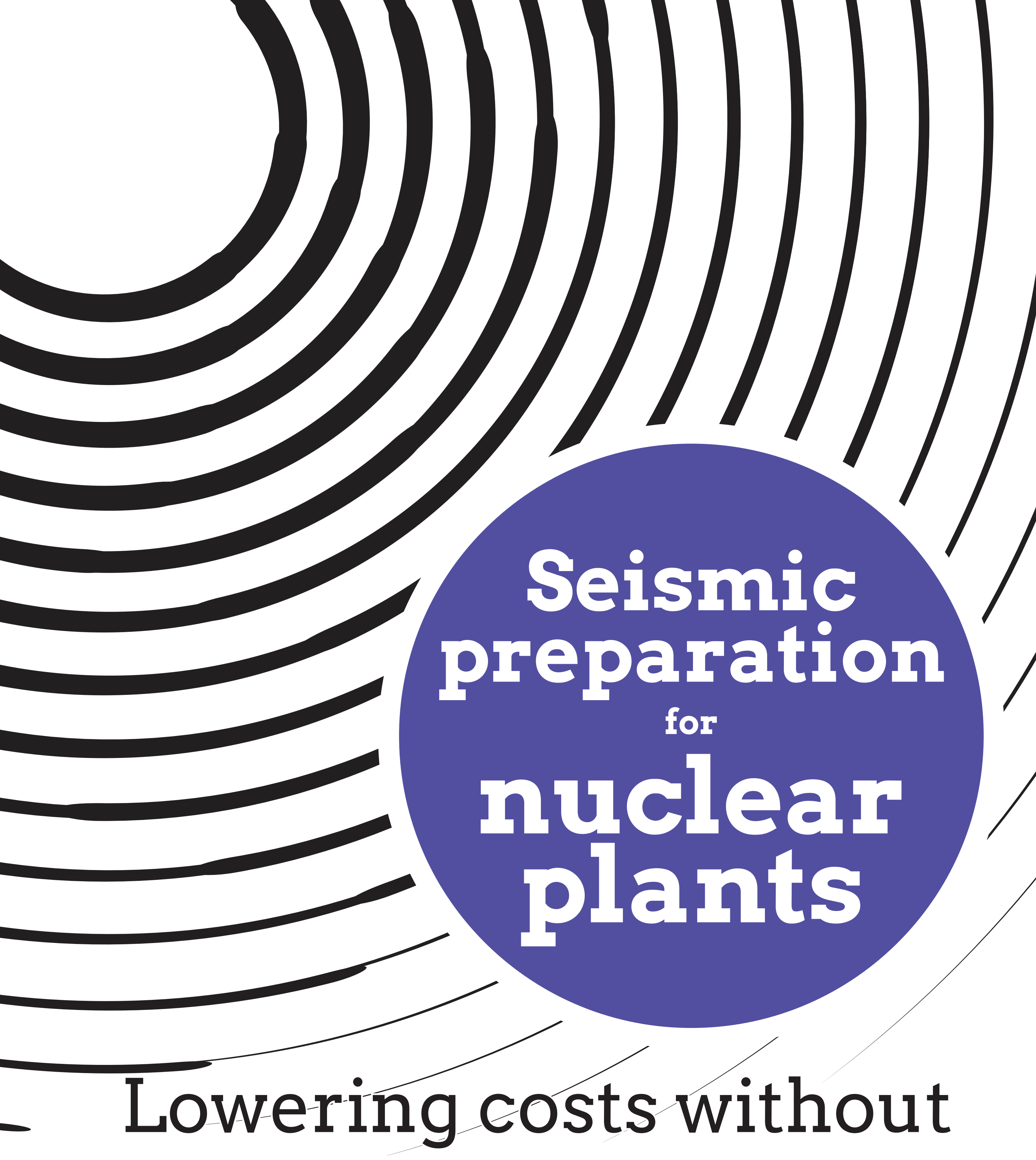


Seismic preparation for nuclear plants

Lowering costs without compromising safety

Rethinking seismic design may be key for making nuclear plant construction affordable.

By Cory Hatch

Nuclear power plants not only provide the nation's largest source of carbon-free electricity, they also can operate 24 hours a day, 365 days a year to augment intermittent renewables such as wind and solar. Further, studies show that nuclear energy is among the safest forms of energy production, especially when considering factors such as industrial accidents and disease associated with fossil fuel emissions. All said, nuclear has the potential to play a key role in the world's energy future. Before nuclear can realize that potential, however, researchers and industry must overcome one big challenge: cost.

A team at Idaho National Laboratory is collaborating with experts around the nation to tackle a major piece of the infrastructure equation: earthquake resilience. INL's Facility Risk Group is taking a multipronged approach to reduce the amount of concrete, rebar, and other infrastructure needed to improve the seismic safety of advanced reactors while also substantially reducing capital costs. The effort is part of a collaboration between INL, industry, the Department of Energy's Advanced Research Projects Agency–Energy (ARPA-E), and the State University of New York–Buffalo (SUNY Buffalo).

The cost of nonstandardization

For reactors built in the 1970s or earlier, the large number of utilities, reactor design companies, and vendors involved in the nuclear power industry meant that U.S. nuclear power plants varied significantly in design. This meant that each new nuclear power plant was custom-built, which increased the probability of costly construction errors or last-minute design changes. Further, the lack of standardization increased the time and expense of the regulatory process.

The same is true for more recent projects. Two well-documented nuclear power projects using Westinghouse AP1000 reactors highlight the state of the industry. In South Carolina, a $9.8 billion expansion to the V. C. Summer Nuclear Station was abandoned in 2017 after costs spun out of control. Another project, adding two reactors to the Vogtle Electric Generating Plant in Georgia, has seen costs rise from the original estimate of $14 billion to more than $25 billion.

"The overnight capital cost of nuclear is four to five times too high," said Andrew Whittaker, SUNY Buffalo distinguished professor in the Department of Civil, Structural, and Environmental Engineering. "A lot of this work is focused on, how do we deliver sufficient safety and drive down overnight capital cost? How do we squeeze every penny we can out of new-build nuclear plants, recognizing that other industries have been doing this for a long time?"

Continued

Earthquake mitigation expense

Utilities and nuclear engineers, going for economies of scale, have typically settled on building multiple large reactors at each power plant site. For a light-water reactor, that means a great deal of infrastructure—in the form of reinforced and prestressed concrete and steel—to contend with not only the high pressures required for operation, but also consequence mitigation in the event of a major earthquake or other natural disaster.

At some reactor construction sites, ensuring seismic stability starts with removing and replacing all of the soil at the site. Then the foundation, cooling towers, and other infrastructure are built with many tons of reinforced concrete, which is a composite of concrete and steel rebar.

This strategy of overbuilding nuclear power facilities to mitigate seismic risk has worked well. The World Nuclear Association estimates that 20 percent of the world's nuclear reactors are operating in areas of significant seismic activity, yet damage to nuclear reactors resulting directly from earthquakes is rare. Take the situation at Fukushima Daiichi: The magnitude 9.0 Great Tohoku Earthquake caused a 40-foot tsunami that damaged the cooling systems of the nuclear plant, causing the accident. According to the WNA, "Eleven reactors at four nuclear power plants in the region were operating at the time, and all shut down automatically when the earthquake hit. Subsequent inspection showed no significant damage to any from the earthquake. . . . The [Fukushima Daiichi] reactors proved robust seismically, but vulnerable to the tsunami."

The Fukushima Daiichi reactors proved robust seismically, but vulnerable to the tsunami.

Still, the way we currently design nuclear power plants for seismic safety often makes new reactor construction prohibitively expensive, especially in the United States.

"For nuclear reactors in the U.S. and Western Europe, the capital costs are so high that very few utilities can afford [to build] one," said Rachel Slaybaugh, associate professor of nuclear engineering at the University of California–Berkeley, who recently served as ARPA-E program director and was a member of President Joe Biden's transition team. Slaybaugh added, "Right now, if you build a new reactor, the cost is 50 percent site preparation and concrete, in part due to earthquake mitigation."

Reducing those capital costs is a big part of the focus at INL, according to Chandu Bolisetti, Facility Risk Group lead at the laboratory. And none of that can happen without considering seismic safety infrastructure. "Recently, people have found that a lot of the economic problems in the nuclear industry are capital costs because of structural and construction engineering," he said. "A majority of the cost is from the structures you build around the core, not the core itself, and seismic hazard is one of the drivers of how you design these structures."

Reducing costs through innovation and standardization

Advanced reactor designs, which rely on a range of fuels and coolants, could help mitigate the cost dilemma. For example, most advanced reactor designs rely on natural circulation systems instead of pumps for coolant circulation and for safety systems in case of accidents. These passive safety features not only reduce the amount of infrastructure—electric pumps, valves, and overbuilt pipes are eliminated—but also make the reactors walk-away safe in case of an accident. In addition, most fast reactor designs operate at near-atmospheric pressure, so they don't require expensive containment domes and all of the associated concrete and rebar.

Further, some advanced reactors could be designed to be built in a factory and shipped to the construction site, as opposed to being custom-built. Standardizing reactor designs this way has the potential to dramatically reduce design errors and construction flaws seen in custom-built reactors. Once a reactor design is proven and approved, repeating the construction of that same reactor should reduce regulatory expenses and shorten the regulatory review time by several years.

But Bolisetti points out a major hurdle. "Right now, you have to build and license a different structure in California [versus] in New York," he said. "Seismic hazard is one big barrier to standardization. How can you use the same equipment everywhere and make it safe at the same time?"

Seismic isolation

Bolisetti and the Facility Risk Group have looked to other industries, especially those in earthquake-prone areas, and combined those technologies with state-of-the-art modeling and analysis to come up with different approaches to the seismic challenge.

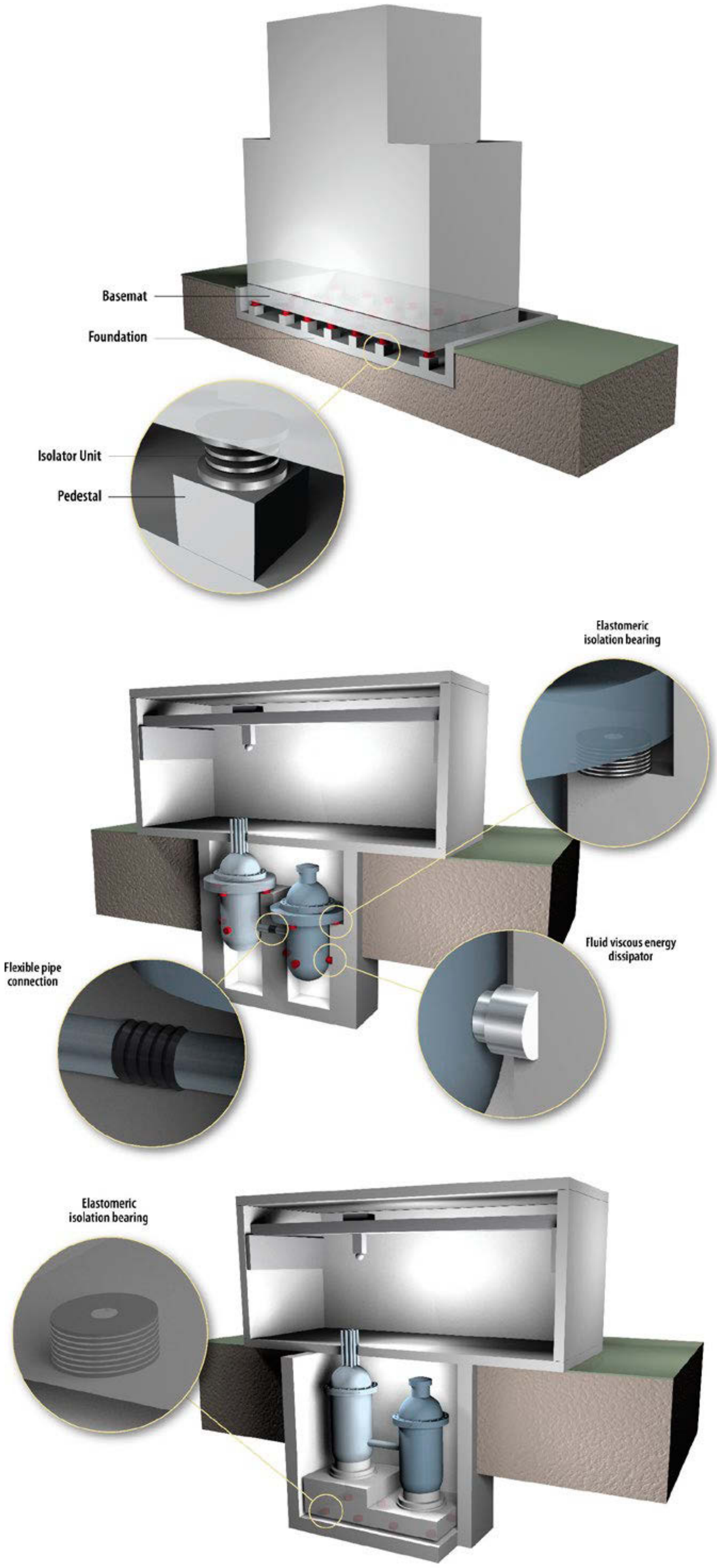
One such solution, seismic isolation, makes use of a technology that has been successfully employed to protect all kinds of infrastructure projects—from schools to offshore drilling platforms to bridges. Examples of buildings in the United States that make use of seismic isolation include San Francisco City Hall, the Utah State Capitol building in Salt Lake City, and Apple's new headquarters in Cupertino, California.

Seismic isolators are essentially shock absorbers placed between a building and its foundation. There are a number of different types of seismic isolators, but one common design is made of alternating layers of rubber and steel with a lead core. Depending on the building, as well as the seismic characteristics of the site, engineers could place tens or even hundreds of seismic isolators under any given building.

"When an earthquake hits a nuclear power plant, seismic isolators absorb the earthquake's energy, and most of the energy will be dissipated," Bolisetti said. "It drastically reduces the shaking you see in the plant."

According to Slaybaugh, seismic isolators represent an important and relatively inexpensive technology for standardizing nuclear reactors. "With isolators, you're trying to get rid of doing this site-specific work," she said. "You're not customizing the building or the reactor, just the seismic mitigations for each site."

Continued



Seismic isolators can be used to provide seismic isolation for an entire structure. One application of seismic isolation is to individually isolate critical components like reactor pressure vessels and generators (center). Seismic isolation can be used to isolate systems within a nuclear power plant, like the reactor and electrical generator together (bottom).
Images: INL

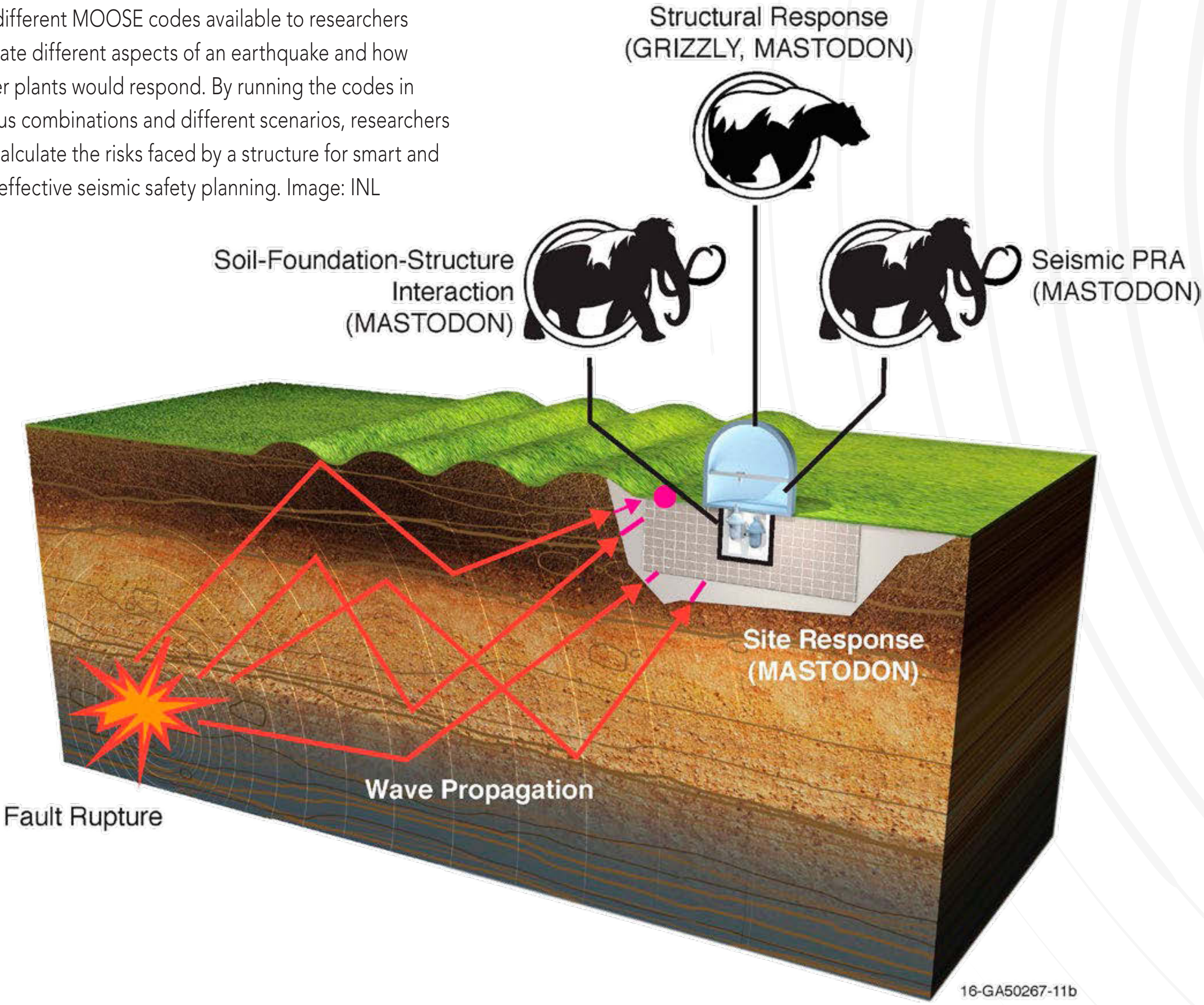
Seismic analysis and risk assessment

Another way to reduce costs of nuclear power facilities is to better assess the risk of earthquakes at a given site and then build the facility accordingly.

Engineers now rely on probabilistic seismic hazard analysis and seismic probabilistic risk assessment—methods of quantifying the intensity of potential earthquakes and the risk of damage to a facility, respectively—to design and maintain nuclear power facilities so they are built to withstand the largest earthquakes expected at a given location. But the existing methodology means that engineers are often overdesigning structures for earthquakes. For instance, nuclear power facilities in France are designed to withstand an earthquake twice as strong as the 1,000-year event calculated for each site, according to the WNA. That may be an appropriate level of seismic safety in some locations, but at other sites, it may be overkill.

Earthquake loads are incredibly challenging to predict and involve a certain amount of uncertainty. “We currently overdesign because we tend to be very conservative and use large safety factors when calculating the seismic load,” said Bolisetti. “We are trying to be more accurate in our predictions of seismic loads, so engineers don’t have to use such large safety factors.”

At INL, Bolisetti and his colleagues are using powerful modeling and simulation tools to better understand the risk from earthquakes at different types of safety-critical facilities such as nuclear power plants and dams. Bolisetti’s team is using the Multiphysics Object-Oriented Simulation Environment (MOOSE), a framework developed at INL that allows researchers to build their own simulation



The different MOOSE codes available to researchers simulate different aspects of an earthquake and how power plants would respond. By running the codes in various combinations and different scenarios, researchers can calculate the risks faced by a structure for smart and cost-effective seismic safety planning. Image: INL applications by plugging in the right physics equations.

Though INL's computer scientists originally designed MOOSE to model how nuclear fuel performs in a reactor, the open-source software is flexible enough to simulate many physics problems, including seismic analyses. One MOOSE application—MASTODON (Multi-hazard Analysis for STOchastic time-DOmaiN phenomena)—is specifically designed to simulate, in 3D, the risks that natural and human-caused hazards such as earthquakes and floods pose to structures such as nuclear reactors.

This modeling and simulation technology can be used to answer complex questions: How does the molten salt/fuel mixture found in some advanced reactors behave when the "fluid" shakes during an earthquake? How might that molten salt mixture respond to an earthquake motion that is damped by seismic isolators?

Another question relates to some advanced reactor designs that would embed the reactor underground. "We know that the seismic load will be smaller when something is embedded," Bolisetti said. "But we don't know by how much. We're using the simulation tools to predict seismic loads on deeply embedded structures."

He added, "If you use more accurate tools to show that a facility has a good safety margin, you don't have to spend $100 million to strengthen something that doesn't need to be strengthened."

> **At the end of the day, it's dollars that are going to drive decisions to build.**

Design optimization

Engineers could also reduce costs by optimizing the design of a nuclear facility to concentrate protection on the pieces of equipment that need it the most.

"Previous work focused on isolating the entire reactor building," said Whittaker. "That's certainly viable, but some reactor developers are looking to isolate specific pieces of equipment for ease of construction, for safety, or to protect an expensive asset."

For instance, the designer of a nuclear power facility may choose to use seismic isolation or some other earthquake mitigation infrastructure for the reactor vessel and the steam generator, since those two pieces of equipment would be expensive to replace and could pose safety hazards.

"How do you design a nuclear power plant in such a way that you are spending the money where you need it?" Bolisetti said. "We want to know how much each component is contributing to the risk so that the money is spent where the risk is the highest."

Not compromising safety

In the end, Bolisetti said, the goal is to make sure that safety is not sacrificed for cost. "We know how to achieve safety," he said. "But, if we want nuclear in the mainstream energy space, we need to make it cheaper."

Whittaker agreed. "We're not going to compromise seismic safety at all, but you also don't need a product that is a hundred times safer than it needs to be. We must meet all safety goals while recognizing that the industry must be commercially viable." Whittaker added that tackling these big-picture questions is where INL's leadership is invaluable.

Most advanced reactor developers understand the need to take a holistic approach to designing and constructing new plants. INL is making important contributions in a number of areas and disciplines for the construction of next-generation reactors, with its work encompassing not just Bolisetti's Facility Risk Group but also the National Reactor Innovation Center and the DOE's Advanced Reactor Demonstration Program.

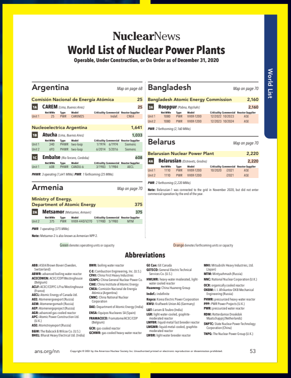
"At the end of the day," Whittaker said, "it's dollars that are going to drive decisions to build, and the industry must develop a pathway to commercial viability, including minimizing the financial risk to potential customers."

Modern seismic preparation techniques—from seismic isolator technology to advances in modeling and design—can play a role.

Cory Hatch (matthew.rodgershatch@inl.gov) is a science writer for Idaho National Laboratory.

23rd Annual

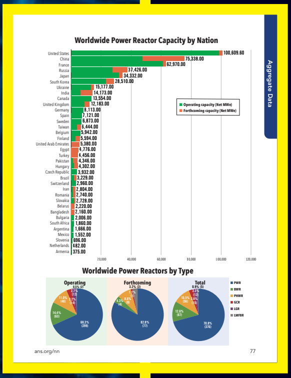
NuclearNews Reference Section



NuclearNews

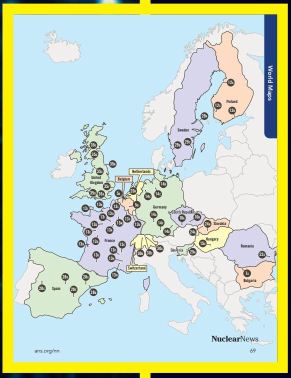
World List of Nuclear Power Plants

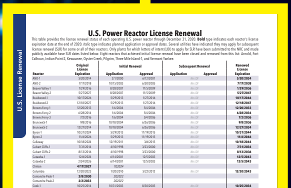
Operable, Under Construction, or On Order as of December 31, 2020



Worldwide Power Reactor Capacity by Nation

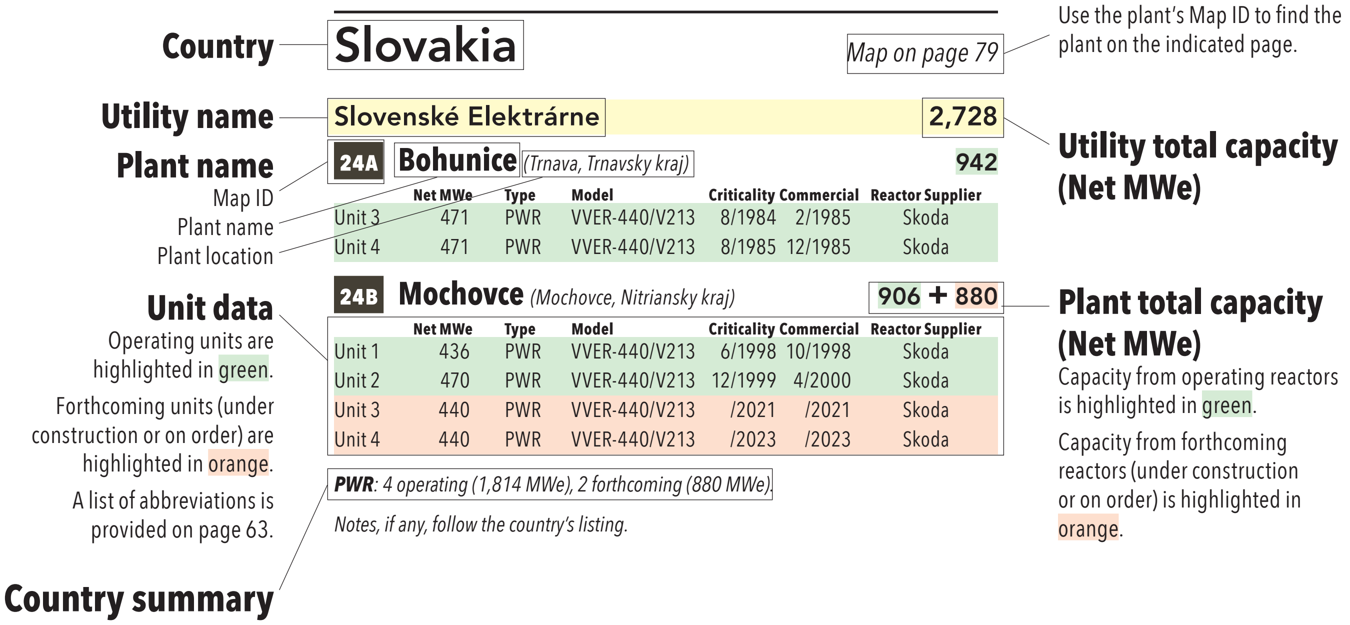
Worldwide Power Reactors by Type





U.S. Power Reactor License Renewal

Your Guide to the World List



Slovakia *Map on page 79*

Slovenské Elektrárne **2,728**

24A **Bohunice** *(Trnava, Trnavsky kraj)* **942**

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	471	PWR	VVER-440/V213	8/1984	2/1985	Skoda
Unit 4	471	PWR	VVER-440/V213	8/1985	12/1985	Skoda

24B **Mochovce** *(Mochovce, Nitriansky kraj)* **906 + 880**

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	436	PWR	VVER-440/V213	6/1998	10/1998	Skoda
Unit 2	470	PWR	VVER-440/V213	12/1999	4/2000	Skoda
Unit 3	440	PWR	VVER-440/V213	/2021	/2021	Skoda
Unit 4	440	PWR	VVER-440/V213	/2023	/2023	Skoda

***PWR**: 4 operating (1,814 MWe), 2 forthcoming (880 MWe).*

Notes, if any, follow the country's listing.

Country

Utility name

Plant name
Map ID
Plant name
Plant location

Unit data
Operating units are highlighted in green.

Forthcoming units (under construction or on order) are highlighted in orange.

A list of abbreviations is provided on page 63.

Country summary

Use the plant's Map ID to find the plant on the indicated page.

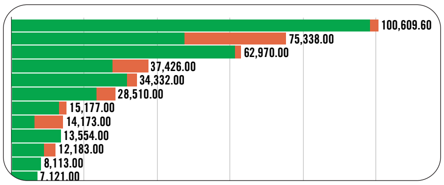
Utility total capacity (Net MWe)

Plant total capacity (Net MWe)
Capacity from operating reactors is highlighted in green.

Capacity from forthcoming reactors (under construction or on order) is highlighted in orange.

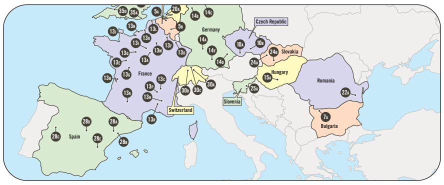
Statistics

Worldwide data summarized
on pages 76–77



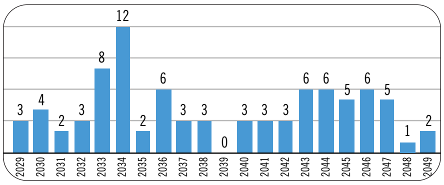
Maps

Plant locations indicated
on pages 78–83



U.S. License Renewal

Status reported
on pages 84–85



Methodology

Nuclear News updates the World List of Nuclear Power Plants and its accompanying tables and maps every year to include new or revised information. When we do not obtain information directly from a plant's owner or operator, we collect information made available by them in other ways (such as from the International Atomic Energy Agency's Power Reactor Information System [pris.iaea.org/pris/], from press releases, or from submittals to government agencies, international organizations, and contractors).

For an operating reactor to be listed, it must be equipped to provide excess net energy for use outside the reactor itself—usually for the production of electricity, but potentially also for purposes such as district heating, process heat, and desalination. Research reactors, test reactors, and facilities with limited roles (such as isotope production) are not included.

For a forthcoming reactor (under construction or on order) to be listed, it must meet the criteria described in the previous paragraph, and there must be a formal commitment to the project by all parties involved. For a few countries where nuclear capacity additions are centrally planned and nuclear programs are well established, a forthcoming reactor may be added based on its having received high-level government approval, even if a contract has not yet been signed. In such a case, however, the project must have a clearly determined site, target date for operation, and preferred choice of reactor model.

Once a reactor is shown as being in commercial operation, it retains that status until the owner or other decision-making authority declares it to be closed.

A separate list of reactors that have been permanently closed begins on page 86. Several reactors started and closed before *NN* began compiling these lists. Our policy is to exclude reactors with a peak power level lower than 10 MWe from both the World List and the list of closed reactors.

NuclearNews

World List of Nuclear Power Plants

Operable, Under Construction, or On Order as of December 31, 2020

Argentina

Map on page 78

Comisión Nacional de Energía Atómica 25

1A CAREM *(Lima, Buenos Aires)* 25

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	25	PWR	CAREM25		Indef.	CNEA

Nucleoelectrica Argentina 1,641

1B Atucha *(Lima, Buenos Aires)* 1,033

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	340	PHWR	two-loop	1/1974	6/1974	Siemens
Unit 2	693	PHWR	two-loop	6/2014	5/2016	Siemens

1C Embalse *(Rio Tercero, Cordoba)* 608

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	608	PHWR	CANDU-6	3/1983	1/1984	AECL

***PHWR**: 3 operating (1,641 MWe). **PWR**: 1 forthcoming (25 MWe).*

Armenia

Map on page 80

Ministry of Energy, Department of Atomic Energy 375

2A Metsamor *(Metsamor, Armavir)* 375

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	375	PWR	VVER-440/V270	1/1980	5/1980	MTM

***PWR**: 1 operating (375 MWe).*

Note: Metsamor-2 is also known as Armenian NPP-2.

Bangladesh

Map on page 80

Bangladesh Atomic Energy Commission 2,160

3A Rooppur *(Pabna, Rajshahi)* 2,160

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1080	PWR	VVER-1200	12/2022	10/2023	ASE
Unit 2	1080	PWR	VVER-1200	12/2023	10/2024	ASE

***PWR**: 2 forthcoming (2,160 MWe).*

Belarus

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Belarusian Nuclear Power Plant 2,220

4A Belarusian *(Ostrovets, Grodno)* 2,220

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1110	PWR	VVER-1200	10/2020	/2021	ASE
Unit 2	1110	PWR	VVER-1200		/2021	ASE

***PWR**: 2 forthcoming (2,220 MWe).*

Note: Belarusian-1 was connected to the grid in November 2020, but did not enter commercial operation by the end of the year.

🟩 Green denotes operating units or capacity

🟧 Orange denotes forthcoming units or capacity

Abbreviations

ABB: ASEA/Brown Boveri (Sweden, Switzerland)
ABWR: advanced boiling water reactor
ACECOWEN: ACEC/COP/Westinghouse (Belgium)
ACLF: ACEC/COP/C-L/Fra/Westinghouse (France)
AECL: Atomic Energy of Canada Ltd.
AEE: Atomenergoexport (Russia)
AEM: Atomenergomash (Russia)
AEP: Atomenergoproject (Russia)
AGR: advanced gas-cooled reactor
APC: Atomic Power Construction Ltd. (U.K.)
ASE: Atomstroyexport (Russia)
B&W: The Babcock & Wilcox Co. (U.S.)
BHEL: Bharat Heavy Electrical Ltd. (India)
BWR: boiling water reactor
C-E: Combustion Engineering, Inc. (U.S.)
CFHI: China First Heavy Industries
CGNPC: China General Nuclear Power Co.
CIAE: China Institute of Atomic Energy
CNEA: Comisión Nacional de Energía Atómica (Argentina)
CNNC: China National Nuclear Corporation
DAE: Department of Atomic Energy (India)
ENSA: Equipos Nucleares SA (Spain)
FRAMACECO: Framatome/ACEC/COP (Belgium)
GCR: gas-cooled reactor
GCHWR: gas-cooled heavy-water reactor
GE Can: GE Canada
GETSCO: General Electric Technical Services Co. (U.S.)
HWLWR: heavy-water moderated, light-water cooled reactor
Huaneng: China Huaneng Group
Indef.: indefinite
Kepco: Korea Electric Power Corporation
KWU: Kraftwerk Union AG (Germany)
L&T: Larsen & Toubro (India)
LGR: light-water-cooled, graphite-moderated reactor
LMFBR: liquid-metal fast breeder reactor
LMGMR: liquid-metal-cooled, graphite-moderated reactor
LWBR: light-water breeder reactor
MHI: Mitsubishi Heavy Industries, Ltd. (Japan)
MTM: Mintyazhmash (Russia)
NNC: National Nuclear Corporation (U.K.)
OCR: organically cooled reactor
OKBM: I. I. Afrikantov OKB Mechanical Engineering (Russia)
PHWR: pressurized heavy-water reactor
PPP: PWR Power Projects (U.K.)
PWR: pressurized water reactor
RDM: Rotterdamse Drookdok Maatschappij (Netherlands)
SNPTC: State Nuclear Power Technology Corporation (China)
TNPG: The Nuclear Power Group (U.K.)

Belgium

Map on page 79

Engie Electrabel 5,942

5A Doel *(Doel, East Flanders)* 2,934

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	445	PWR	two-loop	7/1974	2/1975	ACECOWEN
Unit 2	445	PWR	two-loop	8/1975	12/1975	ACECOWEN
Unit 3	1006	PWR	three-loop	6/1982	10/1982	FRAMACECO
Unit 4	1038	PWR	three-loop	3/1985	7/1985	ACECOWEN

5B Tihange *(Huy, Liege)* 3,008

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	962	PWR	three-loop	2/1975	10/1975	ACLF
Unit 2	1008	PWR	three-loop	10/1982	6/1983	FRAMACECO
Unit 3	1038	PWR	three-loop	6/1985	9/1985	ACECOWEN

***PWR**: 7 operating (5,942 MWe).*

Brazil

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Eletrobras Eletronuclear 3,229

6A Angra *(Itaorna, Rio de Janeiro)* 1,889 + 1,340

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	609	PWR	two-loop	3/1982	1/1985	Westinghouse
Unit 2	1280	PWR	four-loop	7/2000	2/2001	KWU
Unit 3	1340	PWR	four-loop		Indef.	KWU

***PWR**: 2 operating (1,889 MWe), 1 forthcoming (1,340 MWe).*

Bulgaria

Map on page 79

Bulgarian Energy Holding 2,006

7A Kozloduy *(Kozloduy, Vratsa)* 2,006

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 5	1003	PWR	VVER-1000/V320	11/1987	12/1988	AEE
Unit 6	1003	PWR	VVER-1000/V320	5/1991	12/1993	AEE

***PWR**: 2 operating (2,006 MWe).*

Canada

Map on page 78

Bruce Power 6,288

8A Bruce *(Kincardine, Ont.)* 6,288

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	760	PHWR	CANDU	12/1976	9/1977	AECL
Unit 2	760	PHWR	CANDU	7/1976	9/1977	AECL
Unit 3	750	PHWR	CANDU	11/1977	2/1978	AECL
Unit 4	750	PHWR	CANDU	12/1978	1/1979	AECL
Unit 5	817	PHWR	CANDU	11/1984	3/1985	AECL
Unit 6	817	PHWR	CANDU	5/1984	9/1984	AECL
Unit 7	817	PHWR	CANDU	1/1986	4/1986	AECL
Unit 8	817	PHWR	CANDU	2/1987	5/1987	AECL

NB Power 660

8B Point Lepreau *(Bay of Fundy, N.B.)* 660

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	660	PHWR	CANDU-6	7/1982	2/1983	AECL

Ontario Power Generation 6,606

8C Darlington *(Clarington, Ont.)* 3,512

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	878	PHWR	CANDU	10/1990	11/1992	AECL
Unit 2	878	PHWR	CANDU	11/1989	10/1990	AECL
Unit 3	878	PHWR	CANDU	11/1992	2/1993	AECL
Unit 4	878	PHWR	CANDU	3/1993	6/1993	AECL

8D Pickering *(Pickering, Ont.)* 3,094

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	515	PHWR	CANDU	2/1971	7/1971	AECL
Unit 4	515	PHWR	CANDU	5/1973	6/1973	AECL
Unit 5	516	PHWR	CANDU	10/1982	5/1983	AECL
Unit 6	516	PHWR	CANDU	10/1983	2/1984	AECL
Unit 7	516	PHWR	CANDU	10/1984	1/1985	AECL
Unit 8	516	PHWR	CANDU	12/1985	2/1986	AECL

***PHWR**: 19 operating (13,554 MWe).*

Note: Ontario Power Generation holds a site preparation license for a new nuclear plant at Darlington. While OPG announced in November 2020 that it was resuming planning activities for the construction of a small modular reactor by 2028, no technology has been selected and no formal commitments have been made.

China

Map on page 81

China General Nuclear Power Group 36,026

9A Daya Bay *(Shenzhen, Guangdong)* 1,888

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	944	PWR	CPY/M310	7/1993	2/1994	Framatome
Unit 2	944	PWR	CPY/M310	1/1994	5/1994	Framatome

9B Fangchenggang *(Fangchenggang, Guangxi)* 2,000 + 2,000

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1000	PWR	CPR-1000	10/2015	1/2016	CNNC
Unit 2	1000	PWR	CPR-1000	6/2016	10/2016	CNNC
Unit 3	1000	PWR	HPR1000		/2022	Hualong
Unit 4	1000	PWR	HPR1000		Indef.	Hualong

9C Hongyanhe *(Dalian, Liaoning)* 4,244 + 2,122

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1061	PWR	CPR-1000	1/2013	6/2013	CNNC
Unit 2	1061	PWR	CPR-1000	10/2013	5/2014	CNNC
Unit 3	1061	PWR	CPR-1000	10/2014	8/2015	CNNC
Unit 4	1061	PWR	CPR-1000	3/2016	6/2016	CNNC
Unit 5	1061	PWR	ACPR-1000		/2021	CNNC
Unit 6	1061	PWR	ACPR-1000		/2022	CNNC

9D Ling Ao *(Ling Ao, Guangdong)* 3,914

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	950	PWR	CPY/M310	2/2002	5/2002	Framatome
Unit 2	950	PWR	CPY/M310	8/2002	1/2003	Framatome
Unit 3	1007	PWR	CPR-1000	6/2010	9/2010	CNNC
Unit 4	1007	PWR	CPR-1000	2/2011	8/2011	CNNC

9E Ningde *(Fuding, Fujian)* 4,072 + 2,000

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1018	PWR	CPR-1000	11/2012	4/2013	CNNC
Unit 2	1018	PWR	CPR-1000	12/2013	5/2014	CNNC
Unit 3	1018	PWR	CPR-1000	3/2015	6/2015	CNNC
Unit 4	1018	PWR	CPR-1000	3/2016	7/2016	CNNC
Unit 5	1000	PWR	HPR1000		Indef.	CFHI
Unit 6	1000	PWR	HPR1000		Indef.	CFHI

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

9F **Sanao** *(Cangnan, Zhejiang)* 2,234

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1117	PWR	HPR1000		Indef.	CFHI
Unit 2	1117	PWR	HPR1000		Indef.	CFHI

9G **Taipingling** *(Huizhou, Guangdong)* 2,232

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1116	PWR	HPR1000		Indef.	CFHI
Unit 2	1116	PWR	HPR1000		Indef.	CFHI

9H **Taishan** *(Taishan, Guangdong)* 3,320

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1660	PWR	EPR	6/2018	12/2018	Framatome
Unit 2	1660	PWR	EPR	5/2019	9/2019	Framatome

9I **Yangjiang** *(Dongping, Guangdong)* 6,000

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1000	PWR	CPR-1000	12/2013	3/2014	CNNC
Unit 2	1000	PWR	CPR-1000	3/2015	6/2015	CNNC
Unit 3	1000	PWR	CPR-1000	10/2015	1/2016	CNNC
Unit 4	1000	PWR	CPR-1000	12/2016	3/2017	CNNC
Unit 5	1000	PWR	ACPR-1000	5/2018	7/2018	CNNC
Unit 6	1000	PWR	ACPR-1000	6/2019	7/2019	CNNC

China Huaneng Group 3,000

9J **Shidaowan** *(Rongcheng, Shandong)* 3,000

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	200	GCR	HTR-PM twins		/2021	Owner/ Tsinghua Univ.
Unit 2	1400	PWR	CAP1400		Indef.	SNPTC
Unit 3	1400	PWR	CAP1400		Indef.	SNPTC

China National Nuclear Corp. 33,972

9K **Changjiang** *(Changjiang, Hainan)* 1,202 + 2,000

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	601	PWR	CNP-600	10/2015	12/2015	CNNC
Unit 2	601	PWR	CNP-600	6/2016	8/2016	CNNC
Unit 3	1000	PWR	HPR1000		/2025	CNNC/Huaneng
Unit 4	1000	PWR	HPR1000		/2026	CNNC/Huaneng

9L **Fangjiashan** *(Haiyan, Zhejiang)* 2,024

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1012	PWR	CPR-1000	10/2014	12/2014	CNNC
Unit 2	1012	PWR	CPR-1000	12/2014	2/2015	CNNC

9M **Fuqing** *(Fuqing, Fujian)* 5,000 + 1,000

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1000	PWR	CNP-1000	7/2014	11/2014	CNNC
Unit 2	1000	PWR	CNP-1000	7/2015	10/2015	CNNC
Unit 3	1000	PWR	CNP-1000	7/2016	10/2016	CNNC
Unit 4	1000	PWR	CNP-1000	7/2017	9/2017	CNNC
Unit 5	1000	PWR	HPR1000	10/2020	11/2020	CNNC
Unit 6	1000	PWR	HPR1000		/2021	CNNC

9N **Qinshan** *(Haiyan, Zhejiang)* 4,110

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit I-1	298	PWR	CNP-300	12/1991	4/1994	CNNC
Unit II-1	610	PWR	CNP-600	11/2001	4/2002	CNNC
Unit II-2	610	PWR	CNP-600	3/2004	6/2004	CNNC
Unit II-3	619	PWR	CNP-600	7/2010	10/2010	CNNC
Unit II-4	619	PWR	CNP-600	11/2011	4/2012	CNNC
Unit III-1	677	PHWR	CANDU-6	9/2002	12/2002	AECL
Unit III-2	677	PHWR	CANDU-6	4/2003	7/2003	AECL

9O **Sanmen** *(Sanmen, Zhejiang)* 2,314

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1157	PWR	AP1000	6/2018	9/2018	Westinghouse
Unit 2	1157	PWR	AP1000	8/2018	11/2018	Westinghouse

9P **Tianwan** *(Lianyungang, Jiangsu)* 5,070 + 3,400

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	990	PWR	AES-91	12/2005	5/2007	ASE
Unit 2	990	PWR	AES-91	5/2007	8/2007	ASE
Unit 3	1045	PWR	AES-91	9/2017	2/2018	ASE
Unit 4	1045	PWR	AES-91	9/2018	12/2018	ASE
Unit 5	1000	PWR	CNP-1000	7/2020	9/2020	CNNC
Unit 6	1000	PWR	CNP-1000		/2021	CNNC
Unit 7	1200	PWR	VVER-1200		Indef.	ASE
Unit 8	1200	PWR	VVER-1200		Indef.	ASE

9Q **Xiapu** *(Xiapu, Fujian)* 1,200

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	600	LMFBR	CFR-600		/2023	CNNC/CIAE
Unit 2	600	LMFBR	CFR-600		Indef.	CNNC/CIAE

9R **Xudabao** *(Xudabao, Liaoning)* 4,400

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1000	PWR	CPR-1000		Indef.	CNNC
Unit 2	1000	PWR	CPR-1000		Indef.	CNNC
Unit 3	1200	PWR	VVER-1200		/2027	ASE
Unit 4	1200	PWR	VVER-1200		/2028	ASE

9S **Zhangzhou** *(Zhangzhou, Fujian)* 2,252

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1126	PWR	HPR1000		Indef.	CNNC
Unit 2	1126	PWR	HPR1000		Indef.	CNNC

China Power Investment Corp. 2,340

9T **Haiyang** *(Haiyang, Shandong)* 2,340

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1170	PWR	AP1000	8/2018	10/2018	Westinghouse
Unit 2	1170	PWR	AP1000	9/2018	1/2019	Westinghouse

***GCR**: 1 forthcoming (200 MWe). **LMFBR**: 2 forthcoming (1,200 MWe). **PHWR**: 2 operating (1,354 MWe). **PWR**: 47 operating (46,144 MWe), 24 forthcoming (26,440 MWe).*

Note: Two reactors entered commercial operation in 2020: Tianwan-5 (September) and Fuqing-5 (November). The following nine forthcoming units have been added: Changjiang-3 and -4, Ningde-5 and -6, Sanao-1 and -2, Taipingling-1 and -2, and Xiapu-2. Shidaowan-2 and -3 are China's first CAP1400 reactors. They have also been referred to as Guohe-1 and Guohe-2, but they are listed here as projects at China Huaneng Group's Shidaowan site.

Czech Republic

Map on page 79

ČEZ 3,932

10A **Dukovany** *(Trebic, Jihomoravsky)* 1,878

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	468	PWR	VVER-440/V213	2/1985	8/1985	Skoda
Unit 2	471	PWR	VVER-440/V213	1/1986	9/1986	Skoda
Unit 3	468	PWR	VVER-440/V213	10/1986	5/1987	Skoda
Unit 4	471	PWR	VVER-440/V213	6/1987	12/1987	Skoda

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

10B Temelin *(Temelin, Jihocesky)* 2,054

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1027	PWR	VVER-1000/V320	10/2000	10/2004	Skoda
Unit 2	1027	PWR	VVER-1000/V320	3/2002	10/2004	Skoda

***PWR**: 6 operating (3,932 MWe).*

Note: ČEZ applied in March 2020 for a license to build two new PWRs of up to 1,200 MWe each at the Dukovany site, but no formal commitments have been made.

Egypt

Map on page 80

Nuclear Power Plants Authority 4,776

11A El Dabaa *(El Dabaa, Matrouh)* 4,776

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1194	PWR	VVER-1200		/2026	ASE
Unit 2	1194	PWR	VVER-1200		Indef.	ASE
Unit 3	1194	PWR	VVER-1200		Indef.	ASE
Unit 4	1194	PWR	VVER-1200		Indef.	ASE

***PWR**: 4 forthcoming (4,776 MWe).*

Finland

Map on page 79

Fennovoima 1,200

12A Hanhikivi *(Pyhäjoki, Oulun)* 1,200

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1200	PWR	VVER-1200		/2028	ASE

Fortum 1,014

12B Loviisa *(Loviisa, Etela-Suomen)* 1,014

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	507	PWR	VVER-440/V213	1/1977	5/1977	AEE
Unit 2	507	PWR	VVER-440/V213	10/1980	1/1981	AEE

Teollisuuden Voima Oyj 3,380

12C Olkiluoto *(Eurajoki, Lansi-Suomen)* 1,780 + 1,600

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	890	BWR	BWR 75	7/1978	10/1979	ASEA-Atom
Unit 2	890	BWR	BWR 75	10/1979	7/1982	ASEA-Atom
Unit 3	1600	PWR	EPR		3/2022	Framatome

***BWR**: 2 operating (1,780 MWe). **PWR**: 2 operating (1,014 MWe), 2 forthcoming (2,800 MWe).*

France

Map on page 79

Électricité de France 62,970

13A Belleville *(Belleville-sur-Loire, Cher)* 2,620

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1310	PWR	P4	9/1987	6/1988	Framatome
Unit 2	1310	PWR	P4	5/1988	1/1989	Framatome

13B Blayais *(Blaye, Gironde)* 3,640

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	910	PWR	CP1	5/1981	12/1981	Framatome
Unit 2	910	PWR	CP1	6/1982	2/1983	Framatome
Unit 3	910	PWR	CP1	7/1983	11/1983	Framatome
Unit 4	910	PWR	CP1	5/1983	10/1983	Framatome

13C Bugey *(Loyettes, Ain)* 3,580

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	910	PWR	CP0	4/1978	3/1979	Framatome
Unit 3	910	PWR	CP0	8/1978	3/1979	Framatome
Unit 4	880	PWR	CP0	2/1979	7/1979	Framatome
Unit 5	880	PWR	CP0	7/1979	1/1980	Framatome

13D Cattenom *(Cattenom, Moselle)* 5,200

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1300	PWR	P4	10/1986	4/1987	Framatome
Unit 2	1300	PWR	P4	8/1987	2/1988	Framatome
Unit 3	1300	PWR	P4	2/1990	2/1991	Framatome
Unit 4	1300	PWR	P4	5/1991	1/1992	Framatome

13E Chinon *(Chinon, Indre-et-Loire)* 3,620

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit B1	905	PWR	CP2	10/1982	2/1984	Framatome
Unit B2	905	PWR	CP2	9/1983	8/1984	Framatome
Unit B3	905	PWR	CP2	9/1986	3/1987	Framatome
Unit B4	905	PWR	CP2	10/1987	4/1988	Framatome

13F Chooz *(Chooz, Ardennes)* 3,000

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit B1	1500	PWR	N4	4/1996	5/2000	Framatome
Unit B2	1500	PWR	N4	12/1996	9/2000	Framatome

13G Civaux *(Civaux, Vienne)* 2,990

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1495	PWR	N4	9/1997	1/2002	Framatome
Unit 2	1495	PWR	N4	9/1999	4/2002	Framatome

13H Cruas *(Cruas, Ardeche)* 3,660

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	915	PWR	CP2	4/1983	4/1984	Framatome
Unit 2	915	PWR	CP2	8/1984	4/1985	Framatome
Unit 3	915	PWR	CP2	4/1984	9/1984	Framatome
Unit 4	915	PWR	CP2	10/1984	2/1985	Framatome

13I Dampierre *(Ouzouer, Loiret)* 3,560

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	890	PWR	CP1	3/1980	9/1980	Framatome
Unit 2	890	PWR	CP1	12/1980	2/1981	Framatome
Unit 3	890	PWR	CP1	1/1981	5/1981	Framatome
Unit 4	890	PWR	CP1	8/1981	11/1981	Framatome

13J Flamanville *(Flamanville, Manche)* 2,660 + 1,600

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1330	PWR	P4	9/1985	12/1986	Framatome
Unit 2	1330	PWR	P4	6/1986	3/1987	Framatome
Unit 3	1600	PWR	EPR		Indef.	Framatome

13K Golfech *(Valence, Tarn et Garonne)* 2,620

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1310	PWR	P4	4/1990	2/1991	Framatome
Unit 2	1310	PWR	P4	5/1993	3/1994	Framatome

13L Gravelines *(Gravelines, Nord)* 5,460

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit B1	910	PWR	CP1	2/1980	11/1980	Framatome
Unit B2	910	PWR	CP1	8/1980	12/1980	Framatome
Unit B3	910	PWR	CP1	11/1980	6/1981	Framatome
Unit B4	910	PWR	CP1	5/1981	10/1981	Framatome
Unit B5	910	PWR	CP1	8/1984	1/1985	Framatome
Unit B6	910	PWR	CP1	7/1985	10/1985	Framatome

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

13M Nogent-sur-Seine *(Nogent-sur-Seine, Aube)* 2,620

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1310	PWR	P4	9/1987	2/1988	Framatome
Unit 2	1310	PWR	P4	10/1988	5/1989	Framatome

13N Paluel *(Veulettes, Seine-Maritime)* 5,320

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1330	PWR	P4	5/1984	2/1985	Framatome
Unit 2	1330	PWR	P4	8/1984	12/1985	Framatome
Unit 3	1330	PWR	P4	8/1985	2/1986	Framatome
Unit 4	1330	PWR	P4	3/1986	6/1986	Framatome

13O Penly *(Saint-Martin-en-Campagne, Seine-Maritime)* 2,660

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1330	PWR	P4	4/1990	12/1990	Framatome
Unit 2	1330	PWR	P4	1/1992	11/1992	Framatome

13P Saint-Alban *(Auberives, Isere)* 2,670

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1335	PWR	P4	8/1985	5/1986	Framatome
Unit 2	1335	PWR	P4	6/1986	3/1987	Framatome

13Q Saint-Laurent *(Saint-Laurent-des-Eaux, Loir-et-Cher)* 1,830

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit B1	915	PWR	CP2	1/1981	8/1983	Framatome
Unit B2	915	PWR	CP2	5/1981	8/1983	Framatome

13R Tricastin *(Pierrelatte, Drome)* 3,660

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	915	PWR	CP1	2/1980	12/1980	Framatome
Unit 2	915	PWR	CP1	7/1980	12/1980	Framatome
Unit 3	915	PWR	CP1	11/1980	5/1981	Framatome
Unit 4	915	PWR	CP1	5/1981	11/1981	Framatome

PWR: *56 operating (61,370 MWe), 1 forthcoming (1,600 MWe).*

Note: Fessenheim-1 and -2 were permanently shut down in February 2020 and June 2020, respectively. In March 2020 the French government extended the deadline for first fuel loading at Flamanville-3 to April 2024.

Germany

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EnBW Kernkraft GmbH 1,310

14A Neckarwestheim *(Neckarwestheim, Baden-Württemberg)* 1,310

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	1310	PWR	Konvoi	12/1988	4/1989	KWU

Preussen Elektra 4,180

14B Brokdorf *(Brokdorf, Schleswig-Holstein)* 1,410

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1410	PWR	four-loop	10/1986	12/1986	KWU

14C Grohnde *(Emmerthal, Niedersachsen)* 1,360

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1360	PWR	four-loop	9/1984	2/1985	KWU

14D Isar *(Essenbach, Bavaria)* 1,410

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	1410	PWR	Konvoi	1/1988	4/1988	KWU

RWE 2,623

14E Emsland *(Lingen, Niedersachsen)* 1,335

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1335	PWR	Konvoi	4/1988	7/1988	KWU

14F Gundremmingen *(Gundremmingen, Bavaria)* 1,288

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Block C	1288	BWR	BWR-72	10/1984	1/1985	KWU

BWR: *1 operating (1,288 MWe).* ***PWR***: *5 operating (6,825 MWe).*

Hungary

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MVM Group 4,302

15A Paks *(Paks, Tolna)* 1,902 + 2,400

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	479	PWR	VVER-440/V213	12/1982	8/1983	AEE/Skoda
Unit 2	477	PWR	VVER-440/V213	8/1984	11/1984	AEE/Skoda
Unit 3	473	PWR	VVER-440/V213	9/1986	12/1986	AEE/Skoda
Unit 4	473	PWR	VVER-440/V213	8/1987	11/1987	AEE/Skoda
Unit 5	1200	PWR	VVER-1200		Indef.	ASE
Unit 6	1200	PWR	VVER-1200		Indef.	ASE

PWR: *4 operating (1,902 MWe), 2 forthcoming (2,400 MWe).*

India

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Bharatiya Nabhikiya Vidyut Nigam 470

16A PFBR *(Kalpakkam, Tamil Nadu)* 470

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	470	LMFBR	custom-built		/2022	Owner/L&T/BHEL

Nuclear Power Corporation of India Ltd. 13,703

16B Gorakhpur *(Gorakhpur, Haryana)* 1,260

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	630	PHWR	PHWR-700		/2025	Owner/others
Unit 2	630	PHWR	PHWR-700		/2026	Owner/others

16C Kaiga *(Kaiga, Karnataka)* 808

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	202	PHWR	four-loop	9/2000	11/2000	Owner/others
Unit 2	202	PHWR	four-loop	9/1999	3/2000	Owner/others
Unit 3	202	PHWR	four-loop	2/2007	5/2007	Owner/others
Unit 4	202	PHWR	four-loop	11/2010	1/2011	Owner/others

16D Kakrapar *(Kakrapar, Gujarat)* 404 + 1,260

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	202	PHWR	four-loop	9/1992	5/1993	Owner/others
Unit 2	202	PHWR	four-loop	1/1995	9/1995	Owner/others
Unit 3	630	PHWR	PHWR-700	7/2020	/2021	Owner/others
Unit 4	630	PHWR	PHWR-700		Indef.	Owner/others

16E Kudankulam *(Kudankulam, Tamil Nadu)* 1,864 + 3,668

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	932	PWR	AES-92	7/2013	12/2014	ASE
Unit 2	932	PWR	AES-92	7/2016	3/2017	ASE
Unit 3	917	PWR	AES-92		3/2023	ASE
Unit 4	917	PWR	AES-92		11/2023	ASE
Unit 5	917	PWR	AES-92		Indef.	ASE
Unit 6	917	PWR	AES-92		Indef.	ASE

16F **Madras** *(Kalpakkam, Tamil Nadu)* 410

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	205	PHWR	eight-loop	7/1983	1/1984	Owner/others
Unit 2	205	PHWR	eight-loop	8/1985	3/1986	Owner/others

16G **Narora** *(Narora, Uttar Pradesh)* 404

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	202	PHWR	four-loop	3/1989	1/1991	Owner/others
Unit 2	202	PHWR	four-loop	10/1991	7/1992	Owner/others

16H **Rajasthan** *(Kota, Rajasthan)* 1,085 + 1,260

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	90	PHWR	CANDU	8/1972	12/1973	AECL/DAE
Unit 2	187	PHWR	CANDU	10/1980	4/1981	AECL/DAE
Unit 3	202	PHWR	four-loop	12/1999	6/2000	Owner/others
Unit 4	202	PHWR	four-loop	11/2000	12/2000	Owner/others
Unit 5	202	PHWR	four-loop	11/2009	2/2010	Owner/others
Unit 6	202	PHWR	four-loop	1/2010	3/2010	Owner/others
Unit 7	630	PHWR	PHWR-700		Indef.	Owner/others
Unit 8	630	PHWR	PHWR-700		Indef.	Owner/others

16I **Tarapur** *(Tarapur, Maharashtra)* 1,280

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	150	BWR	BWR-1/Mark II	2/1969	10/1969	GE
Unit 2	150	BWR	BWR-1/Mark II	2/1969	10/1969	GE
Unit 3	490	PHWR	two-loop	5/2006	8/2006	Owner/others
Unit 4	490	PHWR	two-loop	3/2005	9/2005	Owner/others

__BWR__: 2 operating (300 MWe). __LMFBR__: 1 forthcoming (470 MWe). __PHWR__: 18 operating (4,091 MWe), 6 forthcoming (3,780 MWe). __PWR__: 2 operating (1,864 MWe), 4 forthcoming (3,668 MWe).

Note: Kakrapar-3 achieved initial criticality in July 2020, but did not reach commercial operation by the end of the year. Ten forthcoming units that are under construction or confirmed for construction are listed here. Another 10 units that have received administrative and financial approval but have no firm build commitments are not listed.

Iran

Map on page 80

Nuclear Power Production and Development Company of Iran/Atomic Energy Organization of Iran 2,804

17A **Bushehr** *(Halileh, Bushehr)* 915 + 1,889

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	915	PWR	VVER-1000	5/2011	9/2013	ASE
Unit 2	974	PWR	VVER-1000		/2025	ASE
Unit 3	915	PWR	VVER-1000		/2027	ASE

__PWR__: 1 operating (915 MWe), 2 forthcoming (1,889 MWe).

Japan

Map on page 81

Chubu Electric Power Co. 3,473

18A **Hamaoka** *(Omaezaki, Shizuoka)* 3,473

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	1056	BWR	BWR-5	11/1986	8/1987	Toshiba
Unit 4	1092	BWR	BWR-5	12/1992	9/1993	Toshiba
Unit 5	1325	BWR	ABWR	3/2004	1/2005	Toshiba

Chugoku Electric Power Co. 2,114

18B **Shimane** *(Matsue-shi, Shimane)* 789 + 1,325

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	789	BWR	BWR-5	5/1988	2/1989	Hitachi
Unit 3	1325	BWR	ABWR		Indef.	Hitachi

Hokkaido Electric Power Co. 1,966

18C **Tomari** *(Tomari-mura, Hokkaido)* 1,966

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	550	PWR	two-loop	11/1988	6/1989	MHI
Unit 2	550	PWR	two-loop	7/1990	4/1991	MHI
Unit 3	866	PWR	three-loop	3/2009	12/2009	MHI

Hokuriku Electric Power Co. 1,613

18D **Shika** *(Shika-machi, Ishikawa)* 1,613

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	505	BWR	BWR-5	11/1992	7/1993	Hitachi
Unit 2	1108	BWR	ABWR	5/2005	3/2006	Hitachi

J-Power 1,328

18E **Ohma** *(Ohma, Aomori)* 1,328

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1328	BWR	ABWR		Indef.	Toshiba/Hitachi

Japan Atomic Power Co. 2,168

18F **Tokai** *(Tokai-mura, Ibaraki)* 1,060

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	1060	BWR	BWR-5	1/1978	11/1978	GE

18G **Tsuruga** *(Tsuruga-shi, Fukui)* 1,108

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	1108	PWR	four-loop	5/1986	2/1987	MHI

Kansai Electric Power Co. 6,254

18H **Mihama** *(Mihama-cho, Fukui)* 780

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	780	PWR	three-loop	1/1976	12/1976	MHI

18I **Ohi** *(Ohi-cho, Fukui)* 2,254

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	1127	PWR	four-loop	5/1991	12/1991	MHI
Unit 4	1127	PWR	four-loop	5/1992	2/1993	MHI

18J **Takahama** *(Takahama-cho, Fukui)* 3,220

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	780	PWR	three-loop	3/1974	11/1974	Westinghouse
Unit 2	780	PWR	three-loop	12/1974	11/1975	MHI
Unit 3	830	PWR	three-loop	4/1984	1/1985	MHI
Unit 4	830	PWR	three-loop	10/1984	6/1985	MHI

Kyushu Electric Power Co. 3,946

18K **Genkai** *(Genkai, Saga)* 2,254

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	1127	PWR	four-loop	5/1993	3/1994	MHI
Unit 4	1127	PWR	four-loop	10/1996	7/1997	MHI

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

18L Sendai *(Satsumasendai, Kagoshima)* 1,692

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	846	PWR	three-loop	8/1983	7/1984	MHI
Unit 2	846	PWR	three-loop	3/1985	11/1985	MHI

Shikoku Electric Power Co. 846

18M Ikata *(Ikata-cho, Ehime)* 846

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	846	PWR	three-loop	2/1994	12/1994	MHI

Tohoku Electric Power Co. 2,659

18N Higashidori *(Higashidori, Aomori)* 1,067

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1067	BWR	BWR-5	1/2005	12/2005	Toshiba

18O Onagawa *(Onagawa, Miyagi)* 1,592

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	796	BWR	BWR-5	11/1994	7/1995	Toshiba
Unit 3	796	BWR	BWR-5	4/2001	1/2002	Toshiba

Tokyo Electric Power Co. 7,965

18P Kashiwazaki Kariwa *(Kashiwazaki, Niigata)* 7,965

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1067	BWR	BWR-5	12/1984	9/1985	Toshiba
Unit 2	1067	BWR	BWR-5	11/1989	9/1990	Toshiba
Unit 3	1067	BWR	BWR-5	10/1992	8/1993	Toshiba
Unit 4	1067	BWR	BWR-5	11/1993	8/1994	Hitachi
Unit 5	1067	BWR	BWR-5	7/1989	4/1990	Hitachi
Unit 6	1315	BWR	ABWR	12/1995	11/1996	Toshiba/GE
Unit 7	1315	BWR	ABWR	11/1996	7/1997	Hitachi/GE

***BWR**: 17 operating (17,559 MWe), 2 forthcoming (2,653 MWe). **PWR**: 16 operating (14,120 MWe).*

Note: While 33 operable plants are listed here, according to the Japan Atomic Industrial Forum only nine have produced power since 2011–2012: Genkai-3 and -4, Ikata-3, Ohi-3 and -4, Sendai-1 and -2, and Takahama-3 and -4.

Mexico

Map on page 78

Comision Federal de Electricidad 1,552

19A Laguna Verde *(Laguna Verde, Veracruz)* 1,552

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	777	BWR	BWR-5	11/1988	7/1990	GE
Unit 2	775	BWR	BWR-5	9/1994	4/1995	GE

***BWR**: 2 operating (1,552 MWe).*

Netherlands

Map on page 79

N.V. Elektriciteits-Produktiemaatschappij Zuid–Nederland 482

20A Borssele *(Borssele, Zeeland)* 482

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	482	PWR	two-loop	6/1973	10/1973	KWU/RDM

***PWR**: 1 operating (482 MWe).*

Pakistan

Map on page 80

Pakistan Atomic Energy Commission 4,346

21A Chashma *(Mianwali, Punjab)* 1,228 + 1,000

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	300	PWR	CNP-300	5/2000	9/2000	CNNC
Unit 2	300	PWR	CNP-300	2/2011	5/2011	CNNC
Unit 3	315	PWR	CNP-300	8/2016	12/2016	CNNC
Unit 4	313	PWR	CNP-300	3/2017	9/2017	CNNC
Unit 5	1000	PWR	HPR1000		Indef.	CNNC

21B Karachi *(Karachi, Sind)* 90 + 2,028

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	90	PHWR	CANDU	8/1971	12/1972	GE Can
Unit 2	1014	PWR	HPR1000		Indef.	CNNC
Unit 3	1014	PWR	HPR1000		Indef.	CNNC

***PHWR**: 1 operating (90 MWe). **PWR**: 4 operating (1,228 MWe), 3 forthcoming (3,028 MWe).*

Romania

Map on page 79

Nuclearelectrica 2,740

22A Cernavoda *(Cernavoda, Constanta)* 1,300 + 1,440

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	650	PHWR	CANDU-6	4/1996	12/1996	AECL/Vickers
Unit 2	650	PHWR	CANDU-6	5/2007	10/2007	AECL/Vickers
Unit 3	720	PHWR	CANDU-6		Indef.	CGNPC/Candu
Unit 4	720	PHWR	CANDU-6		Indef.	CGNPC/Candu

***PHWR**: 2 operating (1,300 MWe), 2 forthcoming (1,440 MWe).*

Russia

Map on page 80–81

Rosenergoatom 37,426

23A Akademik Lomonosov *(Pevek, Chukotka)* 64

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	32	PWR	KLT-40S/floating	10/2018	12/2019	OKBM
Unit 2	32	PWR	KLT-40S/floating	10/2018	12/2019	OKBM

23B Balakovo *(Balakovo, Saratov)* 3,800

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	950	PWR	VVER-1000/V320	12/1985	5/1986	MTM
Unit 2	950	PWR	VVER-1000/V320	10/1987	1/1988	MTM
Unit 3	950	PWR	VVER-1000/V320	12/1988	4/1989	MTM
Unit 4	950	PWR	VVER-1000/V320	3/1993	4/1993	MTM

23C Baltic *(Neman, Kaliningrad)* 2,218

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1109	PWR	VVER-1200		Indef.	AEP
Unit 2	1109	PWR	VVER-1200		Indef.	AEP

23D Beloyarsk *(Zarechnyy, Sverdlovsk)* 1,380

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	560	LMFBR	BN-600	2/1980	11/1981	MTM
Unit 4	820	LMFBR	BN-800	6/2014	10/2016	OKBM

23E Bilibino *(Bilibino, Chukotka)* 33

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	11	LGR	EGP-6	12/1974	2/1975	MTM
Unit 3	11	LGR	EGP-6	12/1975	2/1976	MTM
Unit 4	11	LGR	EGP-6	12/1976	1/1977	MTM

23F Kalinin *(Udomlya, Tver)* 3,800

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	950	PWR	VVER-1000/V338	4/1984	6/1985	MTM
Unit 2	950	PWR	VVER-1000/V338	11/1986	3/1987	MTM
Unit 3	950	PWR	VVER-1000/V338	11/2004	11/2005	MTM
Unit 4	950	PWR	VVER-1000/V338	11/2011	9/2012	MTM

23G Kola *(Polyarnyye Zori, Murmansk)* 1,644

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	411	PWR	VVER-440/V230	6/1973	12/1973	MTM
Unit 2	411	PWR	VVER-440/V230	11/1974	2/1975	MTM
Unit 3	411	PWR	VVER-440/V230	2/1981	12/1982	MTM
Unit 4	411	PWR	VVER-440/V230	10/1984	12/1984	MTM

23H Kursk *(Kurchatov, Kursk)* 3,700 + 2,230

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit I-1	925	LGR	RBMK-1000	10/1976	10/1977	MTM
Unit I-2	925	LGR	RBMK-1000	12/1978	8/1979	MTM
Unit I-3	925	LGR	RBMK-1000	8/1983	3/1984	MTM
Unit I-4	925	LGR	RBMK-1000	10/1985	2/1986	MTM
Unit II-1	1115	PWR	VVER-TOI		/2023	AEP
Unit II-2	1115	PWR	VVER-TOI		/2024	AEP

23I Leningrad *(Sosnovyy Bor, St. Petersburg)* 2,951 + 3,236

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit I-3	925	LGR	RBMK-1000	9/1979	6/1980	MTM
Unit I-4	925	LGR	RBMK-1000	12/1980	8/1981	MTM
Unit II-1	1101	PWR	VVER-1200	2/2018	10/2018	AEP
Unit II-2	1066	PWR	VVER-1200	8/2020	/2021	AEP
Unit II-3	1085	PWR	VVER-1200		/2024	AEM
Unit II-4	1085	PWR	VVER-1200		/2030	AEM

23J Novovoronezh *(Novovoronezh, Voronezh)* 3,536

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit I-4	385	PWR	VVER-440/V230	12/1972	3/1973	MTM
Unit I-5	950	PWR	VVER-1000/V320	4/1980	2/1981	MTM
Unit II-1	1100	PWR	VVER-1200	5/2016	2/2017	AEM
Unit II-2	1101	PWR	VVER-1200	3/2019	10/2019	AEM

23K Rostov *(Volgodonsk, Rostov)* 3,829

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	950	PWR	VVER-1000/V320	2/2001	12/2001	MTM
Unit 2	950	PWR	VVER-1000/V320	1/2010	12/2010	MTM
Unit 3	950	PWR	VVER-1000/V320	12/2014	9/2015	AEP
Unit 4	979	PWR	VVER-1000/V320	12/2017	9/2018	AEP

23L Smolensk *(Desnogorsk, Smolensk)* 2,775 + 2,230

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	925	LGR	RBMK-1000	9/1982	9/1983	MTM
Unit 2	925	LGR	RBMK-1000	4/1985	7/1985	MTM
Unit 3	925	LGR	RBMK-1000	12/1989	1/1990	MTM
Unit II-1	1115	PWR	VVER-TOI		/2030	AEM
Unit II-2	1115	PWR	VVER-TOI		Indef.	AEM

LGR*: 12 operating (8,358 MWe).* ***LMFBR****: 2 operating (1,380 MWe).* ***PWR****: 23 operating (17,774 MWe), 9 forthcoming (9,914 MWe).*

Note: Leningrad I-2 was permanently shut down in November 2020. Leningrad II-2 was connected to the grid in October 2020 but did not enter commercial operation by the end of the year. In June 2020 Rosenergoatom announced the planned construction of two VVER-1200 units at Leningrad (II-3 and II-4) and two VVER-TOI units at Smolensk (II-1 and II-2).

Slovakia

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Slovenské Elektrárne 2,728

24A Bohunice *(Trnava, Trnavsky kraj)* 942

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	471	PWR	VVER-440/V213	8/1984	2/1985	Skoda
Unit 4	471	PWR	VVER-440/V213	8/1985	12/1985	Skoda

24B Mochovce *(Mochovce, Nitriansky kraj)* 906 + 880

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	436	PWR	VVER-440/V213	6/1998	10/1998	Skoda
Unit 2	470	PWR	VVER-440/V213	12/1999	4/2000	Skoda
Unit 3	440	PWR	VVER-440/V213	/2021	/2021	Skoda
Unit 4	440	PWR	VVER-440/V213	/2023	/2023	Skoda

PWR*: 4 operating (1,848 MWe), 2 forthcoming (880 MWe).*

Slovenia

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GEN Energija 696

25A Krsko *(Krsko, Vrbina)* 696

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	696	PWR	two-loop	9/1981	1/1983	Westinghouse

PWR*: 1 operating (696 MWe).*

South Africa

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Eskom 1,860

26A Koeberg *(Melkbosstrand, Cape)* 1,860

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	930	PWR	two-loop	3/1984	8/1984	Framatome
Unit 2	930	PWR	two-loop	7/1985	11/1985	Framatome

PWR*: 2 operating (1,860 MWe).*

Note: The National Energy Regulator of South Africa published a consultation paper in November 2020 which included a determination to begin a process to procure 2,500 MW of new nuclear capacity.

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

South Korea

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Korea Hydro & Nuclear Power Co. 28,510

27A **Hanbit** *(Yonggwang-gun, Geonnam)* 5,924

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	995	PWR	three-loop	1/1986	8/1986	Westinghouse
Unit 2	988	PWR	three-loop	10/1986	6/1987	Westinghouse
Unit 3	986	PWR	OPR-1000	10/1994	3/1995	Hanjung/C-E
Unit 4	970	PWR	OPR-1000	7/1995	1/1996	Hanjung/C-E
Unit 5	992	PWR	OPR-1000	11/2001	5/2002	Doosan
Unit 6	993	PWR	OPR-1000	9/2002	12/2002	Doosan

27B **Hanul** *(Ulchin-gun, Gyeongsangbuk-do)* 5,924

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	966	PWR	CP1	2/1988	9/1988	Framatome
Unit 2	967	PWR	CP1	2/1989	9/1989	Framatome
Unit 3	997	PWR	System 80	12/1997	8/1998	Hanjung/C-E
Unit 4	999	PWR	System 80	12/1998	12/1999	Hanjung/C-E
Unit 5	998	PWR	OPR-1000	11/2003	7/2004	Doosan
Unit 6	997	PWR	OPR-1000	12/2004	6/2005	Doosan

27C **Kori** *(Gijang, Busan)* 2,663

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	640	PWR	two-loop	4/1983	7/1983	Westinghouse
Unit 3	1011	PWR	three-loop	1/1985	9/1985	Westinghouse
Unit 4	1012	PWR	three-loop	10/1985	4/1986	Westinghouse

27D **Shin-Hanul** *(Ulchin-gun, Gyeongsangbuk-do)* 2,680

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1340	PWR	APR-1400		7/2021	Doosan
Unit 2	1340	PWR	APR-1400		5/2022	Doosan

27E **Shin-Kori** *(Ulju-gun, Ulsan)* 4,826 + 2,680

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	996	PWR	OPR-1000	6/2010	2/2011	Doosan
Unit 2	996	PWR	OPR-1000	12/2011	7/2012	Doosan
Unit 3	1416	PWR	APR-1400	12/2015	12/2016	Doosan
Unit 4	1418	PWR	APR-1400	4/2019	8/2019	Doosan
Unit 5	1340	PWR	APR-1400		3/2023	Doosan
Unit 6	1340	PWR	APR-1400		6/2024	Doosan

27F **Shin-Wolsong** *(Gyeongjiu-si, Gyeongsangbuk-do)* 1,990

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	997	PWR	OPR-1000	1/2012	7/2012	Doosan
Unit 2	993	PWR	OPR-1000	2/2015	7/2015	Doosan

27G **Wolsong** *(Gyeongjiu-si, Gyeongsangbuk-do)* 1,823

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	596	PHWR	CANDU-6	1/1997	7/1997	AECL/Hanjung
Unit 3	627	PHWR	CANDU-6	2/1998	7/1998	AECL/Hanjung
Unit 4	600	PHWR	CANDU-6	4/1999	10/1999	AECL/Hanjung

PHWR*: 3 operating (1,823 MWe).* ***PWR****: 21 operating (21,327 MWe), 4 forthcoming (5,360 MWe).*

Spain

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Asociación Nuclear Ascó-Vandellós II 3,037

28A **Asco** *(Asco, Tarragona)* 1,992

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	995	PWR	three-loop	6/1983	12/1984	Westinghouse
Unit 2	997	PWR	three-loop	9/1985	3/1986	Westinghouse

28B **Vandellos** *(Vandellos, Tarragona)* 1,045

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	1045	PWR	three-loop	11/1987	3/1988	Westinghouse

Centrales Nucleares Almaraz-Trillo 3,020

28C **Almaraz** *(Almaraz, Caceres)* 2,017

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1011	PWR	three-loop	4/1981	10/1981	Westinghouse
Unit 2	1006	PWR	three-loop	9/1983	2/1984	Westinghouse

28D **Trillo** *(Trillo, Guadalajara)* 1,003

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1003	PWR	three-loop	5/1988	8/1988	KWU/ENSA

Iberdrola 1,064

28E **Cofrentes** *(Cofrentes, Valencia)* 1,064

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1064	BWR	BWR-6	8/1984	3/1985	GE

BWR*: 1 operating (1,064 MWe).* ***PWR****: 6 operating (6,057 MWe).*

Sweden

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Vattenfall 5,473

29A **Forsmark** *(Forsmark, Uppsala)* 3,280

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	990	BWR	BWR 75	4/1980	12/1980	ABB-Atom
Unit 2	1118	BWR	BWR 75	11/1980	7/1981	ABB-Atom
Unit 3	1172	BWR	BWR 75	10/1984	8/1985	ABB-Atom

29B **Ringhals** *(Varberg, Halland)* 2,193

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	1063	PWR	three-loop	7/1980	9/1981	Westinghouse
Unit 4	1130	PWR	three-loop	5/1982	11/1983	Westinghouse

OKG Aktiebolag 1,400

29C **Oskarshamn** *(Oskarshamn, Kalmar)* 1,400

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	1400	BWR	BWR 75	12/1984	8/1985	ABB-Atom

BWR*: 4 operating (4,680 MWe).* ***PWR****: 2 operating (2,193 MWe).*

Note: Ringhals-1 was permanently shut down in December 2020, one year after Ringhals-2 was shut down in December 2019.

Switzerland

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Axpo 730

30A **Beznau** *(Doettingen, Aargau)* 730

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	365	PWR	two-loop	6/1969	12/1969	Westinghouse
Unit 2	365	PWR	two-loop	10/1971	3/1972	Westinghouse

Kernkraftwerk Gösgen-Däniken 1,010

30B **Gösgen** *(Däniken, Solothurn)* 1,010

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1010	PWR	three-loop	1/1979	11/1979	KWU

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

Kernkraftwerk Leibstadt 1,220

30C Leibstadt *(Leibstadt, Aargau)* 1,220

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1220	BWR	BWR-6	3/1984	12/1984	GETSCO

***BWR**: 1 operating (1,220 MWe). **PWR**: 3 operating (1,740 MWe).*

Taiwan

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Taiwan Power Co. 6,444

31A Kuosheng *(Kuosheng, Wang-Li, Taipei)* 1,970

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	985	BWR	BWR-6	2/1981	12/1981	GE
Unit 2	985	BWR	BWR-6	3/1982	3/1983	GE

31B Lungmen *(Kungliao, Taipei)* 2,600

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1300	BWR	ABWR		Indef.	GE
Unit 2	1300	BWR	ABWR		Indef.	GE

31C Maanshan *(Hengchun, Pingtung)* 1,874

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	936	PWR	three-loop	3/1984	7/1984	Westinghouse
Unit 2	938	PWR	three-loop	2/1985	5/1985	Westinghouse

***BWR**: 2 operating (1,970 MWe), 2 forthcoming (2,600 MWe). **PWR**: 2 operating (1,874 MWe).*

Note: Construction at the Lungmen plant was near completion when the units were placed under "asset maintenance management." A national referendum on the commissioning of Lungmen-1 and the continued construction of Lungmen-2 is expected in August 2021.

Turkey

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Akkuyu Nükleer 4,456

32A Akkuyu *(Akkuyu, Adana)* 4,456

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1114	PWR	VVER-1200		/2023	ASE
Unit 2	1114	PWR	VVER-1200		/2024	ASE
Unit 3	1114	PWR	VVER-1200		/2025	ASE
Unit 4	1114	PWR	VVER-1200		/2026	ASE

***PWR**: 4 forthcoming (4,456 MWe).*

Note: Construction began at Akkuyu-2 in April 2020.

Ukraine

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Energoatom 15,177

33A Khmelnitsky *(Neteshin, Khmelnitsky)* 1,900 + 2,070

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	950	PWR	VVER-1000/V320	12/1987	8/1988	MTM
Unit 2	950	PWR	VVER-1000/V320	8/2004	12/2005	MTM
Unit 3	1035	PWR	VVER-1000		Indef.	Skoda
Unit 4	1035	PWR	VVER-1000		Indef.	Skoda

33B Rovno *(Kuznetsovsk, Rovno)* 2,657

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	381	PWR	VVER-440/V213	12/1980	9/1981	MTM
Unit 2	376	PWR	VVER-440/V213	12/1981	7/1982	MTM
Unit 3	950	PWR	VVER-1000/V320	11/1986	5/1987	MTM
Unit 4	950	PWR	VVER-1000/V320	10/2001	4/2006	MTM

Green denotes operating units or capacity

33C South Ukraine *(Konstantinovka, Nikolaev)* 2,850

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	950	PWR	VVER-1000/V302	12/1982	10/1983	MTM
Unit 2	950	PWR	VVER-1000/V338	12/1984	4/1985	MTM
Unit 3	950	PWR	VVER-1000/V320	9/1989	12/1989	MTM

33D Zaporozhye *(Energodar, Zaporozhye)* 5,700

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	950	PWR	VVER-1000/V320	11/1984	4/1985	MTM
Unit 2	950	PWR	VVER-1000/V320	6/1985	10/1985	MTM
Unit 3	950	PWR	VVER-1000/V320	12/1986	1/1987	MTM
Unit 4	950	PWR	VVER-1000/V320	12/1987	1/1988	MTM
Unit 5	950	PWR	VVER-1000/V320	6/1989	10/1989	MTM
Unit 6	950	PWR	VVER-1000/V320	10/1995	9/1996	MTM

***PWR**: 15 operating (13,107 MWe), 2 forthcoming (2,070 MWe).*

United Arab Emirates

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Emirates Nuclear Energy Corp. 5,380

34A Barakah *(Barakah, Abu Dhabi)* 5,380

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1345	PWR	APR-1400	7/2020	/2021	Kepco
Unit 2	1345	PWR	APR-1400		/2021	Kepco
Unit 3	1345	PWR	APR-1400		/2022	Kepco
Unit 4	1345	PWR	APR-1400		/2023	Kepco

***PWR**: 4 forthcoming (5,380 MWe).*

Note: Barakah-1 was connected to the grid in August 2020, but did not enter commercial operation by the end of the year.

United Kingdom

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EDF Energy 12,183

35A Dungeness *(Lydd, Kent)* 1,090

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit B1	545	GCR	AGR	12/1982	4/1985	APC
Unit B2	545	GCR	AGR	12/1985	12/1985	APC

35B Hartlepool *(Hartlepool, Cleveland)* 1,185

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	590	GCR	AGR	6/1983	8/1983	NNC
Unit 2	595	GCR	AGR	9/1984	10/1984	NNC

35C Heysham *(Heysham, Lancashire)* 2,300

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit A1	485	GCR	AGR	4/1983	7/1983	NNC
Unit A2	575	GCR	AGR	6/1984	10/1984	NNC
Unit B1	620	GCR	AGR	6/1988	7/1988	NNC
Unit B2	620	GCR	AGR	11/1988	11/1988	NNC

35D Hinkley Point *(Hinkley Point, Somerset)* 965 + 3,260

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit B1	485	GCR	AGR	9/1976	10/1978	TNPG
Unit B2	480	GCR	AGR	2/1976	9/1976	TNPG
Unit C1	1630	PWR	EPR		6/2026	Framatome
Unit C2	1630	PWR	EPR		/2027	Framatome

35E Hunterston *(Ayrshire, Strathclyde)* 985

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit B1	490	GCR	AGR	1/1976	6/1976	TNPG
Unit B2	495	GCR	AGR	3/1977	3/1977	TNPG

Orange denotes forthcoming units or capacity

35F Sizewell *(Sizewell, Suffolk)* 1,198

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit B	1198	PWR	four-loop	1/1995	5/1995	PPP

35G Torness *(Dunbar, East Lothian)* 1,200

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	595	GCR	AGR	9/1987	5/1988	NNC
Unit 2	605	GCR	AGR	12/1988	2/1989	NNC

***GCR**: 14 operating (7,725 MWe). **PWR**: 1 operating (1,198 MWe), 2 forthcoming (3,260 MWe).*

United States

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Ameren Missouri 1,194

1 Callaway *(Fulton, Mo.)* 1,194

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1194	PWR	SNUPPS	10/1984	4/1985	Westinghouse

American Electric Power Co. 2,288

2 Cook *(Bridgman, Mich.)* 2,288

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1084	PWR	four-loop	1/1975	8/1975	Westinghouse
Unit 2	1204	PWR	four-loop	3/1978	7/1978	Westinghouse

Arizona Public Service Co. 4,003

3 Palo Verde *(Wintersburg, Ariz.)* 4,003

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1333	PWR	System 80	5/1985	1/1986	C-E
Unit 2	1336	PWR	System 80	4/1986	9/1986	C-E
Unit 3	1334	PWR	System 80	10/1987	1/1988	C-E

Dominion Energy 6,770.5

4 Millstone *(Waterford, Conn.)* 2,110.5

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	883.5	PWR	two-loop	10/1975	12/1975	C-E
Unit 3	1227	PWR	four-loop	1/1986	4/1986	Westinghouse

5 North Anna *(Mineral, Va.)* 1,946

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	973	PWR	three-loop	4/1978	6/1978	Westinghouse
Unit 2	973	PWR	three-loop	6/1980	12/1980	Westinghouse

6 Summer *(Jenkinsville, S.C.)* 966

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	966	PWR	three-loop	10/1982	1/1984	Westinghouse

7 Surry *(Surry, Va.)* 1,748

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	874	PWR	three-loop	7/1972	12/1972	Westinghouse
Unit 2	874	PWR	three-loop	3/1973	5/1973	Westinghouse

DTE Energy 1,205

8 Fermi *(Newport, Mich.)* 1,205

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	1205	BWR	BWR-4	6/1985	1/1988	GE

Duke Energy 10,773

9 Brunswick *(Southport, N.C.)* 1,870

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	938	BWR	BWR-4	10/1976	3/1977	GE
Unit 2	932	BWR	BWR-4	3/1975	11/1975	GE

10 Catawba *(York, S.C.)* 2,310

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1160	PWR	four-loop	1/1985	6/1985	Westinghouse
Unit 2	1150	PWR	four-loop	5/1986	8/1986	Westinghouse

11 Harris *(New Hill, N.C.)* 964

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	964	PWR	three-loop	1/1987	5/1987	Westinghouse

12 McGuire *(Huntersville, N.C.)* 2,316

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1158	PWR	four-loop	8/1981	12/1981	Westinghouse
Unit 2	1158	PWR	four-loop	5/1983	3/1984	Westinghouse

13 Oconee *(Seneca, S.C.)* 2,554

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	847	PWR	two-loop	4/1973	7/1973	B&W
Unit 2	848	PWR	two-loop	11/1973	9/1974	B&W
Unit 3	859	PWR	two-loop	9/1974	12/1974	B&W

14 Robinson *(Hartsville, S.C.)* 759

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	759	PWR	three-loop	9/1970	3/1971	Westinghouse

Energy Harbor 4,108

15 Beaver Valley *(Shippingport, Pa.)* 1,923

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	963	PWR	three-loop	5/1976	10/1976	Westinghouse
Unit 2	960	PWR	three-loop	8/1987	11/1987	Westinghouse

16 Davis-Besse *(Oak Harbor, Ohio)* 908

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	908	PWR	two-loop	8/1977	7/1978	B&W

17 Perry *(Perry, Ohio)* 1,277

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1277	BWR	BWR-6	6/1986	11/1987	GE

Energy Northwest 1,207

18 Columbia *(Richland, Wash.)* 1,207

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1207	BWR	BWR-5	1/1984	12/1984	GE

Entergy 7,234

19 Arkansas Nuclear One *(Russellville, Ark.)* 1,823

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	836	PWR	two-loop	8/1974	12/1974	B&W
Unit 2	987	PWR	two-loop	12/1978	3/1980	C-E

20 Grand Gulf *(Port Gibson, Miss.)* 1,433

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1433	BWR	BWR-6	8/1982	7/1985	GE

21 Indian Point *(Buchanan, N.Y.)* 1,041

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	1041	PWR	four-loop	4/1976	8/1976	Westinghouse

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

22 Palisades *(Covert, Mich.)* 811

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	811	PWR	two-loop	5/1971	12/1971	C-E

23 River Bend *(St. Francisville, La.)* 974

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	974	BWR	BWR-6	10/1985	6/1986	GE

24 Waterford *(Killona, La.)* 1,152

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	1152	PWR	two-loop	3/1985	9/1985	C-E

Exelon 21,924

25 Braidwood *(Braceville, Ill.)* 2,386

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1212	PWR	four-loop	5/1987	7/1988	Westinghouse
Unit 2	1174	PWR	four-loop	3/1988	10/1988	Westinghouse

26 Byron *(Byron, Ill.)* 2,347

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1189	PWR	four-loop	2/1985	9/1985	Westinghouse
Unit 2	1158	PWR	four-loop	1/1987	8/1987	Westinghouse

27 Calvert Cliffs *(Lusby, Md.)* 1,788

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	907	PWR	two-loop	10/1974	5/1975	C-E
Unit 2	881	PWR	two-loop	11/1976	4/1977	C-E

28 Clinton *(Clinton, Ill.)* 1,080

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1080	BWR	BWR-6	4/1987	11/1987	GE

29 Dresden *(Morris, Ill.)* 1,845

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	925	BWR	BWR-3	1/1970	6/1970	GE
Unit 3	920	BWR	BWR-3	1/1971	11/1971	GE

30 FitzPatrick *(Scriba, N.Y.)* 842

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	842	BWR	BWR-4	11/1974	7/1975	GE

31 Ginna *(Ontario, N.Y.)* 576

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	576	PWR	two-loop	11/1969	7/1970	Westinghouse

32 LaSalle *(Marseilles, Ill.)* 2,320

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1161	BWR	BWR-5	6/1982	1/1984	GE
Unit 2	1159	BWR	BWR-5	3/1984	10/1984	GE

33 Limerick *(Pottstown, Pa.)* 2,317

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1158	BWR	BWR-4	12/1984	2/1986	GE
Unit 2	1159	BWR	BWR-4	8/1989	1/1990	GE

34 Nine Mile Point *(Scriba, N.Y.)* 1,907

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	620	BWR	BWR-2	9/1969	12/1969	GE
Unit 2	1287	BWR	BWR-5	5/1987	4/1988	GE

35 Peach Bottom *(Delta, Pa.)* 2,645

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 2	1322	BWR	BWR-4	9/1973	7/1974	GE
Unit 3	1323	BWR	BWR-4	8/1974	12/1974	GE

36 Quad Cities *(Cordova, Ill.)* 1,871

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	934	BWR	BWR-3	10/1971	2/1973	GE
Unit 2	937	BWR	BWR-3	4/1972	3/1973	GE

Luminant 2,425

37 Comanche Peak *(Glen Rose, Tex.)* 2,425

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1218	PWR	four-loop	4/1990	8/1990	Westinghouse
Unit 2	1207	PWR	four-loop	3/1993	8/1993	Westinghouse

Nebraska Public Power District 815

38 Cooper *(Brownville, Neb.)* 815

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	815	BWR	BWR-4	2/1974	7/1974	GE

NextEra Energy 6,298

39 Point Beach *(Two Rivers, Wis.)* 1,230

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	615	PWR	two-loop	11/1970	12/1970	Westinghouse
Unit 2	615	PWR	two-loop	5/1972	10/1972	Westinghouse

40 Seabrook *(Seabrook, N.H.)* 1,248

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1248	PWR	four-loop	6/1989	8/1990	Westinghouse

41 St. Lucie *(Jensen Beach, Fla.)* 2,136

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1062	PWR	two-loop	4/1976	12/1976	C-E
Unit 2	1074	PWR	two-loop	6/1983	8/1983	C-E

42 Turkey Point *(Florida City, Fla.)* 1,684

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 3	844	PWR	three-loop	10/1972	12/1972	Westinghouse
Unit 4	840	PWR	three-loop	6/1973	9/1973	Westinghouse

Pacific Gas and Electric Co. 2,289

43 Diablo Canyon *(Avila Beach, Calif.)* 2,289

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1138	PWR	four-loop	4/1984	5/1985	Westinghouse
Unit 2	1151	PWR	four-loop	8/1985	3/1986	Westinghouse

PSEG Nuclear 3,587

44 Hope Creek/Salem *(Hancocks Bridge, N.J.)* 3,587

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Hope Creek	1237	BWR	BWR-4	6/1986	12/1986	GE
Salem-1	1169	PWR	four-loop	12/1976	6/1977	Westinghouse
Salem-2	1181	PWR	four-loop	8/1980	10/1981	Westinghouse

Southern Nuclear 8,040

45 Farley *(Columbia, Ala.)* 1,709

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	854	PWR	three-loop	8/1977	12/1977	Westinghouse
Unit 2	855	PWR	three-loop	5/1981	7/1981	Westinghouse

46 Hatch *(Baxley, Ga.)* 1,793

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	885	BWR	BWR-4	9/1974	12/1975	GE
Unit 2	908	BWR	BWR-4	7/1978	9/1979	GE

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

47 **Vogtle** *(Waynesboro, Ga.)* 2,338 + 2,200

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1169	PWR	four-loop	3/1987	6/1987	Westinghouse
Unit 2	1169	PWR	four-loop	3/1989	5/1989	Westinghouse
Unit 3	1100	PWR	AP1000		/2021	Westinghouse
Unit 4	1100	PWR	AP1000		/2022	Westinghouse

STP Nuclear Operating Co. 2,501.2

48 **South Texas Project** *(Bay City, Tex.)* 2,501.2

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1250.6	PWR	four-loop	3/1988	8/1988	Westinghouse
Unit 2	1250.6	PWR	four-loop	3/1989	6/1989	Westinghouse

Susquehanna Nuclear 2,508

49 **Susquehanna** *(Berwick, Pa.)* 2,508

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1257	BWR	BWR-4	9/1982	6/1983	GE
Unit 2	1251	BWR	BWR-4	5/1984	2/1985	GE

TVA Nuclear 8,468.9

50 **Browns Ferry** *(Athens, Ala.)* 3,764.1

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1254.7	BWR	BWR-4	8/1973	8/1974	GE
Unit 2	1254.7	BWR	BWR-4	7/1974	3/1975	GE
Unit 3	1254.7	BWR	BWR-4	8/1976	3/1977	GE

51 **Sequoyah** *(Soddy-Daisy, Tenn.)* 2,361.8

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1184.4	PWR	four-loop	7/1980	7/1981	Westinghouse
Unit 2	1177.4	PWR	four-loop	11/1981	6/1982	Westinghouse

52 **Watts Bar** *(Spring City, Tenn.)* 2,343

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1173	PWR	four-loop	2/1996	5/1996	Westinghouse
Unit 2	1170	PWR	four-loop	5/2016	10/2016	Westinghouse

Wolf Creek Nuclear Operating Corp. 1,200

53 **Wolf Creek** *(Burlington, Kans.)* 1,200

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	1200	PWR	SNUPPS	5/1985	9/1985	Westinghouse

Xcel Energy 1,771

54 **Monticello** *(Monticello, Minn.)* 671

	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	671	BWR	BWR-3	12/1970	6/1971	GE

55 **Prairie Island** *(Red Wing, Minn.)* 1,100

s	Net MWe	Type	Model	Criticality	Commercial	Reactor Supplier
Unit 1	550	PWR	two-loop	12/1973	12/1973	Westinghouse
Unit 2	550	PWR	two-loop	12/1974	12/1974	Westinghouse

***BWR**: 31 operating (33,581.1 MWe). **PWR**: 63 operating (64,828.5 MWe), 2 forthcoming (2,200 MWe).*

Note: Entergy's Indian Point-2 was permanently shut down on April 30, 2020. NextEra Energy's Arnold plant, scheduled to shut down in October 2020, had an automatic scram and loss of offsite power on August 10 during a destructive wind storm and did not resume operations after the storm. The closure of Entergy's Indian Point-3 is expected in 2021. Exelon announced in August 2020 that, absent legislative action, it intended to shut down Byron-1 and -2 in September 2021 and Dresden-2 and -3 in November 2021. FirstEnergy Nuclear Operating Co. emerged from bankruptcy proceedings early in 2020 as Energy Harbor. For reactors in the United States, the net MWe generating capacity listed is the design electrical rating.

Green denotes operating units or capacity

Orange denotes forthcoming units or capacity

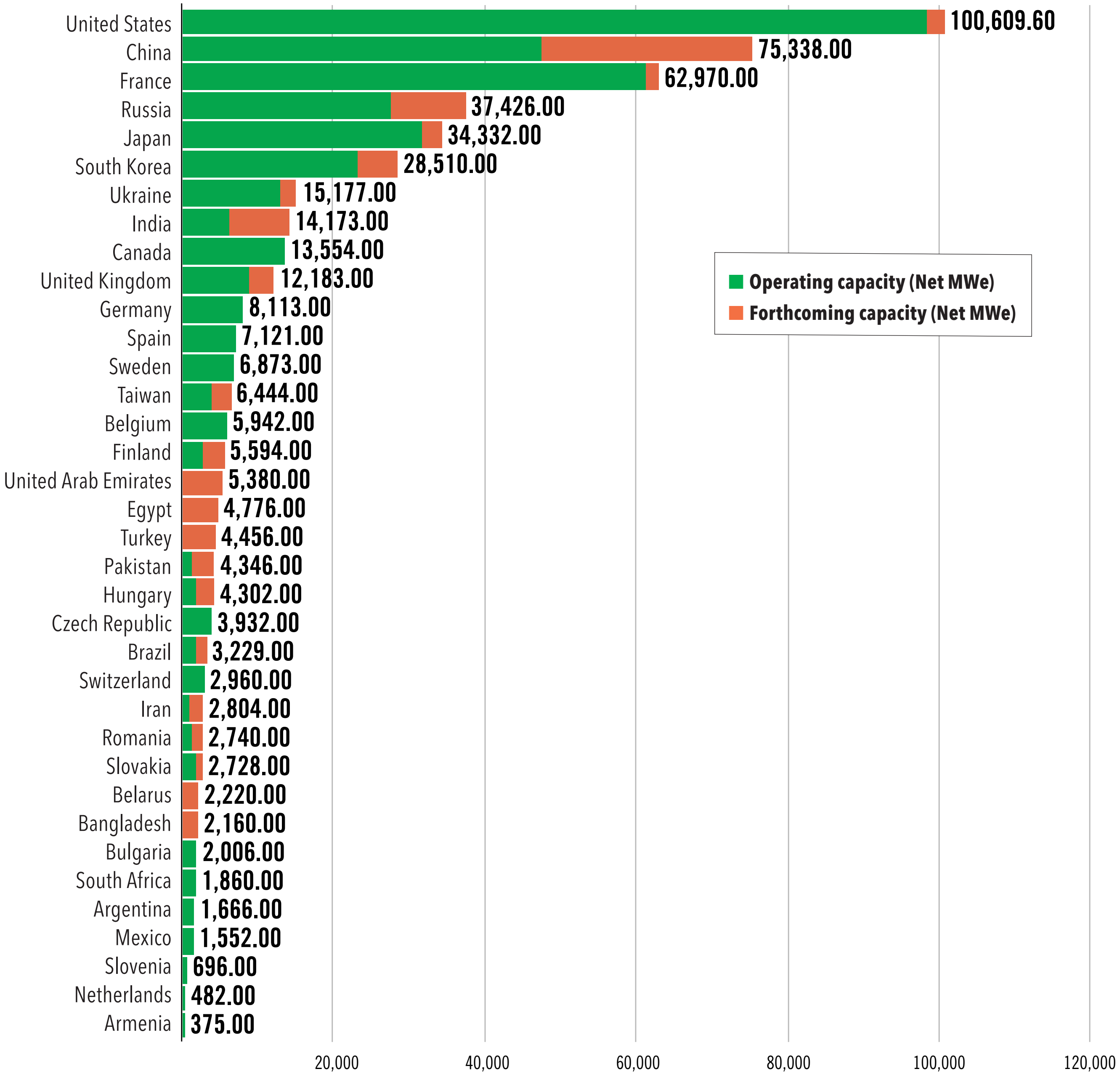
Worldwide Power Reactors and Capacity by Nation

	# Units	Net MWe	# Units	Net MWe	# Units	Net MWe
Nation	**(in operation)**		**(forthcoming)**		**(total)**	
Argentina	3	1,641.00	1	25.00	4	1,666.00
Armenia	1	375.00	0	0.00	1	375.00
Bangladesh	0	0.00	2	2,160.00	2	2,160.00
Belarus	0	0.00	2	2,220.00	2	2,220.00
Belgium	7	5,942.00	0	0.00	7	5,942.00
Brazil	2	1,889.00	1	1,340.00	3	3,229.00
Bulgaria	2	2,006.00	0	0.00	2	2,006.00
Canada	19	13,554.00	0	0.00	19	13,554.00
China	49	47,498.00	27	27,840.00	76	75,338.00
Czech Republic	6	3,932.00	0	0.00	6	3,932.00
Egypt	0	0.00	4	4,776.00	4	4,776.00
Finland	4	2,794.00	2	2,800.00	6	5,594.00
France	56	61,370.00	1	1,600.00	57	62,970.00
Germany	6	8,113.00	0	0.00	6	8,113.00
Hungary	4	1,902.00	2	2,400.00	6	4,302.00
India	22	6,255.00	11	7,918.00	33	14,173.00
Iran	1	915.00	2	1,889.00	3	2,804.00
Japan	33	31,679.00	2	2,653.00	35	34,332.00
Mexico	2	1,552.00	0	0.00	2	1,552.00
Netherlands	1	482.00	0	0.00	1	482.00
Pakistan	5	1,318.00	3	3,028.00	8	4,346.00
Romania	2	1,300.00	2	1,440.00	4	2,740.00
Russia	37	27,512.00	9	9,914.00	46	37,426.00
Slovakia	4	1,848.00	2	880.00	6	2,728.00
Slovenia	1	696.00	0	0.00	1	696.00
South Africa	2	1,860.00	0	0.00	2	1,860.00
South Korea	24	23,150.00	4	5,360.00	28	28,510.00
Spain	7	7,121.00	0	0.00	7	7,121.00
Sweden	6	6,873.00	0	0.00	6	6,873.00
Switzerland	4	2,960.00	0	0.00	4	2,960.00
Taiwan	4	3,844.00	2	2,600.00	6	6,444.00
Turkey	0	0.00	4	4,456.00	4	4,456.00
Ukraine	15	13,107.00	2	2,070.00	17	15,177.00
United Arab Emirates	0	0.00	4	5,380.00	4	5,380.00
United Kingdom	15	8,923.00	2	3,260.00	17	12,183.00
United States	94	98,409.60	2	2,200.00	96	100,609.60
	438	**390,820.60**	**93**	**98,209.00**	**531**	**489,029.60**

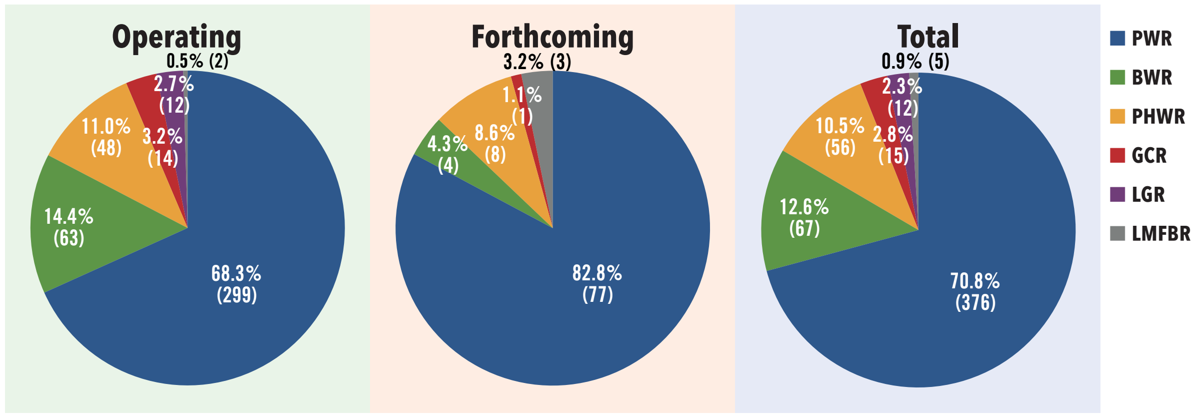
Worldwide Power Reactors and Capacity by Type

	# Units	Net MWe	# Units	Net MWe	# Units	Net MWe
Reactor Type	**(in operation)**		**(forthcoming)**		**(total)**	
Pressurized light-water reactors (PWR)	299	284,510.50	77	85,866.00	376	370,376.50
Boiling light-water reactors (BWR)	63	64,994.10	4	5,253.00	67	70,247.10
Heavy-water reactors, all models (PHWR)	48	23,853.00	8	5,220.00	56	29,073.00
Gas-cooled reactors, all models (GCR)	14	7,725.00	1	200.00	15	7,925.00
Graphite-moderated reactors, all models (LGR)	12	8,358.00	0	0.00	12	8,358.00
Liquid-metal-cooled reactors, all models (LMFBR)	2	1,380.00	3	1,670.00	5	3,050.00
Totals	**438**	**390,820.60**	**93**	**98,209.00**	**531**	**489,029.60**

Worldwide Power Reactor Capacity by Nation



Worldwide Power Reactors by Type



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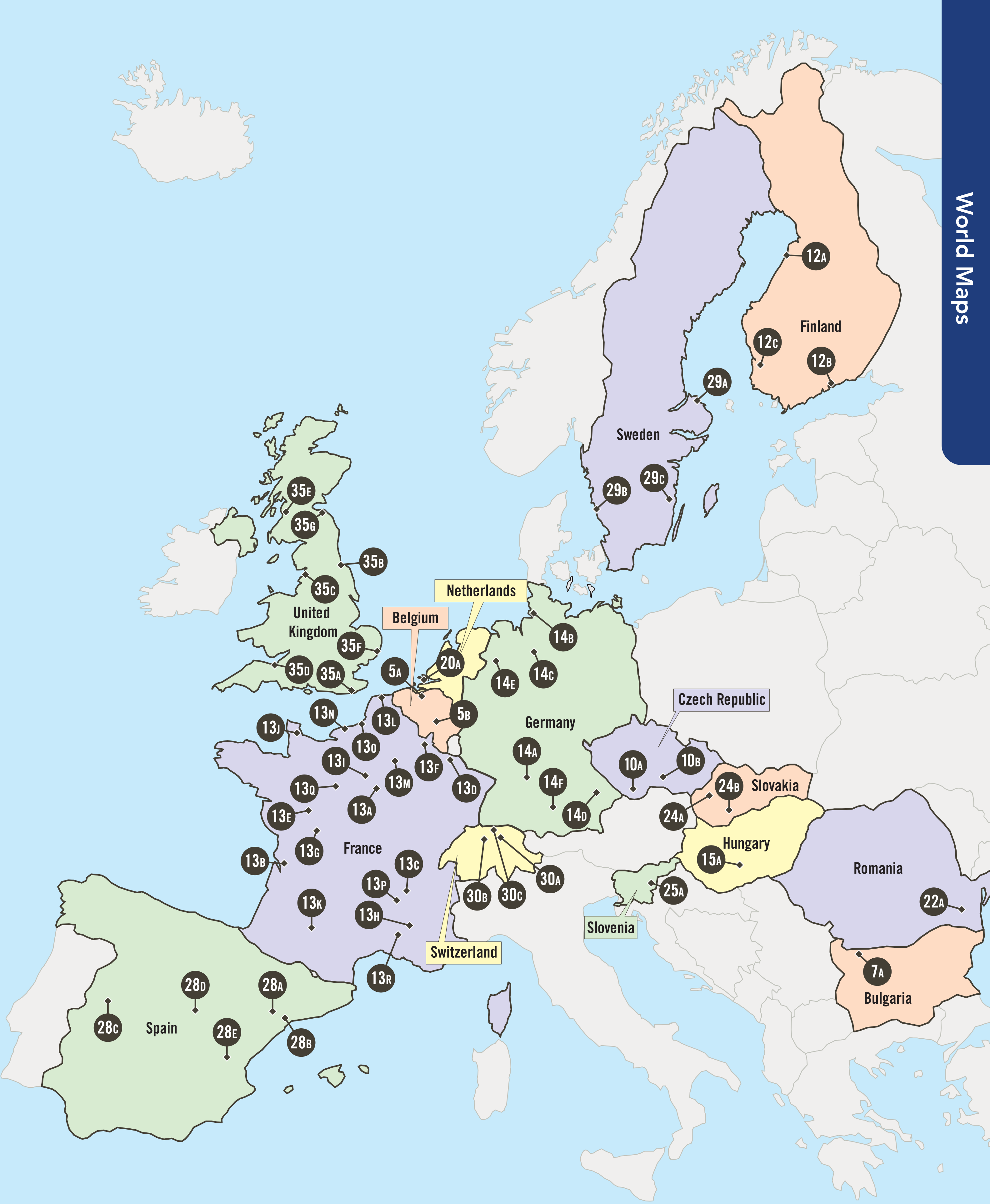
Maps of Commercial Nuclear Power Plants Worldwide

As of December 31, 2020. Plants are identified by numbers that correlate to information in the World List, which begins on page 63.


12A
Finland
12C
12B
29A
Sweden
29B
29C
35E
35G
35B
35C
United Kingdom
35F
35D
35A
Netherlands
Belgium
20A
5A
14B
14E
14C
5B
Germany
Czech Republic
13N
13J
13L
13O
13I
13F
13M
13D
14A
10A
10B
13Q
13A
14F
24B
Slovakia
24A
14D
13E
13G
France
Hungary
15A
Romania
13B
13C
30A
30B
30C
25A
22A
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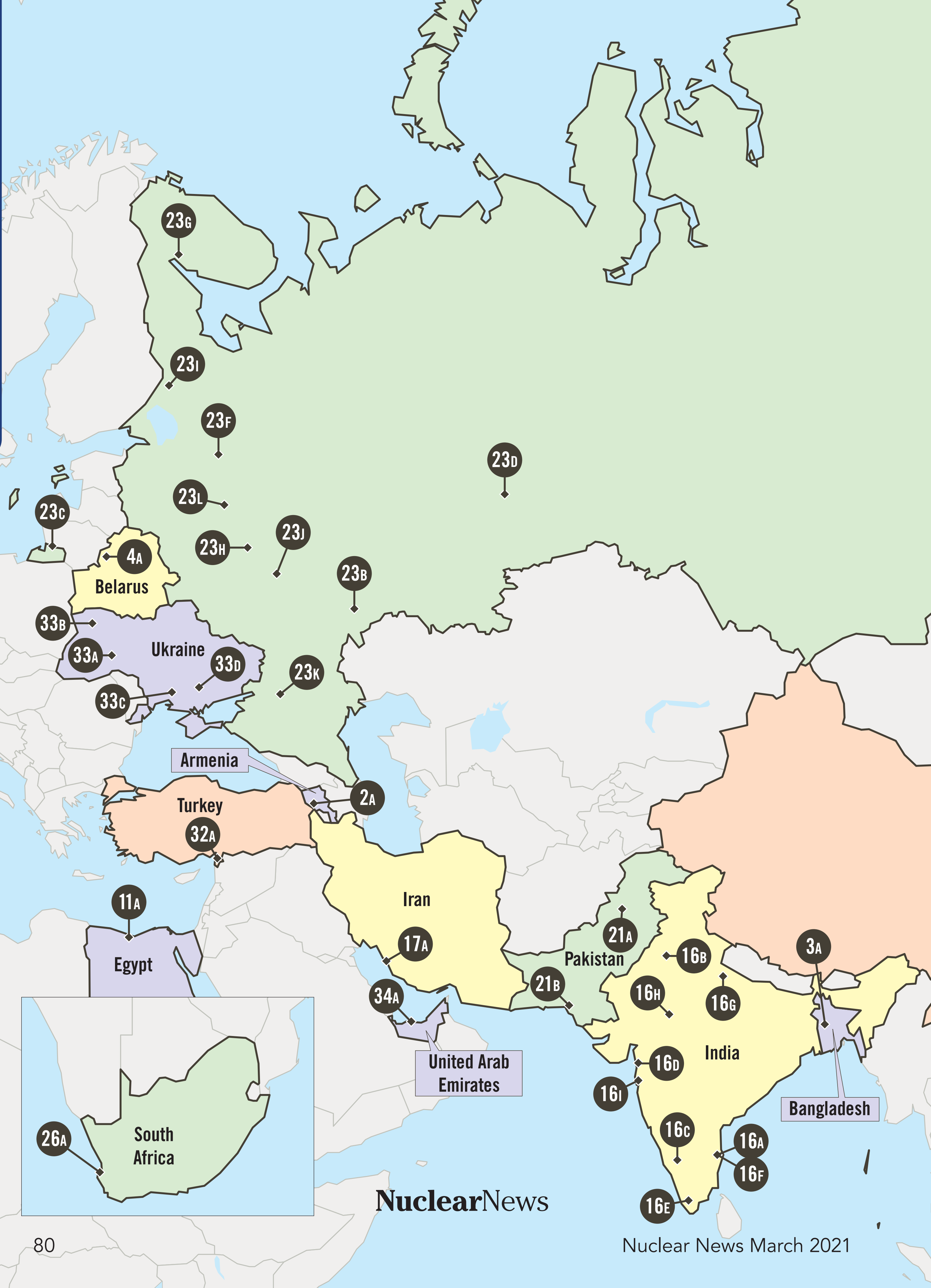
Slovenia
Switzerland
7A
Bulgaria
13R
28D
28A
28C
Spain
28E
28B


23G
23I
23F
23D
23L
23C
23J
23H
4A
Belarus
23B
33B
33A
Ukraine
33D
23K
33C
Armenia
2A
Turkey
32A
11A
Iran
17A
21A
Pakistan
3A
16B
Egypt
21B
16H
16G
34A
India
16D
United Arab Emirates
16I
Bangladesh
16C
16A
16F
16E
26A
South Africa


23A
23E
Russia
China
South Korea
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9R
9C
9J
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9O
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27C
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Taiwan
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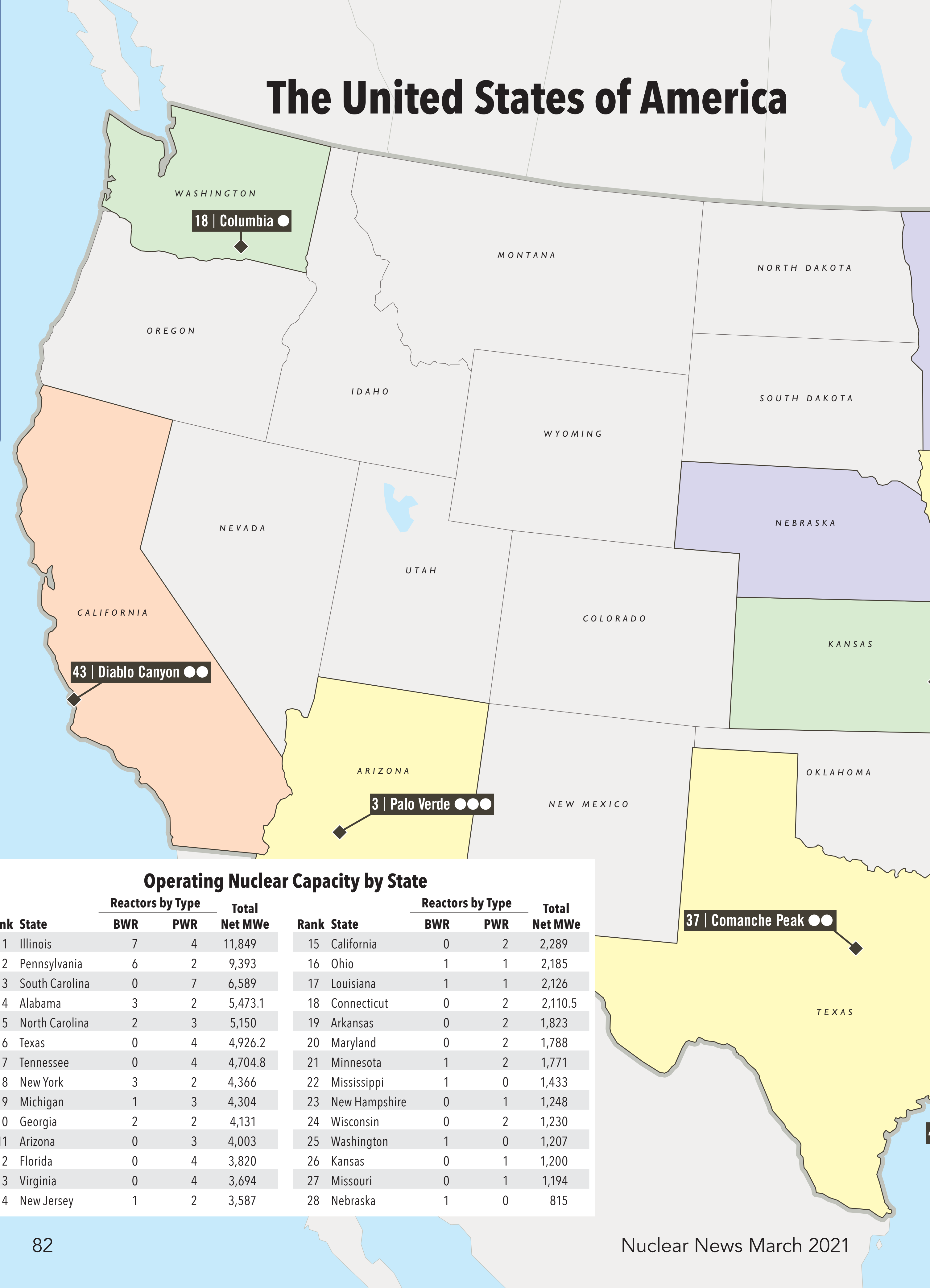
The United States of America



Operating Nuclear Capacity by State

Rank	State	Reactors by Type		Total Net MWe
		BWR	PWR	
1	Illinois	7	4	11,849
2	Pennsylvania	6	2	9,393
3	South Carolina	0	7	6,589
4	Alabama	3	2	5,473.1
5	North Carolina	2	3	5,150
6	Texas	0	4	4,926.2
7	Tennessee	0	4	4,704.8
8	New York	3	2	4,366
9	Michigan	1	3	4,304
10	Georgia	2	2	4,131
11	Arizona	0	3	4,003
12	Florida	0	4	3,820
13	Virginia	0	4	3,694
14	New Jersey	1	2	3,587
15	California	0	2	2,289
16	Ohio	1	1	2,185
17	Louisiana	1	1	2,126
18	Connecticut	0	2	2,110.5
19	Arkansas	0	2	1,823
20	Maryland	0	2	1,788
21	Minnesota	1	2	1,771
22	Mississippi	1	0	1,433
23	New Hampshire	0	1	1,248
24	Wisconsin	0	2	1,230
25	Washington	1	0	1,207
26	Kansas	0	1	1,200
27	Missouri	0	1	1,194
28	Nebraska	1	0	815

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U.S. Power Reactor License Renewal

This table provides the license renewal status of each operating U.S. power reactor through December 31, 2020. **Bold** type indicates each reactor's license expiration date at the end of 2020. *Italic* type indicates planned application or approval dates. Several utilities have indicated they may apply for subsequent license renewal (SLR) for some or all of their reactors. Only plants for which letters of intent (LOI) to apply for SLR have been submitted to the NRC and made publicly available have SLR dates listed below. Eight reactors that achieved initial license renewal have been closed and removed from this list: Arnold, Fort Calhoun, Indian Point-2, Kewaunee, Oyster Creek, Pilgrim, Three Mile Island-1, and Vermont Yankee.

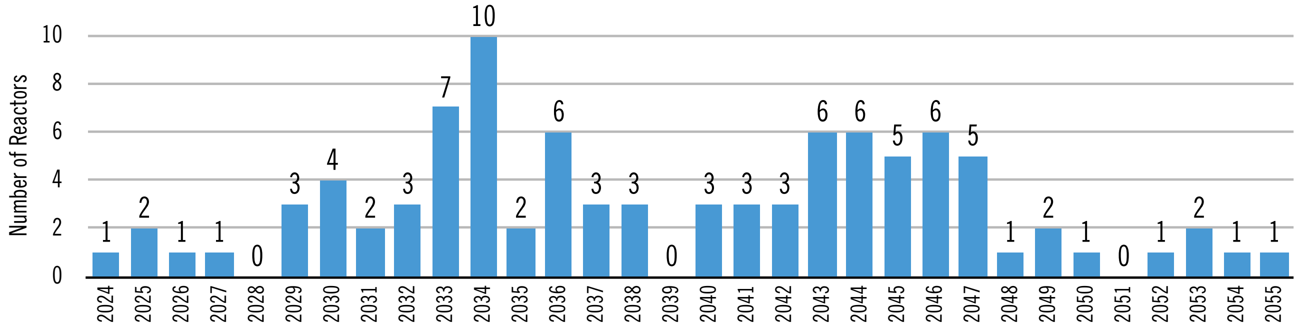
	Original License	Initial Renewal		Subsequent Renewal		Renewed License
Reactor	**Expiration**	**Application**	**Approval**	**Application**	**Approval**	**Expiration**
ANO-1	5/20/2014	2/1/2000	6/12/2001	*No LOI*		**5/20/2034**
ANO-2	7/17/2018	10/15/2003	6/30/2005	*No LOI*		**7/17/2038**
Beaver Valley-1	1/29/2016	8/28/2007	11/5/2009	*No LOI*		**1/29/2036**
Beaver Valley-2	5/27/2027	8/28/2007	11/5/2009	*No LOI*		**5/27/2047**
Braidwood-1	10/17/2026	5/29/2013	1/27/2016	*No LOI*		**10/17/2046**
Braidwood-2	12/18/2027	5/29/2013	1/27/2016	*No LOI*		**12/18/2047**
Browns Ferry-1	12/20/2013	1/6/2004	5/4/2006	*No LOI*		**12/20/2033**
Browns Ferry-2	6/28/2014	1/6/2004	5/4/2006	*No LOI*		**6/28/2034**
Browns Ferry-3	7/2/2016	1/6/2004	5/4/2006	*No LOI*		**7/2/2036**
Brunswick-1	9/8/2016	10/18/2004	6/26/2006	*No LOI*		**9/8/2036**
Brunswick-2	12/27/2014	10/18/2004	6/26/2006	*No LOI*		**12/27/2034**
Byron-1	10/31/2024	5/29/2013	11/19/2015	*No LOI*		**10/31/2044**
Byron-2	11/6/2026	5/29/2013	11/19/2015	*No LOI*		**11/6/2046**
Callaway	10/18/2024	12/19/2011	3/6/2015	*No LOI*		**10/18/2044**
Calvert Cliffs-1	7/31/2014	4/10/1998	3/23/2000	*No LOI*		**7/31/2034**
Calvert Cliffs-2	8/13/2016	4/10/1998	3/23/2000	*No LOI*		**8/13/2036**
Catawba-1	12/6/2024	6/14/2001	12/5/2003	*No LOI*		**12/5/2043**
Catawba-2	2/24/2026	6/14/2001	12/5/2003	*No LOI*		**12/5/2043**
Clinton	**4/17/2027**	*1Q2024*				
Columbia	12/20/2023	1/20/2010	5/22/2012	*No LOI*		**12/20/2043**
Comanche Peak-1	**2/8/2030**	*2Q2022*				
Comanche Peak-2	**2/2/2033**	*2Q2022*				
Cook-1	10/25/2014	10/31/2003	8/30/2005	*No LOI*		**10/25/2034**
Cook-2	12/23/2017	10/31/2003	8/30/2005	*No LOI*		**12/23/2037**
Cooper	1/18/2014	9/30/2008	11/29/2010	*No LOI*		**1/18/2034**
Davis-Besse	4/22/2017	8/30/2010	12/8/2015	*No LOI*		**4/22/2037**
Diablo Canyon-1	**11/2/2024**	*				
Diablo Canyon-2	**8/26/2025**	*				
Dresden-2	12/22/2009	1/3/2003	10/28/2004	*No LOI*		**12/22/2029**
Dresden-3	1/12/2011	1/3/2003	10/28/2004	*No LOI*		**1/12/2031**
Farley-1	6/25/2017	9/15/2003	5/12/2005	*No LOI*		**6/25/2037**
Farley-2	3/31/2021	9/15/2003	5/12/2005	*No LOI*		**3/31/2041**
Fermi-2	3/20/2025	4/30/2014	12/15/2016	*No LOI*		**3/20/2045**
FitzPatrick	10/17/2014	8/1/2006	9/8/2008	*No LOI*		**10/17/2034**
Ginna	9/18/2009	8/1/2002	5/19/2004	*No LOI*		**9/18/2029**
Grand Gulf	11/1/2024	11/1/2011	12/1/2016	*No LOI*		**11/1/2044**
Harris	10/24/2026	11/16/2006	12/17/2008	*No LOI*		**10/24/2046**
Hatch-1	8/6/2014	3/1/2000	1/15/2002	*No LOI*		**8/6/2034**
Hatch-2	6/13/2018	3/1/2000	1/15/2002	*No LOI*		**6/13/2038**
Hope Creek	4/11/2026	8/18/2009	7/20/2011	*No LOI*		**4/11/2046**
Indian Point-3	12/12/2015	4/30/2007	9/17/2018	*No LOI*		**4/30/2025**
LaSalle-1	4/17/2022	12/9/2014	10/19/2016	*No LOI*		**4/17/2042**
LaSalle-2	12/16/2023	12/9/2014	10/19/2016	*No LOI*		**12/16/2043**
Limerick-1	10/26/2024	6/22/2011	10/20/2014	*No LOI*		**10/26/2044**
Limerick-2	6/22/2029	6/22/2011	10/20/2014	*No LOI*		**6/22/2049**
McGuire-1	6/12/2021	6/14/2001	12/5/2003	*No LOI*		**6/12/2041**
McGuire-2	3/3/2023	6/14/2001	12/5/2003	*No LOI*		**3/3/2043**
Millstone-2	7/31/2015	1/22/2004	11/28/2005	*No LOI*		**7/31/2035**
Millstone-3	11/25/2025	1/22/2004	11/28/2005	*No LOI*		**11/25/2045**
Monticello	9/8/2010	3/24/2005	11/8/2006	*No LOI*		**9/8/2030**
Nine Mile Point-1	8/22/2009	5/27/2004	10/31/2006	*No LOI*		**8/22/2029**
Nine Mile Point-2	10/31/2026	5/27/2004	10/31/2006			**10/31/2046**
North Anna-1	4/1/2018	5/29/2001	3/20/2003	8/24/2020	*4/2022*	**4/1/2038**
North Anna-2	8/21/2020	5/29/2001	3/20/2003	8/24/2020	*4/2022*	**8/21/2040**

Reactor	Original License Expiration	Initial Renewal		Subsequent Renewal		Renewed License Expiration
		Application	Approval	Application	Approval	
Oconee-1	2/6/2013	7/7/1998	5/23/2000	*4Q2021*		**2/6/2033**
Oconee-2	10/6/2013	7/7/1998	5/23/2000	*4Q2021*		**10/6/2033**
Oconee-3	7/19/2014	7/7/1998	5/23/2000	*4Q2021*		**7/19/2034**
Palisades	3/24/2011	3/31/2005	1/17/2007	*No LOI*		**3/24/2031**
Palo Verde-1	6/1/2025	12/15/2008	4/21/2011	*No LOI*		**6/1/2045**
Palo Verde-2	4/24/2026	12/15/2008	4/21/2011	*No LOI*		**4/24/2046**
Palo Verde-3	11/25/2027	12/15/2008	4/21/2011	*No LOI*		**11/25/2047**
Peach Bottom-2	8/8/2013	7/2/2001	5/7/2003	7/10/2018	3/5/2020	**8/8/2053**
Peach Bottom-3	7/2/2014	7/2/2001	5/7/2003	7/10/2018	3/5/2020	**7/2/2054**
Perry	**11/7//2026**	*3Q2023*				
Point Beach-1	10/5/2010	2/26/2004	12/22/2005	11/16/2020	*7/2022*	**10/5/2030**
Point Beach-2	3/8/2013	2/26/2004	12/22/2005	11/16/2020	*7/2022*	**3/8/2033**
Prairie Island-1	8/9/2013	4/15/2008	6/27/2011	*No LOI*		**8/9/2033**
Prairie Island-2	10/29/2014	4/15/2008	6/27/2011	*No LOI*		**10/29/2034**
Quad Cities-1	12/14/2012	1/3/2003	10/28/2004	*No LOI*		**12/14/2032**
Quad Cities-2	12/14/2012	1/3/2003	10/28/2004	*No LOI*		**12/14/2032**
River Bend	8/29/2025	5/31/2017	12/20/2018	*No LOI*		**8/29/2045**
Robinson-2	7/31/2010	6/17/2002	4/19/2004	*No LOI*		**7/31/2030**
Salem-1	8/13/2016	8/18/2009	6/30/2011	*No LOI*		**8/13/2036**
Salem-2	4/18/2020	8/18/2009	6/30/2011	*No LOI*		**4/18/2040**
Seabrook	3/15/2030	6/1/2010	3/12/2019	*No LOI*		**3/15/2050**
Sequoyah-1	9/17/2020	1/15/2013	9/24/2015	*No LOI*		**9/17/2040**
Sequoyah-2	9/15/2021	1/15/2013	9/24/2015	*No LOI*		**9/15/2041**
South Texas Project-1	8/20/2027	10/28/2010	9/28/2017	*No LOI*		**8/20/2047**
South Texas Project-2	12/15/2028	10/28/2010	9/28/2017	*No LOI*		**12/15/2048**
St. Lucie-1	3/1/2016	11/30/2001	10/2/2003	*No LOI*		**3/1/2036**
St. Lucie-2	4/6/2023	11/30/2001	10/2/2003	*No LOI*		**4/6/2043**
Summer-1	8/6/2022	8/6/2002	4/23/2004	*No LOI*		**8/6/2042**
Surry-1	5/25/2012	5/29/2001	3/20/2003	10/15/2018	**	**5/25/2032**
Surry-2	1/29/2013	5/29/2001	3/20/2003	10/15/2018	**	**1/29/2033**
Susquehanna-1	7/17/2022	9/13/2006	11/24/2009	*No LOI*		**7/17/2042**
Susquehanna-2	3/23/2024	9/13/2006	11/24/2009	*No LOI*		**3/23/2044**
Turkey Point-3	7/19/2012	9/11/2000	6/6/2002	1/30/2018	12/4/2019	**7/19/2052**
Turkey Point-4	4/10/2013	9/11/2000	6/6/2002	1/30/2018	12/4/2019	**4/10/2053**
Vogtle-1	1/16/2027	6/29/2007	6/3/2009	*No LOI*		**1/16/2047**
Vogtle-2	2/9/2029	6/29/2007	6/3/2009	*No LOI*		**2/9/2049**
Waterford-3	12/18/2024	3/23/2016	12/27/2018	*No LOI*		**12/18/2044**
Watts Bar-1	**11/9/2035**	*No LOI*				
Watts Bar-2	**10/22/2055**	*No LOI*				
Wolf Creek	3/11/2025	10/4/2006	11/20/2008	*No LOI*		**3/11/2045**

*Initial license renewal applications for Diablo Canyon-1 and -2 were filed in 2009 and withdrawn in 2018.

**The NRC finished its review of submitted materials for Surry-1 and -2 in June 2020 as scheduled, but license renewal approval has been delayed pending an additional licensee submittal for the environmental review.

U.S. Power Reactor License Expirations by Year



The license expiration year for every operating U.S. reactor as of December 31, 2020, is represented in this graph. Successful SLR applications extend expiration dates by 20 years and could reshape this graph in the future.

Power Reactors No Longer in Service

	Net MWe	Type	Started	Closed
Armenia				
Metsamor-1	440	PWR	10/1977	2/1989
Bulgaria				
Kozloduy-1	408	PWR	10/1974	12/2002
Kozloduy-2	408	PWR	11/1975	12/2002
Kozloduy-3	408	PWR	1/1981	12/2006
Kozloduy-4	408	PWR	6/1982	12/2006
Canada				
Douglas Point	216	PHWR	9/1968	5/1984
Gentilly-1	250	PHWR	5/1972	6/1977
Gentilly-2	635	PHWR	10/1983	12/2012
Pickering-2	515	PHWR	12/1971	5/2007
Pickering-3	515	PHWR	6/1972	10/2008
France				
Bugey-1	540	GCR	7/1972	6/1994
Chinon A1	70	GCR	2/1964	4/1973
Chinon A2	210	GCR	2/1965	6/1985
Chinon A3	480	GCR	8/1966	6/1990
Creys-Malville	1200	LMFBR	1/1986	12/1998
Chooz A	310	PWR	4/1967	10/1991
Fessenheim-1	880	PWR	12/1977	2/2020
Fessenheim-2	880	PWR	3/1978	6/2020
Marcoule G2	38	GCR	4/1959	2/1980
Marcoule G3	38	GCR	4/1960	6/1984
Monts d'Arree	70	GCHWR	6/1968	7/1985
Phénix	233	LMFBR	7/1974	3/2009
Saint-Laurent A1	480	GCR	6/1969	4/1990
Saint-Laurent A2	515	GCR	11/1971	5/1992
Germany				
Biblis A	1167	PWR	2/1975	8/2011
Biblis B	1240	PWR	1/1977	8/2011
Brunsbuettel	771	BWR	2/1977	8/2011
Grafenrheinfeld	1275	PWR	6/1982	6/2015
Gundremmingen A	237	BWR	4/1967	1/1980
Gundremmingen B	1284	BWR	7/1984	12/2017
Isar-1	878	BWR	3/1979	8/2011
Kruemmel	1346	BWR	3/1984	8/2011
Lingen	256	BWR	10/1968	5/1979
Muelheim-Kaerlich	1219	PWR	10/1987	6/2001
Neckar-1	785	PWR	12/1976	8/2011
Niederaichbach	100	GCHWR	1/1973	8/1974
Nord-1	408	PWR	7/1974	12/1990
Nord-2	408	PWR	4/1975	2/1990
Nord-3	408	PWR	5/1978	2/1990
Nord-4	408	PWR	11/1979	6/1990
Nord-5	408	PWR	11/1989	11/1989
Obrigheim	340	PWR	4/1969	5/2005
Philippsburg-1	890	BWR	2/1980	8/2011
Philippsburg-2	1402	PWR	4/1985	12/2019
Rheinsberg-1	70	PWR	10/1966	10/1990
Stade	630	PWR	5/1972	11/2003
Unterweser	1345	PWR	9/1979	8/2011
THTR-300	296	GCR	6/1987	10/1989
Wuergassen	640	BWR	12/1972	5/1995
Italy				
Caorso	860	BWR	12/1981	6/1990
Garigliano	150	BWR	6/1964	3/1982
Latina	153	GCR	1/1964	12/1987
Trino Vercellese	260	PWR	1/1965	6/1990
Japan				
Fugen ATR	148	HWLWR	3/1979	3/2003
Fukushima Daiichi-1	439	BWR	3/1971	3/2011
Fukushima Daiichi-2	760	BWR	7/1974	3/2011
Fukushima Daiichi-3	760	BWR	3/1976	3/2011
Fukushima Daiichi-4	760	BWR	10/1978	3/2011
Fukushima Daiichi-5	760	BWR	4/1978	12/2013
Fukushima Daiichi-6	1067	BWR	10/1979	12/2013
Fukushima Daini-1	1067	BWR	4/1982	7/2019
Fukushima Daini-2	1067	BWR	2/1984	7/2019
Fukushima Daini-3	1067	BWR	6/1985	7/2019
Fukushima Daini-4	1067	BWR	8/1987	7/2019
Genkai-1	529	PWR	10/1975	3/2015
Genkai-2	529	PWR	3/1981	4/2019
Hamaoka-1	515	BWR	3/1976	1/2009
Hamaoka-2	806	BWR	11/1978	1/2009
Ikata-1	538	PWR	9/1977	5/2016
Ikata-2	538	PWR	3/1982	3/2018
Mihama-1	320	PWR	11/1970	3/2015
Mihama-2	470	PWR	7/1972	3/2015
Monju FBR	246	LMFBR	**	12/2017
Ohi-1	1120	PWR	3/1979	3/2018
Ohi-2	1120	PWR	12/1979	3/2018
Onagawa-1	498	BWR	6/1984	12/2018
Shimane-1	439	BWR	3/1974	3/2015
Tokai-1	159	GCR	7/1966	3/1998
Tsuruga-1	340	BWR	3/1970	3/2015
Kazakhstan				
Aktau	135	LMFBR	7/1973	4/1999
Lithuania				
Ignalina-1	1187	LGR	12/1983	12/2004
Ignalina-2	1185	LGR	8/1987	12/2009
Netherlands				
Dodewaard	55	BWR	1/1969	3/1997
Russia				
Beloyarsk-1	102	LGR	4/1964	1/1983
Beloyarsk-2	146	LGR	12/1969	1/1990
Bilibino-1	11	LGR	4/1974	1/2019
Leningrad I-1	925	LGR	11/1974	12/2018
Leningrad I-2	925	LGR	2/1976	11/2020
Novovoronezh I-1	265	PWR	12/1964	2/1988
Novovoronezh I-2	336	PWR	4/1970	8/1990
Novovoronezh I-3	385	PWR	6/1972	12/2016
Troitsk A	100	LGR	9/1958	/1989

Power Reactors No Longer in Service

	Net MWe	Type	Started	Closed
Troitsk B	100	LGR	12/1959	/1989
Troitsk C	100	LGR	12/1960	/1989
Troitsk D	100	LGR	12/1961	11/1990
Troitsk E	100	LGR	12/1962	11/1990
Troitsk F	100	LGR	12/1963	11/1990
VK-50	50	BWR	1/1966	1/1989

Slovakia

	Net MWe	Type	Started	Closed
Bohunice A1	104	GCHWR	12/1972	5/1979
Bohunice 1	408	PWR	4/1980	12/2006
Bohunice 2	408	PWR	1/1981	12/2008

South Korea

	Net MWe	Type	Started	Closed
Kori-1	576	PWR	4/1978	6/2017
Wolsong-1	661	PHWR	4/1983	12/2019

Spain

	Net MWe	Type	Started	Closed
José Cabrera	142	PWR	2/1969	4/2006
Santa Maria de Garoña	446	BWR	5/1971	12/2012
Vandellos-1	480	GCR	8/1972	10/1989

Sweden

	Net MWe	Type	Started	Closed
Barsebaeck-1	615	BWR	7/1975	12/1999
Barsebaeck-2	600	BWR	9/1977	5/2005
Oskarshamn-1	473	BWR	12/1980	6/2017
Oskarshamn-2	638	BWR	7/1981	12/2016
Ringhals-1	881	BWR	1/1976	12/2020
Ringhals-2	904	PWR	5/1975	12/2019

Switzerland

	Net MWe	Type	Started	Closed
Muehleberg	373	BWR	11/1972	12/2019

Taiwan

	Net MWe	Type	Started	Closed
Chinshan-1	604	BWR	12/1978	10/2018
Chinshan-2	604	BWR	7/1979	10/2018

Ukraine

	Net MWe	Type	Started	Closed
Chernobyl-1	950	LGR	5/1978	11/1996
Chernobyl-2	950	LGR	5/1979	8/1991
Chernobyl-3	950	LGR	6/1982	12/2000
Chernobyl-4	950	LGR	4/1984	12/1986

United Kingdom

	Net MWe	Type	Started	Closed
Berkeley-1	138	GCR	11/1962	3/1989
Berkeley-2	138	GCR	11/1962	10/1988
Bradwell-1	123	GCR	8/1962	3/2002
Bradwell-2	123	GCR	12/1962	3/2002
Calder Hall-1	50	GCR	10/1956	3/2003
Calder Hall-2	50	GCR	3/1957	3/2003
Calder Hall-3	50	GCR	4/1959	3/2003
Calder Hall-4	50	GCR	5/1959	3/2003
Chapelcross-1	50	GCR	3/1959	6/2004
Chapelcross-2	50	GCR	8/1959	6/2004
Chapelcross-3	50	GCR	12/1959	6/2004
Chapelcross-4	50	GCR	3/1960	6/2004
Dounreay PFR	250	LMFBR	8/1976	3/1994
Dungeness A1	225	GCR	12/1965	12/2006
Dungeness A2	225	GCR	12/1965	12/2006
Hinkley Point A1	235	GCR	4/1965	5/2000
Hinkley Point A2	235	GCR	5/1965	5/2000
Hunterston A1	160	GCR	3/1964	3/1990
Hunterston A2	160	GCR	9/1964	12/1989
Oldbury A1	217	GCR	12/1967	2/2012
Oldbury A2	217	GCR	12/1967	6/2011
Sizewell A1	210	GCR	3/1966	12/2006
Sizewell A2	210	GCR	9/1966	12/2006
Trawsfynydd-1	195	GCR	3/1965	2/1991
Trawsfynydd-2	195	GCR	4/1965	2/1991
Winfrith SGHWR	92	HWLWR	2/1968	9/1990
Wylfa-1	490	GCR	11/1971	12/2015
Wylfa-2	490	GCR	1/1972	4/2012

United States

	Net MWe	Type	Started	Closed
Arnold	621.9	BWR	2/1975	8/2020
Big Rock Point	67	BWR	11/1965	8/1997
BONUS	72	BWR	8/1964	6/1968
Crystal River-3	860	PWR	3/1977	2/2013
CVTR	17	PHWR	12/1963	1/1967
Dresden-1	200	BWR	7/1960	10/1978
EBR-II	20	LMFBR	8/1964	9/1994
Elk River	23*	BWR	7/1964	2/1968
Fort Calhoun	502	PWR	9/1973	10/2016
Fermi-1	61	LMFBR	8/1966	11/1972
Fort St. Vrain	330	GCR	1/1979	8/1989
Haddam Neck	582	PWR	1/1968	12/1996
Hallam	75	LMGMR	1/1963	9/1964
Hanford-N	860	LGR	7/1966	2/1988
Humboldt Bay-3	63	BWR	8/1963	7/1976
Indian Point-1	257*	PWR	1/1963	10/1974
Indian Point-2	1028	PWR	8/1974	4/2020
Kewaunee	574	PWR	6/1974	5/2013
LaCrosse	50	BWR	11/1969	4/1987
Maine Yankee	860	PWR	12/1972	8/1997
Millstone-1	660	BWR	6/1971	8/1998
Oyster Creek	625	BWR	12/1969	9/2018
Pathfinder	59	BWR	7/1966	10/1967
Peach Bottom-1	40	GCR	6/1967	11/1974
Pilgrim	688	BWR	12/1972	5/2019
Piqua	12	OCR	11/1963	1/1966
Rancho Seco	913	PWR	4/1975	6/1989
San Onofre-1	436	PWR	1/1968	11/1992
San Onofre-2	1070	PWR	8/1983	6/2013
San Onofre-3	1080	PWR	4/1984	6/2013
Shippingport	60	PWR/LWBR	12/1957	10/1982
Shoreham	809	BWR	**	5/1989
Three Mile Island-1	837	PWR	9/1974	9/2019
Three Mile Island-2	792	PWR	12/1978	3/1979
Trojan	1095	PWR	5/1976	11/1992
Vermont Yankee	617	BWR	11/1972	12/2014
Yankee	175	PWR	7/1961	9/1991
Zion-1	1040	PWR	12/1973	1/1998
Zion-2	1040	PWR	9/1974	1/1998

* Including output from fossil-fired superheaters. ** Criticality was achieved, but the reactor was closed before it could begin commercial operation.

First Hualong One reactor now in operation

Unit 5 at the Fuqing nuclear plant in China's Fujian Province has entered commercial operation, becoming the world's first Hualong One reactor to do so, China National Nuclear Corporation (CNNC) announced on January 30.

The pressurized water reactor was connected to the power grid in late November of last year, after having achieved initial criticality the previous month.

Also known as the HPR1000, the Hualong One is a Chinese-designed and -developed 1,000-MWe Generation III PWR, incorporating design elements of CNNC's ACP1000 and China General Nuclear's ACPR1000+ reactors.

The Fuqing nuclear plant in southeastern China. Photo: CNNC

Fuqing-5's twin HPR1000, Fuqing-6, is scheduled for commercial startup later this year. In addition, CNNC is building two Hualong One reactors at the Zhangzhou site in Fujian Province (construction of Unit 1 began in October 2019, while Unit 2's construction commenced last September) and one at Taipingling in Guangdong Province, with another planned for the site.

Also, China General Nuclear is building two Hualong One reactors (Units 3 and 4) at its Fangchenggang plant in Guangxi Province (2022 planned startup), while two CNNC units are under construction at Pakistan's Karachi plant (commercial start dates of 2021 and 2022).

Yu Jianfeng, CNNC chairman, said in the announcement that his company will accelerate the progress of mass constructing Hualong One reactors and developing new series technologies in a bid to promote the Hualong One for export and to achieve the target of carbon neutrality.

POLICY

Hanson designated 18th NRC chairman

President Joe Biden on January 23 appointed Christopher T. Hanson to serve as chairman of the Nuclear Regulatory Commission. Hanson replaces Kristine Svincki, who resigned as chairman on January 20. Svinicki had been the longest-serving commissioner in the history of the agency (2008–2021), according to the NRC.

"I am honored to have been selected by President Biden to serve as the next NRC chairman and to lead the talented women and men who oversee the licensing and regulation of our nation's civilian use of radioactive materials," said Hanson. "I look forward to building on Chairman Svinicki's many accomplishments as the commission takes on new challenges and faces new opportunities as nuclear energy technologies continue to evolve and uses of nuclear materials expand in the future."

Hanson was nominated for a seat on the commission by President Trump in February of last year and confirmed by the Senate in May. He was sworn in on June 8 to fill the vacancy created by the resignation of Stephen Burns and will serve the remainder of Burns's term, which expires on June 30, 2024.

Prior to joining the NRC, Hanson served as a staff member on the Senate Appropriations Committee's Energy and Water Subcommittee under Sen. Dianne Feinstein (D-Calif.), and before that as a senior advisor in the Department of Energy's Office of Nuclear Energy.

NRC commissioner Christopher T. Hanson participates in the commission briefing on the agency's response to the COVID-19 pandemic. Photo: NRC

UNITED KINGDOM

New-build project for Wylfa site scrapped

The loosely connected plug keeping the United Kingdom's Wylfa Newydd nuclear new-build project alive has been officially pulled.

Horizon Nuclear Power, the Hitachi subsidiary that remained involved in the project following its parent company's pullout in September 2020, has formally withdrawn its application for a development consent order (DCO) regarding the proposed nuclear plant. (DCOs are required for large infrastructure projects in the United Kingdom to move forward.) The facility was to be sited adjacent to the decommissioned Wylfa reactors on the island of Anglesey, off the northwest coast of Wales.

A decision on the DCO application, under review by the U.K. Planning Inspectorate since 2018, was expected by April 30, after a series of successful requests for extensions from Duncan Hawthorne, Horizon's chief executive officer, who had cited "discussions with third parties that have expressed an interest in progressing with the development" of Wylfa Newydd.

But in a January 27 letter to the Planning Inspectorate, Horizon wrote that negotiations on the future of the project "have not, unfortunately, led to any definitive proposal that would have allowed the transfer to some new development entity. In light of this, and in the absence of a new funding policy from HM Government, Hitachi Ltd. has taken the decision to wind-up Horizon as an active development entity by 31 March 2021. As a result, we must now, regretfully, withdraw the application."

Despite Horizon's decision to close the project, Hawthorne noted in a statement that "nuclear power has a critical role to play in helping tackle our energy needs, meeting our climate change targets, and leveling up the economy through green growth and job creation. Wylfa Newydd on Anglesey and Oldbury on Severn [Horizon was also considering land near Oldbury in South Gloucestershire as a site for a new nuclear plant] are highly desirable sites for new nuclear build."

Horizon's letter drew this response from the U.K. government: "We offered a significant package of potential support to this project that went well beyond what any government has been willing to consider in the past, including taking a one-third equity stake, providing all required debt financing, and offering generous financial support through our contract for difference scheme. We understand that this will be disappointing news for the people of north

Power & Operations continues

Wales. However, Wylfa remains an important site for potential new projects, and the U.K. government will continue to explore future opportunities for it."

One possible future for nuclear power at the Wylfa site came into view on January 15, when British firm Shearwater Energy announced that it is teaming with U.S.-based NuScale Power to develop a hybrid project at Wylfa that would use wind energy and small modular reactor technology to produce power and green hydrogen.

Delay, cost increase announced for Hinkley Point C

The unfortunate effects of the COVID-19 pandemic on nuclear new-build projects haven't stopped with Vogtle: EDF Energy reported in late January that the expected startup date for Unit 1 at its Hinkley Point C site is being pushed from late 2025 to June 2026.

Perspex screens and reduced seating capacity in the Hinkley Point canteens help protect the workforce during breaks, EDF Energy said. Photo: EDF Energy

In addition, the project's completion costs are now estimated to be in the range of £22 billion to £23 billion (about \$30.2 billion to \$31.5 billion), some £500 million (about \$686 million) more than the 2019 estimate, EDF said, adding the caveat that these revisions assume an ability to begin a return to normal site conditions by the second quarter of 2021.

"We've been able to keep working through COVID because our teams have gone to extraordinary lengths to keep the site and our community safe, with many measures put in place to prevent infection and to enable social distancing," said Stuart Crooks, the project's managing director, in a video posted on the company's website. "So in these very challenging circumstances, it's a considerable achievement that we hit 18 of our 20 milestones last year, with the last two not far behind. That has been done with fewer people on site and with considerable disruption among our suppliers."

ADVANCED NUCLEAR

Canada and Europe team up to drive new technologies

The Canadian Nuclear Association (CNA) and the European Atomic Forum (FORATOM) have signed a memorandum of understanding to collaborate in the promotion of advanced nuclear technologies. The agreement, announced on January 27, aims to boost efforts to advance the development, application, and deployment of nuclear energy to meet climate change goals, according to the announcement.

Among other things, the CNA and FORATOM agree to:

- Support the accelerating wave of innovation in nuclear energy and the increasing international activity among the groups' respective memberships in existing nuclear and the development and deployment of small modular and advanced reactors.
- Promote innovation in research and development initiatives in key applications, such as medical diagnosis and treatment, and in other economic sectors, including industry, agriculture, resource development, and advanced materials.

- Champion public awareness, understanding, and engagement around the benefits of nuclear to the climate.
- Exchange information on relevant announcements related to communications, government decisions, and policy.
- Provide a forum for the discussion and resolution of issues of concern to members, industry, and the public.
- Promote the inclusion of nuclear technologies in bilateral Canadian-European dialogues and in multilateral forums.

Inking the agreement were John Gorman, CNA president and chief executive officer, and Yves Desbazeille, FORATOM director general.

"We are excited to sign this memorandum of understanding with FORATOM," Gorman said. "Nuclear energy already makes important contributions to combating climate change. This agreement will work to ensure that nuclear is part of the clean energy mix to meet the climate change challenge on both sides of the Atlantic."

Desbazeille added, "Climate change is a global challenge. This is why it is important that all regions of the world work together to find solutions. Together, we will be able to send a coordinated message to our policymakers with the goal of demonstrating the important role which different nuclear technologies can play."

U.S. boosts SMR development in Romania

U.S. ambassador to Romania Adrian Zuckerman (right) and SNN chief executive officer Cosmin Ghita at the signing. Photo: U.S. Embassy in Romania

The U.S. Trade and Development Agency (USTDA) has awarded a $1.28 million grant to Romania's nuclear energy authority, Societatea Nationala Nuclearelectrica (SNN), for technical assistance to support the development of small modular reactors in that country, the agency announced on January 14.

The grant will be used to identify a short list of SMR-suitable sites, assess SMR technology options, and develop site-specific licensing roadmaps. SNN has selected Chicago-based Sargent & Lundy to carry out the assistance.

"USTDA is an ideal partner for Romania as it seeks cutting-edge civil nuclear energy technology for its future energy needs," said Todd Abrajano, USTDA's chief operating officer and head of agency. "Our assistance will build stronger ties between our respective industries and create new business opportunities for U.S. industry in an important market."

SNN's chief executive officer, Cosmin Ghita, stated, "In addition to the current development of [Cernavoda] reactors 3 and 4, SNN is also interested in assessing the development of small modular reactors as a long-term solution to further develop the Romanian nuclear industry. We are interested in features like flexibility, modularity, and higher efficiency that could provide advantages for both the energy system and businesses after 2035. The grant awarded by USTDA will allow us to further explore siting and technology compatibility with the proper technical assistance and have this assessment process initiated in due time for further decision-making."

Last October, Dan Brouillette, former U.S. energy secretary, and Virgil Popescu, Romania's minister of economy, energy, and business development, initialed a draft intergovernmental agreement to cooperate on the construction of two additional reactors at Cernavoda, Romania's only nuclear power plant, as well as the refurbishment of Unit 1.

Power & Operations continues

POINT BEACH

NRC accepts SLR application

The Nuclear Regulatory Commission has accepted for review NextEra Energy's subsequent license renewal (SLR) application for its Point Beach reactors, making them the fifth and sixth units currently under consideration for a second 20-year license renewal. (SLR applications for Dominion Energy's North Anna-1 and -2 and Surry-1 and -2 are also being reviewed, while SLR approval has been granted for Exelon's Peach Bottom and NextEra's Turkey Point units.)

NextEra submitted the SLR application in November of last year—the first such application involving a Midwestern nuclear plant. The NRC approved the plant's initial license renewal in December 2005, allowing Unit 1 to operate through October 5, 2030, and Unit 2 through March 8, 2033.

On January 22, the NRC published in the *Federal Register* a notice of opportunity to request a hearing and to petition for leave to intervene in the license renewal proceeding. Such requests "by anyone whose interest may be affected by the proposed license renewal and who wishes to participate as a party in the proceeding" must be filed by March 23, 2021, the NRC said in the notice.

Point Beach, Wisconsin's only operating nuclear power plant, is located on the shore of Lake Michigan in Two Rivers, Wis. It comprises two 615-MWe two-loop Westinghouse pressurized water reactors that have been in commercial operation since the early 1970s.

FUEL

NRC agrees to review Westinghouse topical report

Westinghouse announced via a January blog post that a topical report on its advanced doped pellet technology (ADOPT) fuel has been accepted for review by the Nuclear Regulatory Commission, calling the decision a "major achievement for the advanced fuel portfolio Westinghouse is developing as part of our EnCore fuel program."

The company submitted the report in May of last year, requesting approval by February 2022. According to Westinghouse, a draft safety evaluation from the agency is expected this summer.

ADOPT fuel is a direct replacement for standard uranium dioxide fuel, providing enhanced fuel pellet properties to enable higher burnup and improved accident tolerance, according to the topical report. The 92-page document also notes that Westinghouse has obtained "extensive operating experience with ADOPT fuel through its use as a commercial fuel product in Europe."

Westinghouse developed EnCore fuel as part of the Department of Energy's accident tolerant fuel program. In September 2019, the company announced the completion of a first-of-a-kind installation of EnCore fuel at Exelon's Byron plant. The fuel was installed in Unit 2 during the scheduled spring refueling outage. The two lead test assemblies contained chromium-coated zirconium cladding for enhanced oxidation and corrosion resistance, higher density ADOPT pellets for improved fuel economics, and uranium silicide pellets.

"ADOPT fuel offers significant enhancements to a plant's current fuel performance, as well as increased flexibility for long-term operations," said Jeff Bradfute, vice president of Americas Fuel Delivery at Westinghouse. "We're excited to continue to make advancements toward offering this solution to our U.S. customers and supporting their near- and long-term operational goals."

In Case You Missed It—Power & Operations

The new year has brought with it a new nuclear pact between the United Kingdom and the European Union. Along with the wider Trade and Cooperation Agreement signed in late December by the two governments to address post-Brexit realities, the United Kingdom concluded a stand-alone Nuclear Cooperation Agreement with the European Atomic Energy Community, better known as Euratom. The NCA went into effect January 1. The NCA provides a framework for trade in nuclear materials and technology, facilitates research and development, and enables exchange of information and expertise, including on medical radioisotopes.

The 18-page, 25-article NCA is to remain in force for an initial period of 30 years. After that, it will be automatically renewed for additional 10-year periods—unless, at least six months prior to the expiration of the initial period or any additional period, one party notifies the other of its intent to terminate.

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The Vogtle construction project team expects to further adjust dates for achieving key project milestones, including the start of hot functional testing and fuel load for Unit 3, Southern Company subsidiary Georgia Power announced on January 11. The company added, however, that it continues to expect to bring Unit 3 into service this November and Unit 4 into service in November 2022.

Last October, Vogtle plant operator Southern Nuclear announced a readjustment of its July 2020 "aggressive site schedule" dates for Unit 3 hot functional testing, fuel load, and commercial operation. The dates were moved from October 2020, December 2020, and May 2021, respectively, to January 2021, April 2021, and the third quarter of 2021.

The initial shipment of nuclear fuel for Unit 3 arrives at the Vogtle site. Photo: Georgia Power

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The Department of Energy released its Strategic Vision report in early January, outlining its plan to support the current U.S. reactor fleet, demonstrate the latest innovations in nuclear energy technologies, and explore new market opportunities for nuclear energy. The 36-page document identifies five goals to address challenges in the nuclear energy sector, help realize the potential of advanced technology, and leverage the unique role of the federal government in sparking innovation: 1) enable continued operation of U.S. nuclear reactors, 2) enable deployment of advanced nuclear reactors, 3) develop advanced nuclear fuel cycles, 4) maintain U.S. leadership in nuclear energy technology, and 5) enable a high-performing organization.

For in-depth coverage of these stories and more, see the ANS Newswire at ans.org/news.

Power & Operations continues

ARMENIA

Metsamor-2 operation to be extended

Armenia plans to extend the operational life of Unit 2 at Metsamor (also matter-of-factly known as the Armenian nuclear power plant) beyond 2026 and has not abandoned plans to construct a new reactor, the Armenian news agency *ARKA* reported on January 14, citing the country's new cabinet-approved strategy for energy sector development through 2040. (The Armenian government in 2014 decided to extend Unit 2's service life to 2026.)

Cooling towers at the Metsamor nuclear plant. Photo: ANPP

"Having a nuclear power plant in the energy system will allow Armenia to diversify its energy resources, avoid increasing the country's dependence on imported natural gas, as well as cut the volume of emissions," the strategy document states, according to *ARKA*. "The government remains committed to its policy of having a nuclear power plant in the country's generating capacity. In this context, it should be noted that the option of maximally extending the operating life of the nuclear power plant is a guarantee of the development of the system at the lowest cost."

Metsamor houses two VVER-440 model V270 pressurized water reactors, built in the 1970s. Both units were shut down in 1988 as a result of public pressure following a severe earthquake in the region. With Russian assistance, the 375-MWe Unit 2 was restarted in 1995 and currently accounts for 39 percent of Armenia's electricity generation.

BELLEFONTE

NRC issues EA & FONSI for construction permit extension

The Nuclear Regulatory Commission has issued an environmental assessment (EA) and finding of no significant impact (FONSI) in connection with its proposed action to extend the completion dates for the Tennessee Valley Authority's Bellefonte plant reactor construction permits. If approved by the NRC, the construction permits for Bellefonte Units 1 and 2 would extend to October 1, 2021.

In a notice on the EA and FONSI published in the January 19 *Federal Register*, the NRC explained the reason for the proposed action. "In its March 31, 2017, and August 28, 2020, letters, TVA noted that it sold the Bellefonte property at auction, the sale of Units 1 and 2 did not close, and the purchaser filed a lawsuit against TVA," the notice said. "TVA stated that an extension is needed to allow the parties additional time to obtain a decision in the lawsuit."

TVA sold the Bellefonte plant in November 2016 to Nuclear Development LLC for $111 million, concluding a six-month competitive auction process for the partially completed nuclear facility-located near Scottsboro, Ala. Nuclear Development—owned by Franklin Haney, a Chattanooga, Tenn., developer—had been formed in 2012 for the specific purpose of acquiring, financing, completing, and operating the two partially completed reactors at Bellefonte.

In November 2018, Haney's firm submitted its construction permit transfer application for the reactors to the NRC. Some two weeks later, however, just days before the deal's scheduled closing, TVA announced that it did not intend to complete the sale, saying that Section 101 of the Atomic Energy Act requires that the construction permits be approved by the NRC before the transaction can be completed. Nuclear Development proceeded to file suit against TVA, and the utility filed a motion to dismiss the suit in response. That motion was later rejected by a U.S. District Court judge. The case remains mired in court proceedings at this writing.

The unfinished Bellefonte nuclear plant. Photo: Wikimedia Commons

Purdue team uses Argonne's APS for 3D view of irradiated fuel

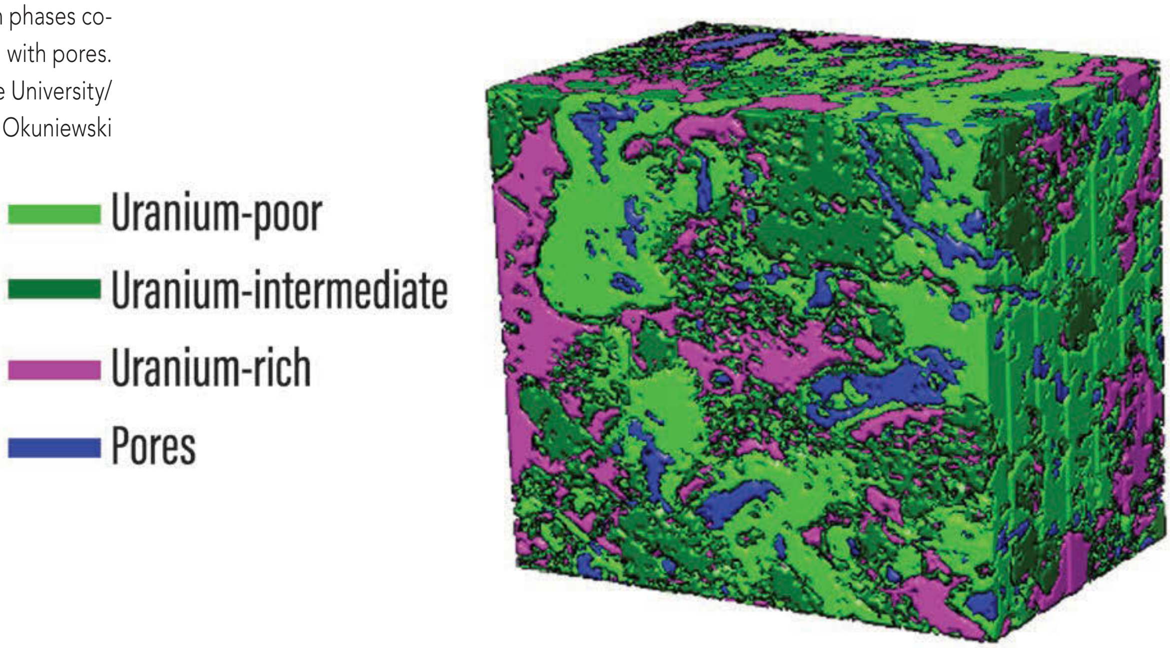
A team of researchers led by Purdue University has used X-ray imaging conducted at Argonne National Laboratory's Advanced Photon Source to obtain a three-dimensional view of the interior of an irradiated nuclear fuel sample. The use of synchrotron micro-computed tomography could lead to more accurate modeling of fuel behavior and more efficient nuclear fuel designs, according to the researchers.

The results of the study were published in the *Journal of Nuclear Materials*, in a paper titled "The application of synchrotron micro-computed tomography to characterize the three-dimensional microstructure in irradiated nuclear fuel," and were also described in a press release issued by Argonne and Purdue University on January 19.

Micro-computed tomography detects an X-ray beam as it emerges on the other side of the sample. From multiple images taken as a sample is rotated, the internal features of a sample can be imaged based on how the X-ray beam was altered as it passed through the sample.

At Argonne, the Purdue research team worked with scientists at beamline 1-ID-E, a high-brilliance X-ray source at the APS, to examine the sample. The research marked the first time that synchrotron X-ray micro-computed tomography was used to analyze the morphology of the microstructure of irradiated nuclear fuel in three dimensions, according to the research team.

The subject of investigation was a tiny piece of uranium-zirconium (U-10Zr) from a fuel pin that spent two years at full power in the Fast Flux Test Facility at the Hanford Site, near Richland, Wash., before it was extracted in the early 1990s.



Three-dimensional image reconstruction of a sample of irradiated fuel, showing the three thresholded uranium phases co-existing with pores. Image: Purdue University/Maria Okuniewski

The sample was prepared at Idaho National Laboratory. A cube of the material about 100 microns across—about the width of a human hair—was milled from a fuel pin using a focused ion beam with scanning electron microscopy. “We had to wait decades for this fuel to radiologically cool, or decay,” said Maria Okuniewski, an assistant professor of materials engineering at Purdue University and the paper’s lead author. “It was literally the coolest specimen that we could remove, based on the permissible safety guidelines at both INL and APS.”

Okuniewski and her colleagues wanted to characterize swelling caused by the accumulation of gaseous fission by-products, which limits the useful life of nuclear fuels.

The study revealed the presence of pores and three distinct uranium phase regions: poor, intermediate, and rich. The researchers determined that 7.2 percent of the fuel specimen was porous. Five growth stages of pore evolution were observed, including nucleation, growth, coalescence, interconnected porosity, and extended/interconnected porosity. The research also found that the release of fission gases might continue to occur beyond the thresholds assumed in previous analyses.

“We’re always striving within the nuclear community to figure out ways that we can improve the fuel performance codes,” Okuniewski said. “This is one way to do that. Now we have three-dimensional insight that we previously didn’t have at all.”

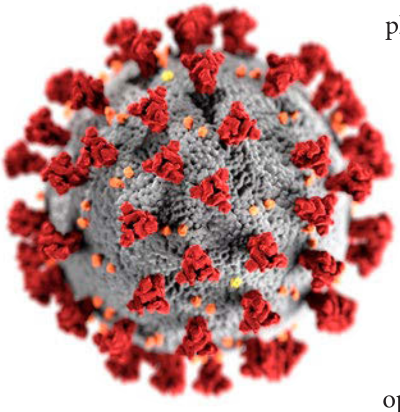
COVID-19

Former NRC chairs issue vaccine timeline recommendation to CDC

Five former chairmen of the Nuclear Regulatory Commission—Stephen Burns, Allison Macfarlane, Nils Diaz, Richard Meserve, and Dale Klein—signed a letter to José Romero, Arkansas health secretary and chair of the Centers for Disease Control and Prevention (CDC) immunization advisory committee. The letter requests that the advisory committee update its recommendation for COVID-19 vaccine allocation guidance for the energy workforce (including nuclear energy workers).

Currently, the CDC has four phases for the COVID-19 vaccine rolloout:

- 1a (the current phase), reserved for healthcare workers and those living in long-term care facilities;
- 1b, reserved for people 75 years and older and frontline essential workers;
- 1c, reserved for persons 65 to 74 years old, those aged 16 to 64 who have high-risk medical conditions, and other categories of essential workers (this includes energy workers); and
- 2, for everyone else that was not named in the previous three phases aged 16 to 64.



The five past NRC chairmen express, in their letter to the CDC advisory committee, an understanding of the difficult and complex undertaking with which the CDC committee is tasked. The former chairs believe, however, that at least a portion of the nuclear energy workforce should be included in phase 1b. The letter states in bold, “We respectfully request that you consider increasing the priority for at least the subset of the nuclear energy workforce necessary to meet the NRC’s regulatory requirements for minimum staffing at nuclear power plants: control room operators, equipment operators,

Research & Applications continues

security officers, radiation protection technicians, maintenance technicians, and chemistry technicians. If a nuclear plant were unable to comply with the NRC's staffing requirements, it would be required to shut down."

The letter provides background about the importance of nuclear power for our health infrastructure and national security while also informing the CDC advisory committee that "20 percent of our country's overall electricity and 55 percent of its carbon-free electricity" is generated by the country's nuclear fleet. The letter adds, "Essential nuclear energy workers ensure not only that our homes and businesses are powered, but that our nation's critical infrastructure—from our telecommunications systems to the hospitals that care for our most vulnerable—remains functioning during this time of crisis."

AGRICULTURE

Nuclear techniques help Pakistan's textile industry

The International Atomic Energy Agency has entered a partnership with the Food and Agriculture Organization of the United Nations, working with local experts in Pakistan to develop and introduce new varieties of cotton that are more resilient and better adapted to the increasingly negative effects of climate change. The new varieties are developed through mutation breeding techniques, wherein seeds, cuttings, or tissue-culture material is exposed to radiation or other mutagen sources, like an X-ray or gamma ray source.

According to the IAEA in January, seeds first are exposed to radiation and then planted in greenhouses. Subsequent generations are then propagated—three or four generations beyond the initially irradiated seeds. Then, the resulting mutated plants are examined for the specific traits desired in the program, and promising candidates are planted in trials to prove their performance. If the mutants display desirable traits, seeds are released to farmers for cultivation.

According to a report from the IAEA, mutant varieties have improved the quality traits of crops. The mutations in the crop varieties have led to "decrease[d] use of pesticides (due to increased disease resistance), a reduction in using fertilizers and consumption of water (due to the highly efficient nutrient intake and better tolerance to drought), superior quality, and higher crop yields," the report states.

The new varieties developed now account for 40 percent of all cotton produced in Pakistan, up from just 25 percent two years ago and from nonexistent yield in 2016. Pakistani farmer Muhammad Ikram said, "I was able to harvest my crop this year with a 30 percent higher yield than what I could achieve with traditional varieties." This is a big success for Pakistan, considering the textile industry employs 40 percent of the labor force in the country.

IAEA support, including trainings, workshops, and fellowships, as well as practical lectures such as this one in Pakistan, have contributed to building the national capacity in cotton breeding techniques. Photo: L. Jankuloski/ Joint FAO/IAEA

INTEGRATED ENERGY SYSTEMS

NuScale SMR chosen for U.K. wind-nuclear hybrid

British hybrid clean energy company Shearwater Energy is joining with U.S.-based NuScale Power to develop a hybrid project using wind energy and small modular reactor technology to produce power and green hydrogen.

The two companies signed a memorandum of understanding to collaborate on an initial project, which could be sited at the now-decommissioned Wylfa nuclear power station on the island of Anglesey, off the northwestern coast of Wales. No land agreements have been reached, however.

Shearwater said in January that the project could produce more than 3 million kilograms of green hydrogen annually for use in the U.K.'s transportation sector. It also could provide both baseload and load-following power as needed, with any excess electricity used to create green hydrogen (defined as hydrogen produced using renewable energy instead of fossil fuels).

The United Kingdom has announced plans to rapidly expand offshore wind capacity by 2030 and invest in SMR development to meet net-zero carbon emissions goals by 2050. Shearwater and NuScale in their announcement said that hybrid wind-nuclear energy systems not only would provide reliable power but also would help the power grid overcome intermittency and grid stability issues.

POLICY

Climate change needs an Operation Warp Speed

The government of the United States should throw its muscle behind ramping up a mammoth, rapid rollout of all forms of renewable energy through Operation Warp Speed, similar to what is being done with the COVID-19 vaccine, Clive Thompson wrote in an Ideas column posted to the *Wired* site in January.

The rollout should include energy sources that we already know how to build—like solar and wind—but also experimental emerging sources such as geothermal and small nuclear, and cutting-edge forms of energy storage or transmission.

For the past 40 years, the United States has spent 37 percent more on R&D for fossil fuels than for renewables. Thompson notes that an Operation Warp Speed for climate change should invert that ratio, adding that the government should become a bulk buyer of renewable energy. The feds' vaccine purchase is what jolted pharmaceutical companies to move rapidly with a COVID-19 vaccine. The virus created the demand; the feds created the market, according to Thompson.

As a starting point, Operation Warp Speed for climate could use the organizational push from the U.S. government and military to bring clean energy to every federal building nationwide, Thompson writes.

"The new Biden administration plans to retire the Warp Speed name, but hopefully not the approach," Thompson opines. "When you're finally jabbed with the new vaccine, savor our public victory. Then call your congresscritter [*sic*] to demand a Warp Speed for climate. The planet needs the same shot in the arm."

Research & Applications continues

MICROREACTORS

INL's MARVEL could demonstrate remote operation on a micro scale

The Department of Energy is considering the construction of the Microreactor Applications Research Validation & EvaLuation (MARVEL) project microreactor inside Idaho National Laboratory's Transient Reactor Test (TREAT) Facility.

The MARVEL design is a sodium-potassium–cooled thermal microreactor fueled by uranium zirconium hydride fuel pins using high-assay low-enriched uranium (HALEU). It would be a 100-kWt reactor capable of generating about 20 kWe using Stirling engines over a core life of about two years.

The DOE proposes to install the MARVEL microreactor in a concrete storage pit in the north high bay of the TREAT reactor building.

In Case You Missed It—Research & Applications

Lal

NASA has appointed ANS member Bhavya Lal as the space agency's acting chief of staff. She served as a member of the Biden Presidential Transition Agency Review Team for the agency, NASA said.

Lal cofounded and is cochair of the policy track of the ANS annual conference on Nuclear and Emerging Technologies in Space (NETS). She has contributed as an author and guest editor for the upcoming NETS 2020 special issue of ANS technical journal *Nuclear Technology*.

In addition, she helps organize a seminar series on space history and policy with the Smithsonian National Air and Space Museum.

NASA's announcement appointing Lal was made in late January.

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Lesher

Shelly Lesher, a University of Wisconsin–La Crosse professor, is hosting the My Nuclear Life podcast series centered on how nuclear science is perceived in the community.

My Nuclear Life explores the intersection of nuclear science and society. Lesher, a 2020 American Physical Society Fellow, covers a range of topics, from the use of radium therapy for treating cancer to the U.S. environmental movement.

Lesher, who has taught a "Navigating Global Nuclear Issues" course at UW-L for the past five years, first began the podcast after noticing a void in society when it comes to nuclear science. "Students often ask why they aren't being taught about it," she told La Crosse television station WXOW.

Featured guests have included Richard Nephew, lead U.S sanctions expert on the Joint Comprehensive Plan of Action with Iran, and Richard Rhodes, Pulitzer Prize–winning author of *The Making of the Atomic Bomb*.

For in-depth coverage of these stories and more, see the ANS Newswire at ans.org/news.

Modifications to the building to accommodate MARVEL are anticipated to take five to seven months. Constructing, assembling, and performing preoperational testing are expected to take another two to three months prior to fuel loading.

INL leads the DOE's Microreactor Program, conducting fundamental and applied R&D to reduce the risks associated with new technology performance and manufacturing readiness of microreactors and to ensure that microreactor concepts can be commercially licensed and deployed.

"Nuclear energy has always been a reliable power source that doesn't emit carbon dioxide into the atmosphere," INL director John Wagner said in the DOE press release announcing MARVEL's public review period. "MARVEL takes the next step. It will provide for prompt, small-scale demonstrations of several environmentally friendly technologies associated with advanced microreactors as well as larger reactors, which will benefit the nuclear energy industry and end users."

"MARVEL will be capable of testing power applications such as load-following electricity demand to complement intermittent renewable energy sources such as wind and solar," Wagner explained. "It will also test the use of nuclear energy for water purification, hydrogen production, and heat for chemical processing. It will additionally provide industry partners with the ability to test new microreactor-related technologies and will provide real-world, viewable examples of how commercial end users could incorporate microreactors into their clean energy portfolios."

MARVEL is designed to

- test, demonstrate, and address issues to achieve unattended operation, including normal operating transients such as startup and load management as well as cyber and physical security hardening.
- enable remote monitoring, including sensors and instrumentation for live data acquisition and wireless transmission to a remote monitoring location.
- use control systems to integrate the reactor with the grid and a range of applications to manage grid demand and reactor power supply and to demonstrate integration approaches for a range of applications such as process heating and hydrogen production.

The DOE's public comment period for the draft environmental assessment for the project was closed in late January. ⊠


MARVEL reactor concept with Stirling engines. Image: INL

Waste Management

Presented by ANS's **Radwaste Solutions**
See the latest issue at ans.org/rs

New York sues NRC over Indian Point decommissioning

New York Attorney General Letitia James filed a lawsuit on behalf of the State of New York against the Nuclear Regulatory Commission over the sale of the Indian Point nuclear power plant to subsidiaries of Holtec International for decommissioning.

Indian Point nuclear power plant in Buchanan, N.Y. Photo: Entergy Nuclear

Filed in the U.S. Court of Appeals for the District of Columbia Circuit on January 22, the suit challenges the NRC's denial of New York's petition for a hearing regarding the transfer of Indian Point's licenses from owner Entergy to Holtec, as well as the NRC's initial approval of the license transfer. The NRC approved the transfer in November 2020 while challenges from the state and other groups were still being adjudicated. The NRC issued its order denying New York's petition to intervene on January 15.

The transfer of ownership of the plant from Entergy to Holtec is targeted to occur after Indian Point-3 shuts down in April 2021. Indian Point-2 permanently ceased operations in April 2020, and Indian Point-1 has been shut down since 1974. The pressurized water reactors are located in Buchanan, N.Y., approximately 24 miles north of New York City.

In its lawsuit, New York also challenges the NRC's approval of license exemptions allowing Holtec to use money from Indian Point's decommissioning trust funds for the management of the plant's spent nuclear fuel.

"Of the approximately $2.1 billion of aggregated trust funds intended to decommission the facility, Holtec intends to spend more than $630 million for spent fuel management alone, raising concerns regarding the sufficiency of the remaining funds to conduct safe and comprehensive decommissioning at a site known to harbor substantial contamination," a press release from Attorney General James states.

As a result of the Department of Energy's breach of the Standard Contract for the Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste, owners of commercial nuclear power plants can recover spent fuel management costs from the federal government, a point the NRC raised in its denial of New York's petition to intervene.

Correction: A line of type was missing from the Waste Management story about the Palisades nuclear power plant on page 69 of the February issue. The full sentence from which the line of type was inadvertently omitted should read, "Singh added that Holtec, as a proven leader in decommissioning and with a fleet of projects around the United States and the world, would assure Palisades' neighbors and stakeholders of its 'strong and steadfast commitment to safety, precision, and efficiency as our Holtec team decommissions this facility and brings a new economic future to the region.'" *NN* regrets the error.

YUCCA MOUNTAIN

Administration opposes Nevada repository, Granholm says

Jennifer Granholm, President Joe Biden's nominee for energy secretary, told a congressional panel that the administration disapproves of Yucca Mountain as the country's nuclear waste repository, preferring a consent-based strategy as proposed by President Barack Obama's Blue Ribbon Commission on America's Nuclear Future.

"The administration opposes the use of Yucca Mountain for the storage of nuclear waste," Granholm told Sen. Catherine Cortez Masto (D–Nev.) during a confirmation hearing before the Senate Energy and Natural Resources Committee on January 27.

Granholm, a Democrat, served two terms as Michigan governor from 2003 to 2011. According to reports, Granholm was twice considered a candidate for energy secretary under President Obama, but ultimately was not picked.

In response to questions by Sen. Angus King (I–Maine) regarding U.S. spent nuclear fuel, Granholm said, "It is clearly a very sticky situation and we have to maybe look at what the Blue Ribbon Commission did on this, which was to engage with some consensus strategies that will allow us to determine where that waste will go."

During the hearing, Cortez Masto said that Nevada's entire congressional delegation plans to reintroduce legislation on a consent-based siting process, as recommended by the Blue Ribbon Commission, to include Nevada. Asked if she would support such legislation, Granholm said, "Absolutely."

Granholm

LOW-LEVEL WASTE

DOE looks to dispose of SRS equipment under HLW interpretation

The Department of Energy is considering disposing of contaminated process equipment from its Savannah River Site (SRS) at a commercial low-level waste facility using its recent interpretation of the statutory term "high-level radioactive waste," which classifies waste generated from the reprocessing of spent nuclear fuel based on its radiological content rather than its origin.

In a January 19 *Federal Register* notice, the DOE announced that it intends to prepare a draft environmental assessment on the disposal of contaminated process equipment from SRS at a licensed LLW disposal facility outside of South Carolina. The DOE said that it will analyze commercial disposal options for three specific types of equipment that were contaminated during the on-site treatment of reprocessing waste: Tank 28F salt sampling drill string, glass bubblers, and glass pumps. Currently, there is no disposal pathway for SRS process equipment that has been contaminated with reprocessing waste.

This would be the second time that the DOE has used its revised HLW interpretation to dispose of a waste stream from the South Carolina site in a LLW facility. Last year, the DOE shipped eight gallons of recycled wastewater from the Defense Waste Processing Facility to Waste Control Specialists' (WCS's) disposal facility in Texas.

The DOE is considering two disposal alternatives. Under the first alternative, if the equipment is determined to be Class A LLW, it would be shipped to either the WCS facility in Texas or EnergySolutions' facility in Clive, Utah. Under the second alternative, if the equipment is found to be Class B or C LLW, it would go to WCS's facility. Both options are dependent on waste content and compliance with facility waste acceptance criteria.

Waste Management continues

Prior to making a decision, the DOE would characterize the contaminated process equipment to verify that it meets the department's HLW interpretation for disposal as non-HLW and complies with the waste acceptance criteria and all other requirements of the chosen disposal facility. The waste would be stabilized and packaged at SRS prior to being shipped off-site.

The DOE said that it plans to issue an *FR* notice this year on the availability of the draft environmental assessment. Based on that analysis, the department will either issue a finding of no significant impact or announce its intention to prepare an environmental impact statement.

The DOE has also updated its Manual 435.1-1, *Radioactive Waste Management Manual*, to formally incorporate the department's interpretation of the statutory definition of HLW. Notice of limited change to Manual 435.1-1 was published in the January 19 *FR*. According to the DOE, the objective of the change is to continue to ensure that all DOE radioactive waste, including reprocessing waste, is managed in a manner that protects worker and public health and safety, and the environment.

SAVANNAH RIVER SITE

Salt Waste Processing Facility clears testing phase, begins full operations

The hot commissioning testing phase of operations at the Salt Waste Processing Facility (SWPF) has been completed, signaling the facility's entrance into fully integrated operations with the other liquid waste facilities at the Department of Energy's Savannah River Site in South Carolina.

Radiation shielding, environmental emissions, and product waste acceptance requirements were all tested and validated during the commissioning phase of the SWPF, the DOE announced on January 19. The SWPF will treat the approximately 31 million gallons of remaining salt waste currently stored in underground tanks at SRS.

Parsons Corporation, the contractor that designed and built the first-of-a-kind facility, will operate the SWPF until January 2022. It is anticipated that the facility will process up to 6 million gallons of waste during the first year of operations.

Processing of the radioactive waste began in early October 2020, and by mid-November the SWPF had begun processing undiluted feed from Tank 49 in Savannah River's H Tank Farm. According to the DOE, all hot commissioning testing objectives were met on schedule and without incident. In total, more than 450,000 gallons of decontaminated salt solution have been transferred from the SWPF.

The startup of the SWPF is the last major piece of the liquid waste system at SRS and, according to the DOE, represents a significant leap forward in the department's ability to tackle the largest and one of its most challenging environmental risks—legacy radioactive tank waste. With the SWPF fully operational, it is expected that nearly all of the salt waste inventory at SRS will be processed by 2030.

An aerial view of the Salt Waste Processing Facility at the Savannah River Site. Photo: DOE

HANFORD

Waste transport system testing conducted at WTP

Hanford workers discuss LAW Facility mechanical equipment testing on the two units that make up the "bogie" transport rail system. Photo: DOE

Startup engineers at the Hanford Site's Waste Treatment and Immobilization Plant (WTP) have been performing mechanical equipment testing on the two units that make up the "bogie," or cart, transport rail system, in the lower level of the Low-Activity Waste (LAW) Facility.

During future plant operations, containers will be filled with vitrified radioactive and chemical waste and placed on the bogie transport rail that leads to the facility's finishing line area before the containers are moved to storage.

To date, all 94 systems in the LAW Facility have been turned over to startup, and 38 of those have been handed over for commissioning, according to the DOE on January 26.

The WTP will cover 65 acres with four nuclear facilities—for pretreatment, high-level waste vitrification, and low-activity waste vitrification, along with an analytical laboratory—as well as operations and maintenance buildings, utilities, and office space. The LAW Facility is 330 feet long and 240 feet wide, approximately the size of one and a half football fields, and 90 feet, or seven stories, high.

In the LAW Facility, concentrated low-activity waste will be mixed with silica and other glass-forming materials. The mixture will be fed into the LAW facility's two melters and heated to 2,100 °F. The 300-ton melters are approximately 20 feet by 30 feet and 16 feet high and, when completed, will be the largest waste glass melters in the world, according to the DOE. The glass mixture will then be poured into stainless steel containers, which are 4 feet in diameter, 7 feet tall, and weigh more than 7 tons.

The low-activity waste containers will be stored on the Hanford Site, near Richland, Wash., in permitted trenches and covered with soil.

OAK RIDGE

Y-12 project recovers, reuses mercury

The Department of Energy's Oak Ridge Office of Environmental Management and its contractor UCOR have found a way to reuse instead of dispose of mercury collected from a cleanup project at the Y-12 National Security Complex near Oak Ridge National Laboratory in Tennessee. "This questioning attitude and innovative thinking by our workforce is a major contributor to how our program is able to accomplish its projects under budget and ahead of schedule on a consistent basis," said OREM manager Jay Mullis.

The DOE is conducting a number of projects to address mercury contamination—the most significant environmental risk is at Y-12, according to the agency. The work includes the cleanout and removal of equipment at Y-12's

Waste Management continues

Alpha-4, a building that was used initially for uranium separation in 1944 and 1945. Ten years later, the building started being used for lithium separation, a process that required large amounts of mercury and involved column exchange (COLEX) equipment. Over the years, a significant amount of mercury from the process leached into the equipment, buildings, and surrounding soils.

Although the COLEX equipment was drained when operations ended at Alpha-4 in the 1960s, recoverable amounts of mercury remained in the aging lines and equipment that had rusted and deteriorated over the decades. Cleanup crews have so far retrieved more than 10,000 pounds of mercury, the DOE announced on January 26. As crews have retrieved the element, it was usually sent off-site to be treated for its subsequent storage.

Recently, instead of being sent to interim storage, a batch of nearly 1,200 pounds was shipped to ORNL after being purified to laboratory-grade quality. It will be used by researchers in an experiment to determine physical properties for liquid metal flow. The data gained from this research will inform models for innovative concepts for material transfer and storage in a variety of fields. ⊠

Crews cleaned and demolished COLEX equipment on the west end of the Alpha-4 building at the Y-12 National Security Complex. Photo: DOE

In Case You Missed It—Waste Management

ANS is urging the NNSA to rethink its "dilute-and-dispose" plan for managing surplus weapons-grade plutonium. In comments submitted to the National Nuclear Security Administration, the American Nuclear Society notes that a better solution for the agency's inventory of surplus plutonium is to convert it to nuclear fuel for advanced reactors, as was originally intended. The comments are in response to a December 16 *Federal Register* notice by the NNSA that it intends to prepare an environmental impact statement on the scope of its Surplus Plutonium Disposition Program, which proposes to dilute and dispose of 34 metric tons of surplus plutonium at the Waste Isolation Pilot Plant in New Mexico.

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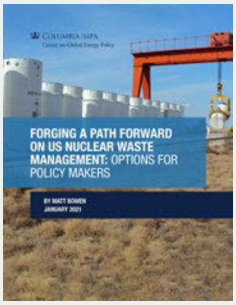
Recommendations for improving U.S. nuclear waste management are offered in a new report out of Columbia University's Center on Global Energy Policy (CGEP). The report, *Forging a Path Forward on U.S. Nuclear Waste Management: Options for Policy Makers*, explains how the United States reached its current stalemate over the disposal of spent nuclear fuel and high-level waste. It then examines productive approaches in other countries, and a few domestic approaches, that could guide policymakers through options for improving the prospects for finding a disposal path for U.S. nuclear waste. The report is available on the CGEP website at energypolicy.columbia.edu.



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Center on Global Energy Policy

FORGING A PATH FORWARD ON US NUCLEAR WASTE MANAGEMENT: OPTIONS FOR POLICY MAKERS

BY MATT BOWEN
JANUARY 2021

For in-depth coverage of these stories and more, see the ANS Newswire at ans.org/news.

ANS student section conducts letter-writing campaign to help save two Illinois nuclear plants

The ANS student section at the University of Illinois–Urbana-Champaign (ANS at UIUC) spearheaded a letter-writing campaign in February aimed at state lawmakers to help in the effort to save the Byron and Dresden nuclear plants in Illinois. Both are scheduled to be prematurely shut down by the end of 2021, Exelon announced last summer.

Following advice from a member of the Illinois Senate, the students decided that a letter-writing campaign would be an effective tool for making an impact on legislators. “On the Internet, you can copy and paste the same message to every representative in the state,” said Anna Balla, the ANS at UIUC external vice president and a senior in the Nuclear, Plasma, and Radiological Engineering (NPRE) Department. “We wanted to make it clear that we are real people with real concerns, and we took time out of our day to write them down. Scribbled-out words and unique handwriting can go a long way to making your message feel personal.”

ANS at UIUC held a virtual meeting on February 3 that began with a primer on the issues surrounding the closures. The second part featured advice on how to write effective letters to legislators. Attendees were then given time to work on their letters while members of the executive committee were there to answer questions. The meeting, which was open to the general public, attracted 45 attendees, including 19 nonmembers.

The plight of the plants has clearly struck a personal chord for the students. “I’m working to save Dresden and Byron because, in addition to the environmental and economic impacts of these closures, it would also be a blow to our nuclear department and the ANS student section as a whole,” said Jimmy Shehee, ANS at UIUC president and a senior in NPRE.

The Byron plant near Rockford, Ill., is one of two plants that Exelon plans to prematurely close in 2021. The Dresden plant in Morris, Ill., is the other. Photo: Christopher Peterson/ Creative Commons

Balla worries about the economic impact that plant closures will have on the surrounding communities, especially in Byron, the hometown of her roommate. She said her roommate's high school was able to provide every student with tablets because of the tax money generated by the plant. "Without the nuclear plant there, I fear that the future generations of Byron students won't have the same resources and opportunities afforded to those before them."

Dilan Kurukulasuriya, the section's outreach coordinator, sees the closings as a loss in the fight against climate change. "Nuclear power is an invaluable ally in the path to a carbon-free society," he said, "and the fact that Illinois is about to throw it away is such a tragedy."

ANS webinar puts focus on low-dose radiation risk

Radiation risk is such a hot topic in the nuclear community that it couldn't be contained to a session at the ANS Virtual Winter Meeting in November, when as many as 60 questions went unanswered due to time constraints.

To address the continued interest in the topic, ANS held a virtual Q&A roundtable in January, "Talking About Low-dose Radiation Risk." It served as a follow-up to the President's Special Session, "Risky Business."

"Radiation is the most misunderstood aspect of nuclear," according to ANS president Mary Lou Dunzik-Gougar. "All applications of nuclear science and technology are impacted by regulations stemming from a lack of understanding of radiation and the misinterpretation of dose limits."

Dunzik-Gougar was joined by panelists Amir A. Bahadori of Kansas State University, Donald A. Cool of the Electric Power Research Institute, Shaheen Dewji of Texas A&M University, and Paul Locke of the Johns Hopkins Bloomberg School of Public Health.

The topics addressed included the following:

- How do we get "reasonable" put back into the implementation of ALARA (as low as reasonably achievable)? What government/industry players must come together to make this happen?
- What can scientists/engineers do to help dispel myths about radiation and nuclear and explain their benefits?
- What can we learn from how other industries manage risk?

"We know much more about the risks of low-dose radiation than we did 50-plus years ago, when dose limits were established," Dunzik-Gougar said. "While we seek to answer the remaining questions, we must revisit the common practices for dose limit implementation. A misguided focus on dose minimization, rather than radiation protection optimization, has unnecessarily burdened the nuclear industry. Let's put 'reasonable' back into ALARA."

ANS members can view the webinar and the President's Special Session on demand at ans.org/webinars.

A 1947 health physics poster from Oak Ridge National Laboratory spoke to a general lack of understanding about radiation. Nearly 75 years later, it's still a misunderstood topic, which ANS addressed during the Virtual Winter Meeting in November and a Q&A webinar in January.

ANS News continues

2021 Student Conference looks to make up for lost time

The COVID-19 pandemic may have derailed the ANS Student Conference last year, but the student organizers at North Carolina State University were eager for another chance to host. They'll get that shot with the 2021 Student Conference, which runs April 8–10. "We put so many hours in as a team to create an awesome conference for students, professors, and industry professionals, and to have it not happen was hard to comprehend initially," said Justin Weinberg, the conference finance cochair. "We [the planning committee] took these roles because we wanted to host a conference. So, at the end of the day, no matter what happened, we know we're still able to fulfill that commitment we made back in 2019."

Keynote speakers at the virtual 2021 Student Conference include Rita Baranwal, vice president of nuclear and chief nuclear officer at EPRI, and Tanya M. Hamilton, senior vice president at Duke Energy.

Of course, hosting a virtual conference is much different than hosting an in-person one, so this year's planning committee faced a challenge—one not unfamiliar to meeting organizers all over the world since the pandemic began. "We learned a lot from previous virtual conferences, such as the ANS Annual and Winter Meetings," said Ishita Trivedi, Student Conference general chair and Ph.D. candidate in nuclear engineering at NC State. "We were able to take most of our technical program and translate to a virtual format with help from the ANS staff. The hardest part was certainly the tours and socials, as we had some very exciting in-person events planned, which are hard to replicate virtually. However, we have a very creative team of people working tirelessly to give our attendees an enjoyable and fulfilling experience."

This year's conference features preconference workshops, technical sessions with at least 23 tracks, a career fair, virtual tours, "Monte Carlo" night, participation in the ANS virtual 5K fun run, and a trivia night to conclude the meeting. "We're excited about our virtual networking and social activities," said Trivedi. "For example, we will be hosting the first Monte Carlo night social, a take on what we do in the discipline, but casino style. The cost of attendance is included with conference registration."

Among the benefits of hosting a virtual meeting are the ability to reach a larger audience and to garner additional participation from professionals, who can attend without having to worry about travel and accommodations. The meeting organizers at NC State are also excited to showcase their own Nuclear Engineering department, which is celebrating its 70th anniversary in 2020–2021. "We have grown from the days of the first nuclear engineering curriculum in the nation to a department that has 25 faculty members with over 300 students in research areas including reactor dynamics and fuel modeling, multiphase research, nuclear materials, probability risk assessment, plasma for life sciences, radiation detection application in nuclear security, and more," said Trivedi. "The 2021 ANS Student Conference will showcase what NC State has to offer around our theme: Enlighten, Embrace, and Empower young nuclear professionals."

Keynote speakers include Rita Baranwal, vice president of nuclear and chief nuclear officer at the Electric Power Research Institute, and Tanya M. Hamilton, senior vice president at Duke Energy.

Visit ans.org/meetings/student2021 for more information and to register now. Questions may be directed to ANS2021StudentConference@ncsu.edu.

New Members

The ANS members and student members listed below joined the Society in January 2021.

Baker, Clark F., Idaho National Laboratory/Advanced Test Reactor
Bartlett, Nathan B., Auburn University
Behringer, Thomas, Sargent & Lundy
Bingham, Benjamin M., Tennessee Valley Authority

Caldwell, Jason, Weather & Water
Case, Rebecca L., Idaho National Laboratory, Battelle Energy Alliance

Gaye, Thomas, Duke Energy Catawba Station

Goh, Jia F., Home Team Science and Technology Agency

Karim, Jordan, Dominion Due Diligence Group
Kissinger, Ryan M., Pacific Northwest National Laboratory

Marro, Ralph J., Huntington Ingalls Industries
Maybee, Mark, NWS Technologies
Miller, Ryan

Nattress, Jason T., Oak Ridge National Laboratory
Neumann, Kyle V., Fluor Marine Propulsion
Nordt, Kevin M., Grant PUD
Nylec, Thomas, Westinghouse

Padgett, James N., Newport News Shipbuilding

Rashidifard, Nasser, Radiation Safety & Control Services
Ryan, William T., Southern Nuclear Company

Spadola, Giuseppe, St. Petersburg College

Treadway, Ryan I., Duke Energy
Trellue, Holly R., Los Alamos National Laboratory

Valaitis, Mark, Five Star Products
Vellon, Bernardo, Jr., Florida Power and Light

STUDENT MEMBERS

Aiken Technical College
Long, Jennifer D.

Colorado State University
Saunders, Clayton S.

Columbia Basin Community College
Snyder, Christopher L.

Excelsior College
Huffman, Kyle R.

Georgia Institute of Technology
Chambers, Kiara Elijah-Ali

Illinois Institute of Technology
Ajmeri, Aftab S.

Kennesaw State University
Fordham, John T.

Louisiana State University
Templeton, Colin

Massachusetts Institute of Technology
Sesler, Jefferson B.

North Carolina State University
Isler, Kyle

Ohio State University
Sarici Turkmen, Gulcin

Pennsylvania State University
Jerry, Chance

Polytechnic University of Turin (Italy)
Valerio, Domenico

Purdue University
Abrams, Oliver
Daudish, Mary F.
Yu, Haoxuan

Texas A&M University
Gamez, Christopher M.
Le, Chi Vu Thien

Texas Tech University
Clark, Raimi

Three Rivers Community College
Chenail, Devin R.
McEntee, Dane T.
Williams, Christopher M.

United States Naval Academy
Buckman, William T.
Farnan, Elizabeth
Toriano, Nelsene C.

University of Alabama–Tuscaloosa
Paul, Shiddartha

University of California–Berkeley
Amezcua, Esteban
Nelson, Malachi
Wilson, Miles

University of Florida
Lucas, Virginia
Snyder, Bradley J.

University of Idaho
Quinones, Luis A.

University of Illinois–Urbana-Champaign
Alkhatib, Sari
Hunter, Amber
Seifert, Luke

University of Maryland–College Park
Shen, Joy

University of Massachusetts–Lowell
Nikolopoulos, Vasilios K.

University of Michigan
Schoenwald, Julianna L.

University of New Mexico
Allen, Sean
Cakez, Cemal

University of South Carolina
Howard, Caroline G.

University of Tennessee–Knoxville
Cagle, Jackson C.
Payne, Trentin D.

University of Utah
Schulzke, Christoph

Utah State University
Mansfield, Colton
Smith, Jackson

Virginia Commonwealth University
Chadwick, Arthur E.
Hegge, William J.

Virginia Polytechnic Institute
Shakhatreh, Abdulsalam I.

Washington State University
Senk, Michael D.

NOTE: *Nuclear News* publishes news about nuclear industry contracts—but only about contract awards. We generally do not publish announcements that the work is underway or announcements that the work has been completed. Send your new contract award announcements to: Industry Editor, *Nuclear News*, 555 N. Kensington Ave., La Grange Park, IL 60526; fax 708/579-8204; email nucnews@ans.org.

BUSINESS DEVELOPMENTS

U.K. Space Agency, Rolls-Royce launch study into nuclear-powered space exploration

The **U.K. Space Agency** and **Rolls-Royce** are joining forces to conduct a study into how nuclear technologies could be used for space exploration. This new research contract, which was announced on January 12, will see planetary scientists working together to explore the potential of nuclear power as a plentiful source of energy, capable of making possible deeper space exploration in the decades to come.

■ **UniTech Services Group** has been awarded a basic ordering agreement by the Department of Energy's Office of Environmental Management. The agreement enables UniTech to conduct low-level and mixed low-level waste receiving, handling, and treatment services at Environmental Management cleanup sites. Following the December 3 announcement of the agreement, UniTech officially launched decommissioning support services to current and future nuclear reactor decommissioning sites in the United States. Waste received by UniTech will be processed at the company's Oak Ridge Service Center in Oak Ridge, Tenn.

■ **Lightbridge Corporation**, an advanced nuclear fuel technology company, announced on December 24 that it has received a patent from the Eurasian Patent Office for its innovative nuclear fuel assemblies, comprising multi-lobe fuel rods arranged in a mixed grid pattern. Lightbridge is developing its advanced metallic fuel designed to make both existing and new nuclear power plants more efficient, more cost competitive, and even safer.

CONTRACTS

Design contract secured for Dounreay waste repackaging facility

The **Dounreay Decommissioning Framework Alliance**, led by **Cavendish Nuclear** and supported by **KDC Contractors** and **BAM Nuttall**, has been awarded a contract for the design of a new waste repackaging facility at the Dounreay nuclear site, Cavendish announced on January 13. The program of work is expected to run until early 2022 and forms part of Dounreay Site Restoration Limited's decommissioning services framework. The contract is for the concept and design of a new waste repackaging processing facility, which will support delivery of the site's waste strategy and decommissioning program.

■ Bruce Power has awarded **Candu Energy**, a member of the **SNC-Lavalin Group**, one-year extensions of two existing contracts. Candu Energy will continue to provide fuel channel inspection and tooling maintenance and refurbishment services. Under the extended contracts, SNC-Lavalin will support Bruce Power in executing three fuel channel inspection outages as part of the station's regular outage schedule in 2021.

■ **Battelle Savannah River Alliance** (BRSA) has been selected by the Department of Energy to manage **Savannah River National Laboratory**. The contract includes a five-year base with five one-year options. The estimated value of the contract is $3.8 billion over the course of 10 years if all options are exercised. BSRA, which is led by and wholly owned by Battelle, includes five universities from the region—Clemson

University, the Georgia Institute of Technology, South Carolina State University, the University of Georgia, and the University of South Carolina—as well as small business partners Longenecker & Associates and TechSource.

■ U.S.-based **DuBose National Energy Services** has been awarded a master distributorship for North America to sell **Razor Ribbon** products. Razor Ribbon products have been showcased at recent national security and energy summits and represent a line of products that provide enhanced perimeter security protection for use in the most secure and restricted environments.

ADVANCED REACTOR MARKETPLACE

UAMPS picks Fluor for SMR development and design work

Fluor Corporation announced on January 11 that **Utah Associated Municipal Power Systems** (UAMPS) has awarded the company a cost-reimbursable development agreement to provide estimating, development, design, and engineering services for its Carbon-Free Power Project. The Department of Energy recently provided UAMPS a multiyear cost-share award for up to $1.355 billion in funding, subject to future year appropriations, to aid in the development of the first small modular nuclear reactor project in the United States. The DOE funding is intended to mitigate licensing and financial risk and to accelerate commercial deployment schedules in order to meet critical U.S. energy, environment, and economic goals.

■ **BWX Technologies** (BWXT) has been selected by the Department of Energy to lead a $106.6 million microreactor development project. The DOE is contributing $85.3 million to the cost-share project over seven years, with BWXT funding the remaining amount. The company's BWXT Advanced Nuclear Reactor program will pursue the development of a transportable microreactor, with the design focused on advanced TRISO fuel particles to achieve higher uranium loading and improved fuel utilization. TRISO refers to a specific design of uranium nuclear reactor fuel that has many operational and safety benefits.

Standards approved

The following standards have been approved:

- ANSI/ANS-15.2–1999 (R2021), *Quality Control for Plate-Type Uranium-Aluminum Fuel Elements* (reaffirmation of ANSI/ANS-15.2–1999 [R2016]).

This standard sets forth general requirements for the establishment and execution of a program designed to verify that the quality of plate-type uranium-aluminum fuel elements being purchased for research reactors conforms to the requirements of the contract and applicable technical documents, including specifications, standards, and drawings.

- ANSI/ANS-57.10–1996 (R2021), *Design Criteria for Consolidation of LWR Spent Fuel* (reaffirmation of ANSI/ANS-57.10–1996 [R2016]).

This standard provides design criteria for the process of consolidating light-water reactor spent nuclear fuel in either a wet or a dry environment. It addresses processes for consolidating fuel horizontally or vertically. The standard sets forth requirements for utilizing equipment and systems to perform consolidation, handle fuel rods and non-fuel-bearing components, and handle broken fuel rods. The standard also contains requirements for facility or installation interfaces, nuclear safety, structural design, thermal design, accountability, safeguards, decommissioning, and quality assurance. The standard is not concerned with the storage of the spent fuel either before or after the consolidation process. These areas are covered in the following American National Standards: ANSI/ANS-57.2–1992, *Design Requirements for Light Water Reactor Spent Fuel Facilities at Nuclear Power Plants*; ANSI/ANS-57.7–1992, *Design Criteria for an Independent Spent Fuel Storage Installation (Water Pool Type)*; and ANSI/ANS-57.9–1992, *Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type).*

Standard published

- ANSI/ASME/ANS-RA-S-1.4–2021, *Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants* (new standard).

This standard states requirements for a probabilistic risk assessment (PRA) for advanced non-light-water reactor nuclear power plants. The requirements in this standard were developed for a broad range of PRA scopes that may include the following:

(a) Different sources of radioactive material both inside and outside of the reactor but within the boundaries of the plant whose risks are to be determined within the PRA scope selected by the user.

(b) Different plant operating states, including various levels of power operation and shutdown modes.

(c) Initiating events caused by internal hazards, such as internal events, internal fires, and internal floods; and external hazards, such as seismic events, high winds, and external flooding. The only hazards explicitly excluded from the scope are releases resulting from purposeful human-induced security threats (e.g., sabotage, terrorism).

(d) Different event sequence end states, including those with no adverse consequences, plant damage states (PDSs), and release categories that are sufficient to characterize mechanistic source terms, including releases from event sequences involving two or more reactors or radionuclide sources.

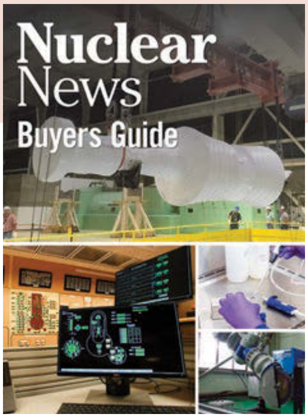
(e) Evaluation of different risk metrics, including the frequencies of modeled PDSs, event sequence families, release categories, risks of off-site radiological exposures and health effects, and the integrated risk of the multi-reactor plant as defined by the selected PRA scope. The risk metrics supported by this standard are established metrics used in existing LWR Level 3 PRAs such as frequency of radiological consequences (e.g., dose, health effects) that are independent of reactor technology. Surrogate risk metrics used in LWR PRAs, such as core damage frequency and large early release frequency, are not applicable to many non-LWR designs and are not used in this standard.

(f) Quantification of the event sequence frequencies, mechanistic source terms, off-site radiological consequences, risk metrics, and associated uncertainties, and using this information to support risk-informed decisions in a manner consistent with the scope and applications PRA.

Volunteer support needed

The following standards projects are in need of volunteer support. Interested individuals should contact standards@ans.org for more information.

- ANS-2.32, *Guidance on the Selection and Evaluation of Remediation Methods for Subsurface Contamination* (development of new standard).
- ANS-2.35, *Guidelines for Estimating Present and Projecting Future Socioeconomic Impacts from the Construction, Operations, and Decommissioning of Nuclear Sites* (development of new standard).
- ANS-8.14, *Use of Soluble Neutron Absorbers in Nuclear Facilities Outside Reactors* (revision of ANSI/ANS-8.14–2004 [R2016]).
- ANS-56.1, *Containment Hydrogen Control* (development of new standard).
- ANS-56.2, *Containment Isolation Provisions for Fluid Systems After a LOCA* (historical revision of ANS-56.2–1989 [W1999]).



Shutting down all of Japan's nuclear plants after Fukushima was a bad idea

By James Conca

By now, more Japanese have died from the closing of Japan's nuclear power plants following the 2011 Tohoku earthquake than from the tsunami and the quake combined. Of course, no one has died from any radiation released from the Fukushima Daiichi nuclear power plant, and no one ever will. There just wasn't enough dose to anyone.

These conclusions are now echoed across the scientific and medical communities. A study by Matthew Neidell, Shinsuke Uchida, and Marcella Veronesi discusses how after the Fukushima Daiichi nuclear accident, when all nuclear power stations ceased operation and nuclear power was replaced by fossil fuels, there was a significant increase in electricity prices and in public mortality.

The increase in price led to a reduction in energy consumption, which caused an increase in mortality during very cold temperatures. An increase in mortality also occurred from the burning of fossil fuels, especially coal, which can cause upper respiratory effects. The estimate of these combined mortalities outnumbers the mortality from the tsunami and earthquake themselves, suggesting that the knee-jerk decision to cease nuclear production was a very bad idea.

Most of Japan's nuclear plants, like Tomari, shown here, were never at risk from earthquakes or tsunamis. The decision to shut them down following the Tohoku quake and replace their generation with coal, oil, and gas was a very bad idea and has resulted in many more deaths than the tsunami itself. Source: Mugu-shisai

The immediate urge to shut down all Japanese nuclear reactors for the years since the event was understandable, but only 15 out of Japan's 54 reactors were at risk from tsunamis. Shutting down these reactors was reasonable in order to determine how to make them more resistant to this particular threat.

The reactors that were not at risk should have continued operating during the safety review following the accident, during the formation of the new nuclear regulatory authority, and during development and implementation of the new safety measures.

Closing all of the reactors at once caused energy imports to rise to 85 percent of Japan's energy requirements, increasing the use of coal, oil, and gas dramatically, along with their demonstrably worse health effects. The combined costs of this error will amount to several hundred billions of dollars by the time the nuclear fleet is restarted.

But few regarded the more indirect environmental and human health effects of increasing the use of fossil fuels to replace the nuclear power.

As Columbia University professor David Weinstein put it, "If Japan had decided to keep all [unaffected] nuclear reactors open in 2012 and had met its energy needs by proportionally reducing coal, oil, LNG, and other energy sources, I estimate that this policy would have saved 9,493 lives, based on the air pollution of that year alone."

The disaster at the Fukushima Daiichi power plant following the devastating tsunami in Japan on March 11, 2011, has proven costly in many ways—politically, economically, and emotionally. Strangely, the costs that were the most feared—radiation-induced cancer and deaths—never materialized. No radiological health effects have resulted, or will result, from the Fukushima disaster—not cancers, deaths, or radiation sickness. No one received a high enough dose, not even the 20,000 workers who have worked tirelessly to recover from this event.

The direct costs of the Fukushima disaster will be about $15 billion in cleanup over the next 20 years and more than $60 billion in refugee compensation.

As big as these numbers are, the reconstruction and recovery costs associated with the earthquake and the tsunami, not including the reactors, will top $250 billion. Since Japan shuttered its nuclear fleet, its trade deficit has become the worst in its history, and Japan is now the second largest net importer of fossil fuel in the world, right behind China.

In all fairness, it was the largest tsunami in history to hit the world's most densely populated industrialized country.

On that day, a magnitude 9.0 earthquake on the Tohoku Fault off the east coast of Japan sent a 50-foot tsunami crashing into the coast with almost no warning, flooding more than 500 square miles of land, killing almost 20,000 people, destroying a million homes and businesses, and making 300,000 people homeless.

When the earthquake hit the region around Fukushima, 11 operating nuclear reactors at four power plants all shut down automatically. None were damaged by the earthquake itself. However, the inadequate seawall surrounding the six reactors at Tokyo Electric Power Company's Fukushima Daiichi plant allowed the tsunami to inundate the plant and destroy the backup generating systems and the electrical switchgear necessary to maintain cooling. Four reactors were destroyed, and 940 petabecquerels of fission products and radioactive material were dispersed into the air.

By March 13, 150,000 people were ordered to evacuate from within 20 kilometers of the nuclear plant. This was very effective in preventing any and all radiation-induced health effects among the public. However, more than 1,600 deaths were caused solely by the evacuation, not by radiation, the earthquake, or the tsunami. They did not need to be so hurriedly evacuated.

Opinion continues

The only health effects suffered from the reactor meltdowns continue to be from stress, depression, and fear.

Before the accident, Japan's nuclear fleet had provided 30 percent of the country's electricity needs, but within 14 months of the accident Japan's nuclear generation was brought to a standstill pending regulatory change. Nine units have been restarted, while 17 reactors are currently in the process of gaining restart approval.

The United Nations Scientific Committee on the Effects of Atomic Radiation found that there had been no deaths, and probably never will be, from radiation that escaped from Fukushima.

We have been trying for decades to convince the governments of the world and their populations that fear-driven overreaction to radiation has more severe consequences than the radiation itself. The noise from non-scientists and ideologues, however, drowns out the science, so the public doesn't know what to believe.

I don't know what to do when support of science begins to crumble in those societies where it was always strong. We should be very concerned.

James Conca is a scientist in the field of the earth and environmental sciences, specializing vin geologic disposal of nuclear waste, energy-related research, planetary surface processes, radiobiology and shielding for space colonies, and subsurface transport and environmental cleanup of heavy metals. Conca also writes about nuclear, the environment, and energy for Forbes; you can view his stories online at forbes.com/sites/jamesconca.

Connery

Joyce Connery, ANS member since 2012, has been appointed chair of the Defense Nuclear Facilities Safety Board (DNFSB) by President Biden. Connery has been a member of the board since August 2015. She was reconfirmed by the Senate to serve on the DNFSB on July 2, 2020, for a term expiring on October 18, 2024. Connery previously held the chairmanship from August 2015 to January 2017.

Slaybaugh

The Department of Energy's Lawrence Berkeley National Laboratory has named **Rachel Slaybaugh**, ANS member since 2003 and associate professor of nuclear engineering at the University of California–Berkeley, to lead the lab's Cyclotron Road Division. Prior to coming to Berkeley, Slaybaugh served as a program director for the DOE's Advanced Research Projects Agency–Energy (ARPA-E), whose mission is to advance high-potential and high-impact energy technologies. From 2017 through 2020, Slaybaugh led ARPA-E programs supporting research in advanced nuclear fission reactors, agriculture technologies, and sensing and data analytics.

Moore

Retired Navy Vice Adm. **Thomas Moore** has been named vice president of nuclear operations for Huntington Ingalls Industries' (HII's) Nuclear and Environmental Services business group. Moore will be responsible for the oversight of all nuclear operations activities for the Technical Solutions Division's Department of Energy portfolio. Prior to joining HII, Moore served for 39 years in the U.S. Navy, retiring in August 2020 as commander of the Naval Sea Systems Command.

Veil

The Nuclear Regulatory Commission has named **Andrea D. Veil** acting director of its Office of Nuclear Reactor Regulation (NRR). She replaces **Ho Nieh**, who left the position in January. Veil joined the agency as an intern in 1992, holding increasingly responsible positions in various offices. In 2019, she was appointed NRR deputy office director, and later that year, she was appointed deputy office director for engineering at NNR, her most recent position.

Cooper

Eiden

Wilson

Sargent & Lundy recently announced the appointments of three senior vice presidents and seven vice presidents. **Matthew Cooper, Paul Eiden**, and **Alan Wilson** were named senior vice presidents. Cooper is a senior director supporting Sargent & Lundy's nuclear energy projects. Eiden is a senior director for Sargent & Lundy's energy and industrial projects and is also leading the company's hydrogen energy program. Wilson, a senior project director supporting Sargent & Lundy's nuclear energy projects, has managed projects for several nuclear power plants across the United States.

The following were named vice presidents: **Chris Blansit**, a director for electric grid infrastructure projects; **Michael Breisch**, a director for nuclear energy projects; **Mike Flanagan**, a director for nuclear energy projects; **Steve Fogarty**, a director for Sargent & Lundy's government services projects; **Sang Gang**, a director for energy consulting projects; **Nelson Rosado**, a director for energy and industrial projects; and **John Szabados**, a director for electric grid infrastructure projects.

People continues


Hunt

The Nuclear Regulatory Commission has named **Christopher Hunt** the new senior resident inspector at the Quad Cities nuclear power plant in Cordova, Ill. The plant is operated by Exelon Generation. Hunt joined the agency in 2010 as a reactor technical reviewer in the NRC's Office of Nuclear Reactor Regulation. He came to the Region III office as a reactor engineer in 2014. Most recently, he was a resident inspector at the Byron plant in Byron, Ill. **Nicholas Karlovich** has been named the new resident inspector at the Browns Ferry plant in Athens, Ala. The three-unit plant is operated by the Tennessee Valley Authority. Karlovich joined the agency in 2008. After completing an extensive training program, he worked as a region-based construction inspector. He then was a construction resident inspector at Watts Bar-2, Summer-2 and -3, and Vogtle-3 and -4. **Noe Cuevas** has been selected as the new resident inspector at the Palo Verde plant in Tonopah, Ariz. Cuevas joined the NRC in June after serving in the U.S. Navy as a nuclear shift test engineer.


Karlovich

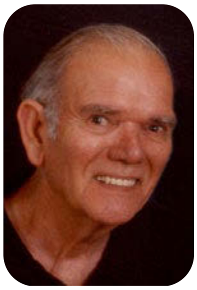
Obituaries


Naughton

William F. Naughton, 76, ANS member since 1973; received a bachelor's degree in electrical engineering from Manhattan College in 1965 and a master's degree and Ph.D. in nuclear engineering from Pennsylvania State University in 1968 and 1972, respectively; joined Commonwealth Edison, where he worked in various positions in nuclear licensing; later positions included nuclear fuel services manager, director of engineering performance, director of strategic licensing policies, program manager of fuels, and director of research and development; when ComEd was acquired by Exelon Nuclear, he was general manager of research and development for its 17 nuclear units until he retired at age 70; died April 23, 2020, from complications of the COVID-19 virus and Alzheimer's disease.


Boyd

Frederick C. Boyd, 93, ANS member since 1960; obtained a bachelor's degree in engineering physics in 1949; after a stint doing seismic exploration in Canada, took a job with Eldorado Mining and Refining, working on the world's first cobalt-60 radiation therapy machines; oversaw the installation of the first machine in London, Ontario, in 1951 and the next three in Italy, England, and the United States; joined the original group at Canadian General Electric designing the first CANDU nuclear power plant; in 1960, became the first nuclear safety official with the Atomic Energy Control Board (AECB), now the Canadian Nuclear Safety Commission; coauthored the first Canadian reactor safety requirements; in the mid-1970s, took on the role of nuclear energy advisor at the Department of Energy, Mines and Resources, as well as a nine-month posting in Korea on behalf of the International Atomic Energy Agency; upon return from Korea, rejoined the AECB, heading a group providing training and advice to countries starting nuclear programs; retired from the AECB in 1989; was a fellow of the Canadian Nuclear Society; died May 10, 2020.


Farrar

J. Preston Farrar Sr., 88; graduated from Lynchburg College with a degree in physics and mathematics; worked as a nuclear physicist at the Babcock & Wilcox Company and held senior reactor operator licenses on four critical experiments, a 1-MWe research reactor, and a 6-MWe test reactor; helped supervise startup of Indian Point reactor; in 1966, joined the

University of Virginia, where he was reactor administrator at UVA's nuclear research reactor facility for more than 31 years; was a member of the American Nuclear Society's ANS-15 Committee, which developed standards for the operation of nuclear research reactors; died October 8, 2020.

McCormack

Claude Gilbert "Mike" McCormack, 98, ANS Fellow and member since 1968; earned a master's degree in physical chemistry in 1949 from Washington State University; in 1950, was hired as a research scientist for the Atomic Energy Commission at the Hanford Site near Richland, Wash.; was elected to the Washington State Legislature in 1956 and to the Washington State Senate in 1960; in 1970, was elected to the U.S. House of Representatives, representing the Fourth District of Washington State, where he served until 1981; while serving as chairman of the House Science and Technology Committee's Subcommittee on Energy, sponsored successful legislation in solar energy, electric and hybrid vehicles, nuclear safety, and research and development for fusion-powered electric production; emphasized nuclear fusion during his career, repeatedly stating that the successful demonstration of a nuclear fusion device to produce electricity would be the most important event in human history since the discovery of fire; died November 7, 2020.

Direct Answer

Index to Advertisers

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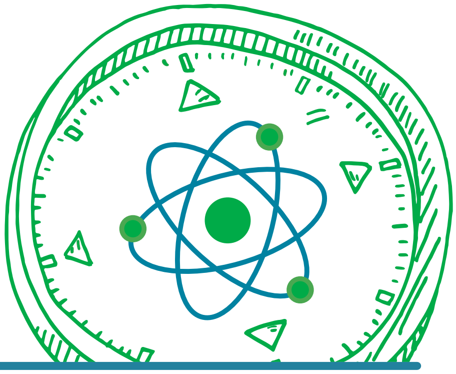

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Calendar

● First time listed or significant change made
✖ Meeting canceled or postponed;
see listing for details

● ■ ANS event
● ■ Non-ANS event cosponsored by ANS

March

Mar. 8–12—**WM Symposia 2021**, virtual meeting. wmsym.org

Mar. 16–18—**EURAD 1st Annual Event**, virtual meeting. ejp-eurad.eu/events/eurad-1st-annual-event

Mar. 24–25—**Nuclear Engineering for Safety, Control and Security**, virtual meeting. events2.theiet.org/nuclear/about.cfm

April

✖ Apr. 3–8—**12th International Conference on Methods and Applications of Radioanalytical Chemistry (MARC XII)**, Kailua-Kona, Hawaii. marcconference.org
Meeting has been postponed until April 2022

■ Apr. 8–10—**ANS Student Conference**, virtual meeting. ans.org/meetings/student2021

✖ Apr. 11–15—**International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering (M&C 2021)**, Raleigh, N.C. mc.ans.org
Meeting has been rescheduled to October 2021

Apr. 20–21—**Nuclear Decommissioning and Waste Management 2021**, virtual meeting. virtual.prosperoevents.com/nuclear-decommissioning-and-waste-management

May

✖ May 3–7—**Atalante 2021**, Nimes, France. atalante2020.org/index.html
Meeting has been canceled

May 10–15—**28th IAEA Fusion Energy Conference (FEC 2020)**, virtual meeting. iaea.org/events/fec-2020

✖ May 15–18—**The Society for Radiological Protection Annual Conference**, Bournemouth, UK. srp-uk.org/events/2021AnnualConference
Meeting has been combined with the 2021 annual conference, occurring July 5–8, 2021

May 17–21—**ICG-EAC Annual Meeting 2021**, virtual meeting. icg-eac.org/event/icg-eac-annual-meeting-2021

May 18–20—**Power Uzbekistan 2021**, Tashkent, Uzbekistan. power-uzbekistan.uz/ru/index.php

✖ May 23–26—**7th International Conference on Nuclear and Renewable Energy Resources (NURER2020)**, Ankara, Turkey. nurer2020.org
Meeting has been postponed until 2022

June

● June 1–2—**Nuclear Power Plants Expo & Summit**, virtual meeting. nuclearpowerplantsexpo.com

June 2–4—**HTR 2021: International Conference on High Temperature Reactor Technology**, Yogyakarta, Indonesia. htr2020.org

June 6–9—**40th Annual CNS Conference/45th Annual CNS/CNA Student Conference**, virtual meeting. cns-snc.ca/events/annual/

June 7–9—**European Cooperative Group on Corrosion Monitoring of Nuclear Materials (ECG-COMON) Annual Meeting 2021**, Villigen, Switzerland. ecg-comon.org/meetings/ecgcomon-meeting-2021

June 7–11—**3rd International Conference on Nuclear Photonics (NP2020)**, virtual meeting. photon.osaka-u.ac.jp/NP2020Kurashiki/

June 8–10—**Nordic Nuclear Forum**, Helsinki, Finland. nordicnuclearforum.fi

June 9–11—**16th IAEA-FORATOM Joint Event on Management Systems—International Forum on Enhancing a Sustainable Nuclear Supply Chain**, Helsinki, Finland. events.foratom.org/mstf2021/

✖ June 9–11—**NUWCEM 2021: International Symposium on Cement-Based Materials for Nuclear Wastes**, Avignon, France. sfen-nuwcem2021.org
Meeting has been rescheduled to September 15–17, 2021

■ June 13–16—**2021 ANS Annual Meeting**, Providence, R.I. ans.org/meetings

■ June 13–17—**12th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC&HMIT 2021)**, Providence, R.I. ans.org/meetings

June 21–25—**12th International Conference on Clustering Aspects of Nuclear Structure and Dynamics**, Dubna, Russia. indico.jinr.ru/event/1026/overview

June 23–24—**Maintenance in Power Plants 2021**, Karlsruhe, Germany. vgb.org/en/instandhaltung_kraftwerken2021.html

June 29–July 1—**RICOMET 2021**, Athens, Greece. sckcen.be

July

July 5–8—**The Society for Radiological Protection Annual Conference**, Bournemouth, U.K. srp-uk.org/events/2021AnnualConference

July 12–16—**ASME Pressure Vessels and Piping Conference (PVP 2021)**, virtual meeting. event.asme.org/PVP

July 19–23—**2021 IEEE Nuclear and Space Radiation Effects Conference (NSREC)**, Ottawa, Ontario, Canada. nsrec.com/nsrec_2021.html

July 20–22—**Power 2021**, virtual meeting. event.asme.org/POWER

July 21–22—**Enlit Australia**, Melbourne, Australia. enlit-australia.com

July 28–30—**48th Annual Review of Progress in Quantitative Nondestructive Evaluation**, virtual meeting . event.asme.org/QNDE

August

Aug. 3–5—**13th Annual Nuclear Deterrence Summit**, Alexandria, Va. exchangemonitor.com/events/nuclear-deterrence-summit/

Aug. 4–6—**28th International Conference on Nuclear Engineering (ICONE 28)**, virtual meeting. event.asme.org/ICONE

■ Aug. 8–11—**Utility Working Conference and Vendor Technology Expo**, Marco Island, Fla. ans.org/meetings/view-351/

Aug. 23–Sep. 3—**International School of Nuclear Law (ISNL)**, Montpellier, France. oecd-nea.org/law/isnl

Aug. 25–27—**KONTEC 2021**, Dresden, Germany. kontec-symposium.com/

■ Aug. 29–Sep. 3—**2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2021)**, Columbus, Ohio. psa.ans.org/2021

September

● Sept. 8–10—**World Nuclear Association Symposium 2021**, London, United Kingdom. wna-symposium.org/

● Sept. 12–16—**14th International Conference on Radiation Shielding and 21st Topical Meeting of the Radiation Protection and Shielding Division (ICRS 14/RPSD-2021)**, Seattle, Wash. ans.org/meetings/icrs14rpsd21/

● Sept. 13–15—**International Conference on Decommissioning Challenges: Industrial Reality, Lessons Learned and Prospects**, Avignon, France. sfen-dem2021.org/

● Sept. 15–17—**NEWCEM 2021: International Symposium on Cement-Based Materials for Nuclear Wastes**, Avignon, France. sfen-nuwcem2021.org/

● Sept. 21–22—**Advanced Clean Energy Summit (ACES 2021)**, virtual event. event.asme.org/ACES

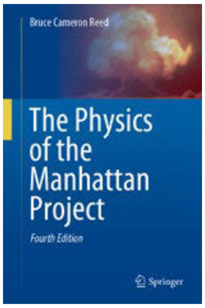
● Sept. 23–24—**Valve World Expo & Conference Asia 2021**, Shanghai, China. valve-world.net/vwa2021/valve-world-asia-2021.html

● Sept. 27–Oct. 1—**NPC 2021: International Conference on Nuclear Plant Chemistry**, Antibes, France. sfen-npc2021.org/

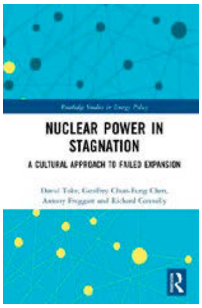
● Sept. 28–30—**Enlit Asia**, Jakarta, Indonesia. enlit-asia.com/

Publications

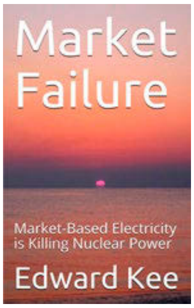
Recently Published



The Physics of the Manhattan Project, 4th ed., by Bruce Cameron Reed. The development of nuclear weapons during the Manhattan Project is one of the most significant scientific events of the 20th century. Revisions to this book, the fourth edition, include many upgrades and new sections. Improvements are made to, among other things, the analysis of the physics of the fission barrier, the time-dependent simulation of the explosion of a nuclear weapon, and the discussion of tamped bomb cores. New sections cover, for example, composite bomb cores, approximate methods for various of the calculations presented, and the physics of the polonium-beryllium "neutron initiators" used to trigger the bombs. An extensive list of references and a number of exercises for self-study are included. (256 pp., HB, $79.99, ISBN 978-3-030-61372-3; order through Springer International Publishing: springer.com/gp/)



Nuclear Power in Stagnation: A Cultural Approach to Failed Expansion, by David Toke, Geoffrey Chun-Fung Chen, Antony Froggatt, and Richard Connolly. This book studies the extent to which nuclear safety issues have contributed to the stagnation of nuclear power development around the world and accounts for differences in safety regulations in different countries. In order to understand why nuclear development has not met widespread expectations, this book focuses on six key countries with active nuclear power programs: the United States, China, France, South Korea, the United Kingdom, and Russia. The authors integrate cultural theory and theory of regulation and examine the links between pressures of cultural bias on regulatory outcomes and political pressures that have led to increased safety requirements vand subsequent economic costs. The findings reveal that differences in the strictness of nuclear safety regulations between countries can be understood by understanding differences in cultural contexts and the changes in this over time. (188 pp., HB, $160, ISBN 978-1-138-34119-7; order from Routledge: routledge.com)



Market Failure: Market-Based Electricity is Killing Nuclear Power, by Edward Kee. This book explains why a market-based electricity industry is killing existing nuclear power plants and stopping new nuclear power plants. Electricity industry reforms have led to the early closure of existing nuclear power plants and stopped new nuclear power development. In the market approach to electricity, short-term electricity market prices set the value of commodity electricity, electricity prices define power plant value, and private companies develop and own power plants based on financial returns. This market approach leads to less nuclear power, with the loss of the considerable public benefits that nuclear power provides. This book includes information on the nuclear power and electricity industries, market failure in the nuclear power industry, and some ideas about resolving this market failure. (162 pp., PB, $39.99, ISBN 1-73236-441-9; order from the Nuclear Economics Consulting Group: nuclear-economics.com/32-market-failure-the-book)

Proceedings Available

The Consortium for Advanced Simulation of Light Water Reactors Virtual Meeting, held November 16–19, 2020, is the topic of the first proceedings published by ANS since the COVID-19 pandemic began. The meeting took place during the ANS Virtual Winter Meeting, and was organized by Scott Palmtag and David Kropaczek. CASL was founded in July 2010 by the Department of Energy as an Energy Innovation Hub with the mission to develop, apply, and deploy advanced modeling and simulation (M&S) technologies to address operational and safety performance challenges impacting the performance of the light-water reactor fleet. The proceedings celebrates the completion of Hub activities and fulfillment of the CASL vision with over 80 papers covering all aspects of the CASL program. Access to this proceedings is available only through a subscription or through ANS membership: epubs.ans.org/?p=proc:3090t; email askanything@ans.org with inquiries.

ANS Technical Journals

FUSION SCIENCE AND TECHNOLOGY • FEBRUARY 2021

Application of Pt-Loaded Honeycomb Catalysts in Air Detritiation *Q. Wu et al.*

A Numerical Simulation for Fusion Reaction in Tokamak D-T Plasma *B. Zeng et al.*

A Framework for International Collaboration on ITER Using Large-Scale Data Transfer to Enable Near-Real-Time Analysis *R. M. Churchill et al.*

A Nodal Model for Tokamak Burning Plasma Space-Time Dynamics *W. M. Stacey*

Cost Drivers for a Tokamak-Based Compact Pilot Plant *M. W. Wade, J. A. Leuer*

Numerical Simulation of Thin-Film MHD Flow for Nonuniform Conductivity Walls *S. Siriano et al.*

Multiphysics Simulations of a Steady-State Lower Hybrid Current Drive Antenna for the FSNF *G. M. Wallace et al.*

NUCLEAR SCIENCE AND ENGINEERING • MARCH 2021

Generation of the Thermal Scattering Law of Uranium Dioxide with Ab Initio Lattice Dynamics to Capture Crystal Binding Effects on Neutron Interactions *J. L. Wormald et al.*

Calculations and Evaluations of the $n+{}^{48}$Ti Reaction Below 200 MeV *X. Su et al.*

Modeling Reactor Noise due to Rod and Thermal Vibrations with Thermal Feedback Using Stochastic Differential Equations *C. Dubi, R. Atar*

Preliminary Study on the Application of Vortex Diodes in Fast Neutron Reactors *H. Yang et al.*

A High-Assay Low-Enriched Uranium Fuel Transportation Concept *E. Eidelpes et al.*

Nuclear Criticality Safety Aspects for the Future of HALEU: Evaluating Heterogeneity in Intermediate-Enrichment Uranium Using Critical Benchmark Experiments *J. A. Christensen, R. A. Borrelli*

Assessment of Critical Experiment Benchmark Applicability to a Large-Capacity HALEU Transportation Package Concept *R. A. Hall et al.*

Secondary-Source Core Reload Modeling with VERA *C. Gentry et al.*

NUCLEAR TECHNOLOGY • MARCH 2021

This special issue features 12 selected papers from the 2019 International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2019)

Modeling Hydrogen Explosion in Level 1 PSA *J. Beaucourt, G. Georgescu*

Operator Action–Induced Two-Phase Flow Condition Resulting in Performance Degradation of Interfacing Passive System *D. A. Fynan, J. Park*

Extension of a Level 2 PSA Event Tree Based on Results of a Probabilistic Dynamic Safety Analysis of Induced Steam Generator Tube Rupture *S. Johst et al.*

Mutual Integration of Classical and Dynamic PRA *D. Mandelli et al.*

Dynamic PRA-Based Estimation of PWR Coping Time Using a Surrogate Model for Accident Tolerant Fuel *R. Christian et al.*

Dynamic PRA Methods to Evaluate the Impact on Accident Progression of Accident Tolerant Fuels *D. Mandelli et al.*

Reevaluating the Current U.S. Nuclear Regulatory Commission's Safety Goals *V. Mubayi, R. Youngblood*

Technical Evaluation of the Margins Between Established Risk Goals and Health Objectives for Nuclear Power Plants *F. Ferrante, S. Lewis*

Understanding and Effectively Managing Conservatisms in Safety Analysis of Nonreactor Nuclear Facilities *M. Modarres et al.*

State-of-the-Art Reactor Consequence Analyses Project: Uncertainty Analyses for Station Blackout Scenarios *S. T. Ghosh et al.*

Use of Risk Insights in the Practical Implementation of an Integrated Risk-Informed Decision-Making Framework *F. Ferrante et al.*

A Novel Approach to Realistic Conservatism in Nuclear Criticality Safety Analysis *R. B. Hayes*

What did Fukushima teach us about public communication?

The challenge that the Fukushima Daiichi accident presented went beyond public communication. It was crisis communication to an audience with little baseline knowledge. The situation on the ground immediately after March 11, 2011, was murky at best, and information was constantly changing as events evolved. Different time zones hampered communication, and language and cultural barriers added to the confusion. Very few reporters had a sound understanding of energy, let alone nuclear energy technology. We saw incorrect images in print and broadcast media, and experts' explanations often generated more misunderstanding than clarity.

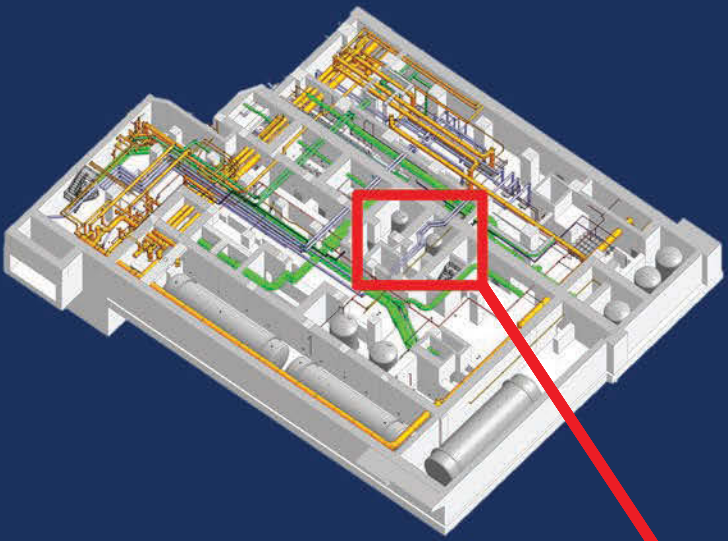
So what did we learn from this?

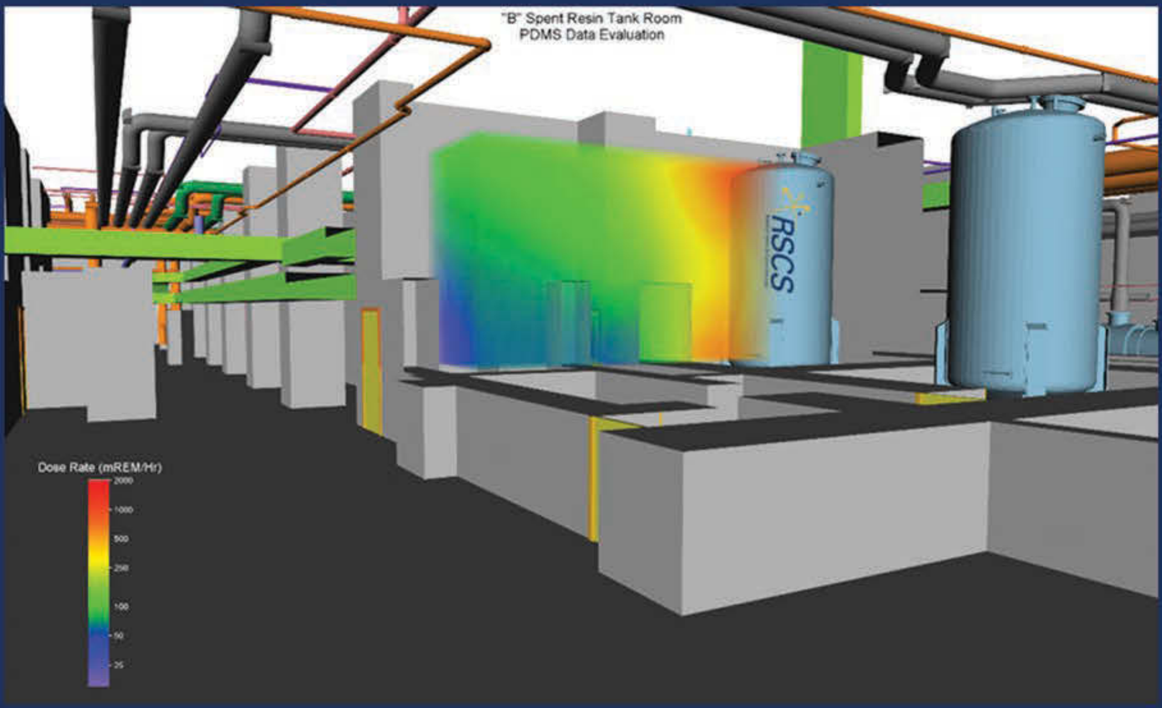
1. Build relationships with reporters and journalists *before* the next crisis. Nuclear power typically doesn't make headlines when things are going well, so reporters and their readers or viewers don't know much, if anything, about the topic. Reporters often don't know who to talk to, which leaves them vulnerable to aggressive outreach from people with an agenda on either side of the truth. Spreading a message that is too optimistic can be just as unhelpful as spreading a message that is too pessimistic.
2. Decide what is being communicated about *before* getting in front of a reporter, microphone, or camera. For nuclear professionals speaking as a member of ANS, the emphasis was on speaking the truth as best we knew it at any given time. For the most part, it was a speculation-free zone that reporters learned was a space where they could get the most accurate interpretation of the complex events that were happening.

Margaret Harding

Harding, president of 4 Factor Consulting, was awarded the ANS Special Award for media and communications in 2012 for her response in the aftermath of the Fukushima Daiichi accident.

3. Keep the messenger in mind. The reporter is operating to a deadline and may have to convince his or her editor that a story is worth printing or broadcasting. Help the reporter write the story. Translate technical jargon into English and use simple analogies that can help the reporter understand what is happening. Think about words and images. Giving the reporter some color and visuals without creating controversy makes for more interesting reading and increases the likelihood that the reporter will use the material.

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