United States Government Accountability Office

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Report to Congressional Requesters

June 2011

NUCLEAR REGULATORY COMMISSION

Oversight of Underground Piping Systems Commensurate with Risk, but Proactive Measures Could Help Address Future Leaks

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Highlights

Highlights of GAO-11-563, a report to congressional requesters

June 2011

NUCLEAR REGULATORY COMMISSION

Oversight of Underground Piping Systems Commensurate with Risk, but Proactive Measures Could Help Address Future Leaks

Why GAO Did This Study

All U.S. nuclear power plant sites have had some groundwater contamination from radioactive leaks, and some of these leaks came from underground piping systems. The Nuclear Regulatory Commission (NRC) regulates nuclear power plants to protect public health and the environment from radiation hazards. GAO was asked to (1) determine experts' opinions on the impacts, if any, of underground piping system leaks on public health and the environment; (2) assess NRC requirements of licensees for inspecting these systems and monitoring and reporting on leaks; (3) identify actions the nuclear power industry, licensees, and NRC have taken in response to leaks; and (4) identify additional NRC requirements, if any, that key stakeholders think could help prevent, detect, and disclose leaks. GAO convened expert discussion groups through the National Academy of Sciences and asked experts to review three case studies, analyzed documents, visited seven plant sites and two NRC regional offices, and interviewed stakeholders.

What GAO Recommends

GAO recommends that NRC periodically assess the effectiveness of the groundwater initiative and determine whether structural integrity tests should be included in licensee inspection requirements, when they become feasible, based on industry research.

NRC stated it agrees with the report and recommendations and asserted that NRC has taken relevant actions.

View GAO-11-563 or key components.
For more information, contact Frank Rusco at (202) 512-3841 or ruscof@gao.gov.

What GAO Found

While experts in our public health discussion group generally agreed that radioactive leaks at the three nuclear power plants in our case studies of actual events had no discernible impact on the public's health, these experts noted that additional information could enhance the identification of the leaks and the characterization of their impacts. The experts in our environmental impact discussion group concluded that environmental resources beyond the plant site have not been impacted discernibly, but that on-site contamination could affect plant decommissioning; for example, the licensee may have to conduct costly remediation to meet NRC regulations for unrestricted release of the site. Experts also identified the need for licensees to transparently report monitoring data and for licensees' groundwater monitoring programs to be independently reviewed.

NRC inspection requirements focus on ensuring the functionality of underground piping systems that are essential for both the safe operation and the shutdown of plants rather than providing information about the condition of the underground piping systems. In addition, NRC's groundwater monitoring requirements generally focus on monitoring off-site locations, where a member of the public could be exposed to radiation, but not on on-site groundwater monitoring, which can improve the likelihood that leaks will be detected before they migrate off-site.

In response to leaks, the nuclear power industry has implemented two voluntary initiatives to increase public confidence in plant safety. The first initiative was intended to improve on-site groundwater monitoring to promptly detect leaks. The second was intended to provide reasonable assurance of underground piping systems' structural and leaktight integrity. Licensees' responses to detected leaks have varied, ranging from repairing the leak source and documenting the leak's extent, to performing extensive mitigation. In addition, NRC has assessed its regulatory framework for, and oversight of, inspection of underground piping systems and groundwater monitoring. Based on the low risk posed by spills to date, NRC determined that no further regulations are needed at this time but has committed to such actions as gathering information on underground piping leak trends and reviewing codes and standards for underground piping.

Key stakeholders identified additional NRC requirements that they thought could help prevent, detect, and disclose leaks. Some saw a need for NRC to require licensees to inspect the structural integrity of underground piping using techniques used in the oil and gas industry, while noting the challenges to applying such techniques at nuclear power plants. Industry is undertaking research to overcome these challenges. Stakeholders also noted that NRC should enhance its on-site groundwater monitoring requirements to promptly detect leaks and minimize their impacts. Finally, stakeholders said that NRC should require licensees to provide leak information in a more timely fashion and should make that information more accessible to the public.

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Abbreviations

AOG	Advanced Off-Gas
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
cfs	cubic feet per second
EPA	Environmental Protection Agency
ESW	Emergency Service Water
Fe-55	Iron-55
GPM	gallons per minute
kg/yr	kilograms per year
L/yr	Liters per year
MDA	minimum detectable activity
MOU	memorandum of understanding
mrem	millirem
mrem/yr	millirem per year
MWt	megawatts-thermal
Ni-63	Nickel-63
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
pCi/L	picocuries per liter
NEI	Nuclear Energy Institute
OCGS	Oyster Creek Generating Station
PWR	Pressurized Water Reactor
Sr-90	Strontium-90
Te-99	Technetium-99
Vernon Dam	Vernon Hydroelectric Dam
VYNPS	Vermont Yankee Nuclear Power Station

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Accountability * Integrity * Reliability

United States Government Accountability Office
Washington, DC 20548

June 3, 2011

The Honorable Edward Markey
The Honorable Peter Welch
House of Representatives

In recent years, a number of nuclear power plants have experienced leaks of radioactive materials from pipe systems that are underground and not easily accessible. Many of these underground pipe leaks resulted in contamination of groundwater by tritium—a radioactive form of hydrogen. In some instances, the contamination has migrated, or is expected to migrate, beyond the plant's boundaries, raising concerns about potential impacts on public health and the environment. The Nuclear Regulatory Commission (NRC), an independent federal agency headed by five commissioners, licenses commercial nuclear power plants and regulates and oversees their safe operation and security. NRC's mission includes protecting public health and the environment from radiation hazards.

Most nuclear power plants have extensive underground piping systems,[1] some of which transport water containing radioactive isotopes, such as tritium. While the amount and type of underground piping systems vary significantly among nuclear power plants, according to NRC officials, most of these underground systems are not safety-related—that is, they are not necessary to ensure reactor integrity, shut down and safely maintain the reactor, or prevent or mitigate the public's exposure to radiation during an accident. As nuclear power plants age, their underground piping systems tend to corrode, but since these systems are largely inaccessible and difficult to inspect, the condition of many underground piping systems at plants across the country is unknown. Further, as pipes continue to age and further corrosion occurs, the likelihood and severity of leaks could increase without mitigating actions.

[1]For the purposes of this report, the term "underground piping systems" includes what NRC defines as: (1) buried piping—piping that is underground and in contact with soil or encased in concrete and (2) underground piping—piping that is below the ground's surface but encased within a tunnel or a vault such that it is in contact with air and located where access for inspection is restricted. In addition, the term includes all piping system components, such as joints and valves, as some of these components have also been the source of reported leaks.

In the past decade, increased reports of buried pipe leaks at nuclear power plants have attracted significant attention and generated public concern about NRC's oversight of underground piping systems, particularly since NRC has issued few violations in association with these leaks.[2] Specifically, stakeholders—such as environmental and antinuclear groups, as well as some scientists and engineers—have questioned the adequacy of NRC requirements pertaining to the safety of underground piping systems and are also seeking to understand the factors responsible for underground piping system leaks. Some stakeholders also have concerns about NRC's license renewal process. As most aging power plants have been applying for—and receiving—20-year extensions of their operating licenses, some stakeholders have filed contentions, including contentions to prevent the relicensing of some plants with underground piping systems that may be subject to leaks.[3]

In this context, you asked us to review underground piping systems and NRC's requirements for them. Our objectives were to (1) determine experts' opinions on the impacts, if any, that underground piping system leaks have had on public health and the environment; (2) assess NRC requirements of licensees for inspecting underground piping systems and monitoring and reporting on leaks from these systems; (3) identify actions the nuclear power industry, licensees, and NRC have taken in response to underground piping system leaks; and (4) identify, according to key stakeholders, what additional NRC requirements, if any, could help prevent, detect, and disclose leaks from underground piping systems.

To address these objectives, we consulted with experts, analyzed documents, conducted visits to selected plant sites and NRC regional offices, and interviewed stakeholders. Specifically, we worked with the National Academy of Sciences to convene two groups of six experts each,[4] in January 2011. The first group addressed the public health impacts of underground piping system leaks, and the second one addressed their environmental impacts. We asked both groups of experts to discuss the impacts of leaks in the context of three case studies of nuclear power

[2]These violations were issued due to licensees' failure to properly evaluate the radiological consequences of the leaks.

[3]Contentions are petitions filed by stakeholders during the NRC licensing process opposing a license application as submitted. 10 C.F.R. Part 2 contains NRC's regulations on licensing proceedings.

[4]Two experts served on both groups.

plants that have experienced leaks in their underground piping systems: Braidwood Generating Station in Illinois, Oyster Creek Generating Station in New Jersey, and Vermont Yankee Nuclear Power Station in Vermont.[5] We selected these case studies because they included plants with underground piping system leaks that generated significant publicity and resulted in high concentrations of tritium detected in on-site groundwater. Additionally, the case studies included a plant at which contamination from a leak was detected off-site (Braidwood). We also analyzed relevant NRC regulations and requirements and interviewed NRC officials from the Office of Nuclear Reactor Regulation, Office of General Counsel, Region I, and Region III. In addition, we selected a nonprobability sample[6] of seven nuclear power plants, most of which had recently experienced an underground piping system leak, and one of which had not experienced a publicized pipe leak, and made site visits to these locations to interview licensee representatives and NRC resident inspectors. During the site visits, we also observed ongoing activities related to mitigation of leaks. Finally, using a standard set of questions, we interviewed a nonprobability sample of over 30 stakeholders including representatives from NRC, other federal and state agencies who have worked on issues related to underground piping system leaks and associated groundwater contamination, representatives from industry and industry groups, standards-setting organizations, and advocacy and other interested groups, as well as independent consultants and experts. A more detailed description of our objectives, scope, and methodology is presented in appendix I. We conducted this performance audit from May 2010 to June 2011, in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

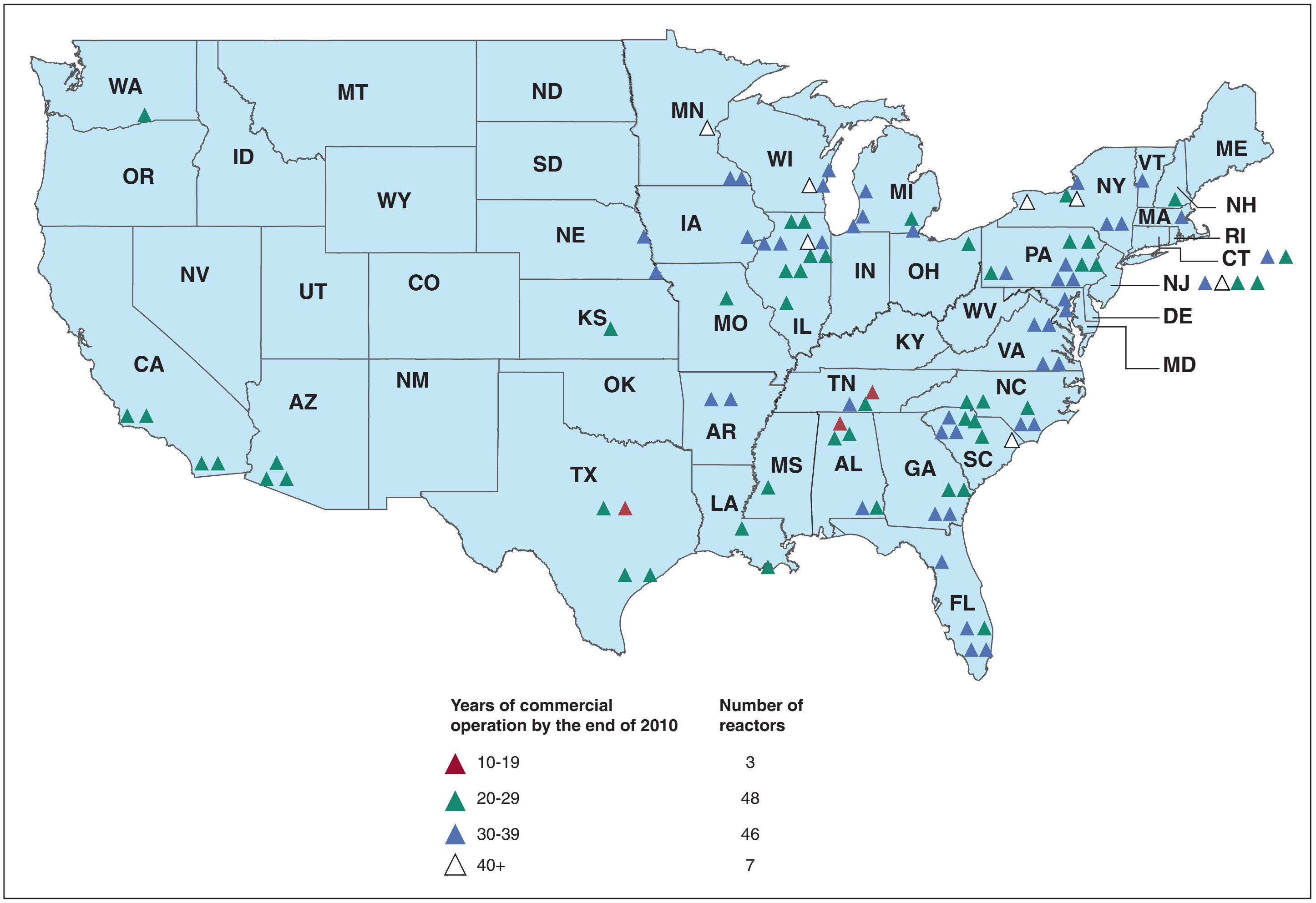
[5]See appendix II for additional information on the case study power plant sites considered by the experts.

[6]Results from nonprobability samples cannot be used to make inferences about a population because, in a nonprobability sample, some elements of the population being studied have no chance or an unknown chance of being selected as part of the sample.

Background

Currently 104 commercial nuclear power plants operate in the United States, together generating, as of 2007, about 20 percent of our nation's electricity. These reactors are located at 65 sites across the country (see fig. 1) and are operated by 26 different companies. Many reactors built in the late 1960s and early 1970s are reaching or have reached the end of their initial 40-year license. As of March 2011, NRC had renewed 63 reactor licenses for an additional 20 years and was currently reviewing 19 license renewal applications.

Figure 1: U.S. Operating Commercial Nuclear Power Reactors

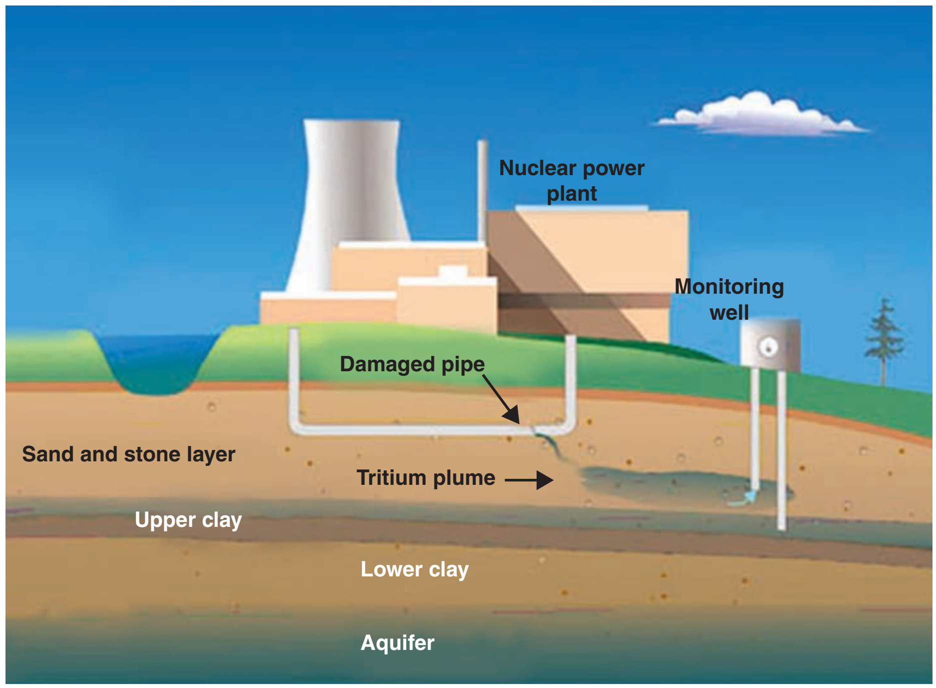


Sources: NRC (data); Map Resources (map).

Since 2008, NRC has been collecting data from licensees on groundwater contamination incidents at nuclear power plants that have resulted from unplanned or uncontrolled releases of radioactive material, including leaks from underground piping systems. Based on these data, NRC has concluded that all 65 reactor sites in the United States have experienced a leak or spill of radioactive material into groundwater. NRC estimates that between 10 and 20 percent of groundwater contamination events at nuclear power plants can be attributed to leaks from underground piping systems.[7] Figure 2 provides a diagram of a hypothetical underground piping system leak at a nuclear power plant. In addition, NRC data suggest that groundwater contamination events have been more prevalent during the last several years; however, the agency attributes this apparent increase to the nuclear industry's enhanced monitoring efforts and increased reporting of leaks during the same time period.

[7]Other common sources of leaks that have resulted in groundwater contamination include spent fuel pools, outside storage tanks—such as condensate storage tanks and radioactive waste storage tanks—sumps, and vaults.

Figure 2: Hypothetical Radioactive Leak from a Nuclear Power Plant Underground Piping System



Source: NRC.

NRC strives to accomplish its mission of protecting public health and safety and the environment by establishing regulations and standards governing licensed activities and inspecting facilities to ensure compliance with requirements. NRC prioritizes its oversight and inspections of structures, systems, and components that are critical to safely operating the plant during normal conditions and safely cooling the reactor core in the case of an emergency shutdown. Therefore, these structures, systems, and components are classified by NRC as "safety-related."

NRC maintains staff at commercial nuclear power plants to inspect, measure, and assess their safety performance—and respond to any deficiency in performance—through its Reactor Oversight Process. Furthermore, according to NRC inspection protocols, performance deficiencies by the company licensed to operate a nuclear power plant, or licensee, can result in more intensive NRC oversight and/or issuance of a violation. However, to assure licensees that requirements placed on them will change only when they are justified from a public health and safety standpoint, the "backfit rule"[8] requires that NRC make the determination that new requirements will result in a substantial increase in the overall protection of public health and safety and that this increased protection justifies the cost of implementing the new requirement.[9]

NRC's regulations allow certain levels of radioactive materials to be discharged into the environment. As a part of its license application, a licensee performs calculations of its expected releases,[10] and NRC reviews these calculations to verify their validity and conformance to NRC requirements. NRC's review and verification are documented in reports,[11] and the licensees are required to monitor their discharges. Most of the systems used to discharge these radioactive materials are not classified as "safety-related." According to NRC officials, the amount of radioactive materials released from underground piping system leaks has been small relative to these permitted discharges. Furthermore, the officials noted that a leak of tritium in and of itself is not a violation of NRC requirements.

NRC has established several layers of radiation standards to protect the public against potential health risks from exposure to radioactive releases from nuclear power plant operations (see table 1). In addition to these standards, the Environmental Protection Agency (EPA) developed drinking water standards for radioactive isotopes using its authority under the Safe Drinking Water Act. These limits apply to public drinking water systems but are also used by many state authorities as groundwater protection standards. For tritium, EPA set a maximum contaminant level

[8]10 C.F.R. § 50.109(a)(1) defines a *backfit* as "the modification of or addition to systems, structures, components, or design of a facility; or the design approval or manufacturing license for a facility; or the procedures or organization required to design, construct or operate a facility; any of which may result from a new or amended provision in the Commission's regulations or the imposition of a regulatory staff position interpreting the Commission's regulations that is either new or different from a previously applicable staff position."

[9]10 C.F.R. § 50.109(a)(3). The backfit rule does not apply when NRC finds that regulatory action is necessary to ensure that protection of public health and safety is adequate. 10 C.F.R. § 50.109(a)(4). In addition, NRC officials told us that the backfit rule applies only to requirements on currently licensed facilities and that additional requirements can be placed on new licensees without requiring a backfit analysis.

[10]The NRC obtains a copy of the licensee's *Offsite Dose Calculation Manual*, which contains the licensee's calculation methodology.

[11]NRC's *Safety Evaluation Report* documenting their review and an Environmental Impact Statement as required under the National Environmental Policy Act.

of 20,000 picocuries per liter (pCi/l).[12] None of the reported underground piping system leaks to date have exceeded NRC limits on the public's exposure to radiation, nor have reported concentrations of radioactive materials in off-site groundwater exceeded EPA standards for drinking water.

Table 1: Radiation Protection Limits

Radiation protection layer	Annual dose limit	Basis
As low as reasonably achievable dose objective for liquid releases[a]	3 millirem (mrem)[b] to the whole body and 10 mrem to any organ of an individual who lives in close proximity to the plant boundary	A fraction of the natural background radiation dose, and an attainable objective that nuclear power plants could reasonably meet.
EPA radiation standards incorporated as NRC regulations[c]	25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ of an individual member of the public	Limit is cost-effective in reducing potential health risks from nuclear power generation facilities' operation.
NRC dose limit[d]	100 mrem to any individual members of the public	International Commission on Radiological Protection[e] recommendation that a lifetime of exposure at this limit would result in a very small health risk and is roughly equivalent to background radiation from natural sources.

Source: NRC.

[a]10 C.F.R. Part 50, App. I.

[b]A millirem is a unit for measuring biological damage from radiation.

[c]10 C.F.R. § 20.1301(e).

[d]10 C.F.R. § 20.1301(a)(1).

[e]The International Commission on Radiological Protection is an organization of international radiation scientists who provide recommendations regarding radiation protection related activities, including dose limits.

When unplanned releases do not exceed NRC dose limits, NRC requirements allow for licensees to remediate the residual radioactivity at the time the site is decommissioned. For a decommissioned nuclear power plant site to be released for unrestricted use, NRC requires that it be cleaned up to an established minimum radiation annual dose limit. In addition to this requirement, NRC has entered into a memorandum of understanding (MOU) with EPA on cleanup of radioactively contaminated

[12]A curie is a measure of radioactivity; a picocurie is one trillionth of a curie.

sites. The MOU includes provisions for NRC to consult with EPA if a site meets NRC cleanup standards but exceeds EPA-permitted levels.[13]

According to Experts, Underground Piping Leaks at Three Nuclear Power Plants Had No Discernible Impact on Public Health or the Environment, but More Information Could Enhance Identification of Leaks and Characterization of Their Impacts

According to the experts in our public health discussion group, no impacts on public health have been discernible from leaks at the three case study nuclear power plants we asked the expects to consider. Experts in our environmental expert group also said that no impacts from these leaks on off-site environmental resources have been discernible to date but that the on-site impacts over time are less certain. Finally, experts in both groups believe that additional information could help facilitate the identification of any future leaks and characterize their impacts.

According to Experts in Our Public Health Discussion Group, Leaks at Three Plants Have Had No Discernible Impact on Public Health but May Have Affected Local Communities in Other Ways

Radioactive leaks at three power plants in Illinois, New Jersey, and Vermont have had no discernible impact on the public's health, according to the participants in our expert discussion group on the public health impacts of the leaks. More specifically, although the experts observed that the risk of impacts to the public's health is not zero, it is immeasurably small. While tritium was detected in the on-site groundwater at each of these plants from one or more leaks, it was detected in an off-site drinking water well only in the case of the Illinois plant. The experts noted that, based on the information reported by the licensees and NRC on off-site contamination levels, the radiation doses to the public from leaks at these plants have been very low—well below NRC regulations for radiation exposure, and orders of magnitude below any exposure that could cause an observable health effect.

[13]NRC and EPA use different methods to calculate radiation standards.

While the experts concluded that leaks at these plants have not discernibly impacted the public's health, some of them noted that the leaks may affect people in the surrounding communities in a less tangible manner. For example, according to two of the experts, even if community members have not been exposed to radiation from the leaks, the perception that contamination could exist in their community or that they cannot trust the operators of a nearby nuclear power plant can degrade individuals' quality of life. In addition, another expert noted that reported leaks at nuclear power plants could have an impact on the property values in the surrounding community based on the perception that the leaks could impact public health. Some of the experts observed that such perceptions are not taken into account in NRC's regulatory framework, which is based on protecting public health and safety. However, they noted that, for NRC or licensees to build trust and gain credibility, they should consider these perceived impacts when determining their actions to address a leak. A few experts said that better communication and complete transparency with the public about the risks associated with very low doses of radiation would be required to change the public's perception of the impacts associated with the leaks. However, one expert acknowledged the difficulty in effectively communicating the complex issue of risks to the public posed by low doses of radiation. Another expert suggested that communication with the public may be more effective if it is done through someone outside of industry with higher credibility from the community's perspective.

No Impacts on Off-site Environmental Resources from Leaks at the Three Plants to Date Have Been Discernible, but Future On-site Impacts Are Less Certain, and Some Risks May Not Be Fully Understood, according to Experts in Our Environmental Impacts Discussion Group

Based on the information that is available on the case studies considered by the experts, the experts in our environmental impacts discussion group concluded that the leaks have had no discernible impact on off-site environmental resources. The experts noted that the leaks are unlikely to have an environmental impact if they do not affect public health, since humans are probably more sensitive to the effects of tritium contamination than most other organisms. However, two experts noted that very little information exists on the sensitivity of other organisms to impacts from environmental tritium contamination. Consequently, subtle effects on other organisms that have not been identified could exist.

A few experts pointed out that even though off-site environmental impacts are not discernible, the on-site groundwater contamination from the leaks may have degraded the on-site environment, potentially limiting the site's future use. The on-site groundwater tritium contamination resulting from two of the case study leaks was detected in concentrations over 100 times the EPA drinking water standard. Consequently, some of the experts noted that when a licensee decommissions a plant with this level of groundwater contamination, the licensee may have to conduct costly remediation to be able to meet NRC regulations for unrestricted release of the site, or the site could have deed restrictions placed on its future use. Some of the experts debated whether the time frames for decommissioning current nuclear power plant sites would be sufficient for existing tritium contamination to naturally decay to levels required for unrestricted release of the site.[14] Regardless, one of the experts noted that the licensees and NRC need to monitor high levels of current on-site contamination and ensure it does not move off-site in the future.

Experts in Both of Our Groups Said That Additional Information Could Help Facilitate the Timely Detection of Leaks and Characterize Their Impacts, and Experts Identified the Need for More Transparency and Independent Review of Information

According to the experts in both of our discussion groups, to facilitate the detection of leaks in a timely manner, it is important that licensees have a thorough understanding of the site's subsurface environment and identify risk areas. NRC requires characterization of a site's hydrogeology—the groundwater and other subsurface characteristics—as a part of the evaluation process to choose an appropriate site for construction of the nuclear power plant. However, one expert pointed out that any construction on-site can significantly modify how groundwater flows through the subsurface, so it is very important to have current knowledge of a site's hydrogeology. In addition, experts also said that it was very important for licensees to have knowledge of their underground infrastructure and to identify critical systems, structures, and components where a leak might occur. This knowledge would enable licensees to strategically place their monitoring wells in order to have confidence that they will promptly detect leaks.

Additional information could help characterize the impacts of leaks, according to the experts. More specifically, the experts noted that industry currently lacks standardized data across nuclear power plants to characterize the impacts of leaks and that data used to inform assessments of risk are limited to the locations where samples are collected. Experts said that, to obtain a complete picture of a leak's consequences, monitoring wells need to be placed in the proper locations, which must be informed by a thorough understanding of a site's hydrogeologic characteristics. Finally, the experts noted that licensees need to have conservative models that can predict how contamination would move if a

[14] According to NRC, the half-life of tritium is approximately 12.3 years, which means that the amount of tritium decreases by half every 12.3 years.

leak were to occur, how long it would take for contamination to migrate off-site or contaminate a drinking water well, and what impacts there might be to public health and the environment.

Finally, experts identified the need for licensees' monitoring data and assessments of impacts to be more transparent and to be independently reviewed to provide greater public confidence in them. One expert noted that groundwater data collected voluntarily by the licensees should be part of their annual environmental reports. Another expert observed that the groundwater reports prepared voluntarily by industry typically oversimplify presented data. In addition, experts expressed concern that there is no process for an agency or third party to review licensees' groundwater monitoring programs. For example, one expert observed that licensees, with their consultants, independently develop their voluntary groundwater monitoring programs, collect the data, and report the results without a formal opportunity for NRC or others to comment on the specifics of the programs such as the number, location, and depth of monitoring wells. Another expert noted that the results of licensees' modeling of radiation doses to the public from a leak should also undergo an independent review. Such a review could assess whether a different conclusion might have been reached if, for example, monitoring wells were placed in a different location. This is important, according to one expert, because NRC relies on licensees to initially determine whether a leak presents a health risk.

NRC Requires Licensees to Inspect the Function of Their Safety-Related Underground Piping Systems, Monitor the Plant Environs for Radiation, and Report Releases in a Timely Manner

NRC inspection requirements related to underground piping systems at all 104 U.S. nuclear power plants focus on ensuring the functionality of safety-related piping systems, monitoring the plant environs for radiation, and reporting planned and unplanned releases.[15] Specifically, NRC requires licensees to periodically test a sample of safety-related piping. Pipes are designated as safety related if they are essential to safely operate the plant or safely shut it down in case of an emergency. NRC inspection regulations, through the adoption of applicable American Society of Mechanical Engineers (ASME) Code provisions,[16] require licensees to perform only pressure tests or flow tests on their safety-related underground piping systems. The pressure test is used to determine if and to what extent pressure is being lost within a section of piping, while the flow test is designed to identify any reduction in flow volume. To pass these tests, the pipes must be able to transport fluids at or above a specified minimum pressure or flow rate, which can be accomplished even when pipes are leaking. According to NRC, the agency's primary concern is whether a system is providing enough water to maintain its functionality at one point in time, which is what the results of the pressure and flow tests indicate.

NRC regulations also require that licensees monitor the "plant environs"[17] for radioactivity that may be released from normal plant operations, as well as from unplanned leakage such as leaks and spills, to ensure the protection of the public's health and safety. NRC requires that licensees establish and implement a site-specific Radiological Environmental Monitoring Program to obtain data on measurable levels of radiation and radioactive materials in the environment. Consistent with NRC guidance for this required monitoring program, licensees conduct radiation monitoring at locations where a member of the public could be exposed to radiation to identify whether levels of off-site radiation exceed federal dose limits. For example, agency guidance recommends quarterly monitoring of off-site groundwater only if it is used as a direct source of drinking water or irrigation and is likely to be contaminated. The agency

[15]NRC officials told us that the scope of inspection requirements has increased for plants operating beyond their original 40-year license.

[16]NRC requires design, testing, and inspection for piping systems in accordance with applicable sections of the ASME Code. The testing prescribed by the code is not necessarily capable of detecting smaller sized leaks.

[17]According to NRC, "plant environs" are the area within the perimeter of the plant site, but outside of the plant buildings and the reactor.

does not generally require that licensees monitor groundwater on-site if it is not used for drinking water.[18] However, if a licensee's monitoring program found radioactive materials off-site, additional on-site monitoring could be required. With on-site monitoring, future leaks and spills have a higher likelihood of being detected before contamination reaches the site boundaries. Even though NRC has not generally required licensees to have on-site groundwater monitoring wells, most plants have installed some on-site wells that could help detect and monitor leaks. Although some contamination has been found to migrate off-site, thus far, according to NRC, reported off-site contamination has not exceeded EPA drinking water standards or NRC radiation exposure limits.

In addition, NRC regulations require that planned and unplanned releases be reported to NRC by licensees in a timely manner.[19] For example, each licensee must submit a written report to NRC within 30 days after learning of an inadvertent release above specified limits of radioactive materials, such as tritium. The licensee's report must include a description of the extent of exposure of individuals to radiation and radioactive material. These NRC reporting requirements are in addition to their immediate notification of incidents requirements. Immediate notification, via an Emergency Notification System or telephone, is required for certain events or situations that may have caused or threatens to cause an individual to receive a high dose of radiation.[20]

[18]NRC requires licensees to monitor groundwater on-site if there have been known leaks or spills or if discharges are likely to affect groundwater or drinking water supplies.

[19]These reporting requirements for licensee events are contained in 10 C.F.R. §§ 20.2203, 50.73.

[20]Under 10 C.F.R. § 20.2202(a), a licensee must, with few exceptions, notify NRC immediately of an event involving a 24-hour dose for which an individual present would receive an intake of five times the annual limit.

The Nuclear Power Industry, Licensees, and NRC Have Taken a Variety of Actions in Response to Underground Piping Leaks

In response to underground piping leaks at nuclear power plants, the nuclear power industry adopted two voluntary initiatives largely intended, according to the Nuclear Energy Institute (NEI),[21] to enhance public confidence in the operation and maintenance of their plants. The actions specified in these initiatives, according to NRC officials, are above and beyond NRC requirements. Groundwater incidents that occurred around the 2005 time frame led to the industry's Groundwater Protection Initiative in 2007,[22] which was intended to boost public confidence in the safe operation of the plants and to improve groundwater monitoring at nuclear power plant sites to promptly detect leaks. All licensees of operating commercial nuclear power plants in the United States have committed to the groundwater initiative and, in so doing, have agreed to perform a site hydrogeologic characterization and risk assessment, establish an on-site groundwater monitoring program, and establish a remediation protocol.

After 2007, additional underground piping leaks were reported, heightening public concern about the degradation of buried pipes at nuclear power plants. As a result, NEI announced another voluntary industry initiative in 2009.[23] This second initiative—called the Buried Piping Integrity Initiative—was designed to provide reasonable assurance of structural and leaktight integrity of all buried pipes. All licensees of operating commercial nuclear power plants in the United States have committed to this initiative as well. The initiative defined a series of milestones for, among other things, assessing the condition of buried pipes and establishing a plan for managing them. Specifically, under this initiative, licensees agreed to rank their buried piping based on the likelihood and consequences of its failure and to develop an inspection plan using the results of the risk ranking, along with other factors, to prioritize the selection of locations at which they will inspect pipes. The initiative placed special emphasis on buried piping that is safety-related and/or contains radioactive material. In 2010, the Buried Piping Integrity Initiative was expanded to the Buried Piping/Underground Piping and Tanks Integrity Initiative to address additional structures. All of the licensees have also committed to implement the expanded initiative.

[21] NEI is the policy organization of the nuclear energy and technologies industry.

[22] This initiative is implemented by NEI-07-07.

[23] This initiative is implemented by NEI-09-14.

Licensees' actions in response to identified leaks at their power plants have varied, ranging from simply repairing the leak source and documenting the extent of the leak for future cleanup, to performing extensive mitigation. Specifically, at six of the seven sites we visited that had experienced underground piping system leaks, most of the licensees had identified and repaired the leak source and conducted remediation and/or monitoring of the groundwater contamination. For example, when we visited the Vermont Yankee Nuclear Power Station, the soil near the identified leak source had been excavated and removed by a radiological waste company hired by the licensee. In addition, at the Oyster Creek Generating Station in New Jersey, the licensee had undertaken a mitigation project to excavate some of its buried piping, either moving the pipes aboveground or placing them in vaults that can be monitored for leakage.

NRC's response to underground piping leaks has taken various forms. First, NRC's response to individual leaks has generally been an increase in oversight at the particular plant, and not issuance of a violation, because most of the leaks have not posed a safety risk. For example, after an April 2009 leak at Oyster Creek Generating Station, NRC sent out regional inspectors to review and evaluate the circumstances associated with the leak. At other power plants, NRC's enhanced review has included overseeing some of the groundwater sampling activities that were performed to characterize leaks. In many of these instances, NRC relied upon split sampling—sending portions of some of the groundwater monitoring samples to a laboratory and comparing its analytical results with those obtained by the licensees' laboratories for the same samples—to verify the licensees' results.

Furthermore, NRC reviewed its oversight of buried piping and took actions on the basis of its review. In particular, in the fall of 2009, after several reported leaks from buried piping resulted in groundwater contamination and increased media coverage, NRC's Chairman tasked the agency staff with reviewing activities NRC had taken related to buried pipe leaks. The resulting December 2009 report concluded that the agency's regulations for the design, inspection, and maintenance of safety-related buried piping are adequate to ensure buried piping can perform its safety function.[24] The report also identified a number of ongoing activities, such as conducting direct visual inspections of piping when a licensee

[24]SECY 09-0174.

excavates underground piping for the purpose of repair and replacements. In 2010, NRC developed a Buried Piping Action Plan under which it would collect a variety of information, including data on buried pipe system leaks; assess the implementation of the industry's Buried Piping/Underground Piping and Tanks Integrity Initiative; participate in reviewing professional codes and standards for buried pipes; and, if warranted, develop responding regulatory actions.

In 2010, NRC actions also included revising its Aging Management Program guidance for licensees to manage the effects of aging on structures or components for license renewal. The revisions include more detailed and comprehensive guidance for preventing and mitigating corrosion of underground piping systems and inspecting them. In addition, NRC proposed requirements for additional groundwater surveys for decommissioning.

Moreover, in 2010 and 2011, NRC reviewed the extent to which the industry has implemented the Groundwater Protection Initiative but did not evaluate its effectiveness. During this review, NRC found that most plants have implemented most but not necessarily all steps outlined in the voluntary initiative. To insure full implementation of the initiative, NRC plans to continue observing the long-term implementation of this initiative through its Reactor Oversight Process. However, NRC has no plans to evaluate the extent to which this initiative, as implemented, will promptly detect leaks and, as a result, has no assurance that the Groundwater Protection Initiative will consistently help to promptly detect leaks as nuclear power plants age. In addition, NRC officials have said they will continue to review the status of the initiative's implementation, but said that the agency is not going to incorporate the initiative into its requirements because of the low level of risk associated with the reported leaks to date. Therefore, the public cannot be assured the initiative will remain in place in the future.

In addition, in 2010 NRC convened a Groundwater Task Force composed of NRC staff to evaluate NRC's actions to address incidents of groundwater contamination at nuclear power plants and identify actions for a senior management review group to consider. Later that year, the task force issued a report that concluded that NRC is accomplishing its stated mission of protecting the public health and safety and the environment through its response to leaks and spills that contaminated groundwater. However, the report also concluded that NRC's response to leaks and spills has varied widely and that NRC should further consider ways to communicate more timely and complete information to the public about these incidents. In early 2011, NRC reported the results of its senior management's review of the Groundwater Task Force report findings. This report included four areas in which the agency committed to action: (1) identifying and addressing policy issues related to groundwater contamination; (2) enhancing the agency's Reactor Oversight Process; (3) developing specific actions in response to key themes and conclusions of the Groundwater Task Force report; and (4) conducting a focused dialogue with other regulators, such as EPA and states, to develop a collaborative approach for enhanced groundwater protection.

Several Stakeholders Recommended That NRC Enhance Its Inspection, Groundwater Monitoring, and Reporting Requirements

Several stakeholders noted that NRC should enhance its inspection requirements for underground piping systems to help prevent leaks. In addition, several stakeholders suggested that NRC make its groundwater monitoring requirements more stringent to help detect leaks. Furthermore, according to some stakeholders, NRC should require more timely disclosure of information on leaks and make this information more accessible to the public. The stakeholders we interviewed included representatives from NRC, other federal and state agencies, industry and industry groups, standards-setting organizations, and advocacy and other interested groups, as well as independent consultants and experts.

Several Stakeholders Identified Enhancements NRC Could Make to Its Inspection Requirements

Several of the stakeholders we interviewed said that NRC should enhance its inspection and testing requirements by requiring that licensees visually inspect underground piping more frequently and regularly, inspect piping's structural integrity,[25] and inspect and test nonsafety-related piping that contains radioactive material. Many stakeholders who recommended more frequent and regular inspections pointed out that NRC requires direct visual inspection of underground pipes only when a pipe has been excavated for another purpose.[26] While some stakeholders wanted NRC to require visual inspections even if that meant licensees would have to excavate underground piping to do so, one stakeholder pointed out that pipes can be damaged during excavation and that some pipes may not be

[25] According to NRC, such tests are typically called nondestructive examinations.

[26] In December 2010, NRC revised its guidance for plants operating beyond their original 40-year license to include direct inspections of some piping even if it has not been excavated for another purpose.

accessible through excavation if, for example, they lie under a road or building.

In addition, some stakeholders we interviewed recommended that NRC require inspections of structural integrity of safety-related underground piping systems, which can be susceptible to corrosion as plants age. NRC officials and other stakeholders noted that the pressure and flow tests NRC currently requires do not provide information about the structural integrity of an underground pipe, such as whether the pipe has degraded to the point that the thickness of its wall could hinder the pipe's future performance. One stakeholder voiced concern that not having structural integrity information about safety-related underground piping systems could create a very significant risk to public health and safety if such pipes were to unexpectedly fail due to corrosion. Moreover, some of the stakeholders we interviewed noted that some of the inspection techniques used in the oil and gas industry to provide additional information about the structural integrity of underground pipes could be used in the nuclear power industry. However, these stakeholders recognized that applying such techniques at nuclear power plants may be difficult, largely because the technology for such tests has not been sufficiently developed for, or adapted to, the nuclear industry site conditions. For example, guided wave technology—a method that transmits ultrasonic energy through a pipe's walls and monitors how the energy is reflected back to identify areas where a pipe may have corrosion—is used in the oil and gas industry, which tends to have miles of relatively straight piping through which waves can travel with little interference. However, the underground piping at nuclear power plants tends to include many bends and turns, which can distort the wave energy and interfere with the inspection test results. In addition, the oil and gas industry uses robotic devices sent through a pipe to capture images of its condition and identify areas of corrosion, but the bends and turns in pipes at nuclear power plants limit the use of robotic devices by the nuclear power industry. Although obtaining information about the structural integrity of pipes is currently challenging, based on stakeholders' observations, NRC and licensees cannot be assured that underground safety-related pipes remain structurally sound without having information about degradation that has occurred. Without such assurance, the likelihood of future pipe failures cannot be as accurately assessed, and this increases the uncertainty surrounding the safety of the plants.

Industry and standards-setting organizations have undertaken activities to address the challenges of inspecting the structural integrity of underground piping systems at nuclear power plants. For example, industry, through the Electric Power Research Institute, has undertaken research to develop new, and improve upon existing, techniques to provide reliable and usable results, and some licensees are trying these techniques at their plants. The licensee at the Seabrook Station, for instance, has plans to pilot test a mechanical robot that was developed by the Electric Power Research Institute to detect cracks in underground piping. In addition, stakeholders representing standards-setting organizations, such as NACE International and ASME, noted that they have undertaken efforts to evaluate and enhance current technologies and codes for inspecting underground piping systems.[27] For example, according to a member of NACE International, the organization formed a buried piping task group to, among other things, evaluate the current state of inspection techniques and technologies for underground piping systems and determine how they could be applied at nuclear power plants.

Moreover, various stakeholders mentioned the need for NRC to require inspections and testing of nonsafety-related piping that contains radioactive material. Although NRC currently does not generally require such inspections,[28] nonsafety-related piping has been the source of many reported leaks that resulted in groundwater contamination. For example, nonsafety-related piping was the source of leaks at the Oyster Creek and Braidwood plants. Some stakeholders said that any system whose failure could result in contamination of the environment should be prioritized for inspection and testing, even if it is not classified as being safety-related.

According to NRC stakeholders, NRC has limited ability to enhance the licensees' inspection requirements of nonsafety-related underground piping systems, given the low level of risk associated with reported leaks to date, and the requirement that NRC justify the cost of new requirements relative to this risk. However, according to industry stakeholders, the voluntary Buried Piping/Underground Piping and Tanks Integrity Initiative may address stakeholder concerns related to inspection of nonsafety-related underground piping that carries radioactive material. This initiative includes a component under which licensees assign a risk rank to

[27]NACE International was formerly known as the National Association of Corrosion Engineers. NACE International develops corrosion prevention and control standards for many industries from chemical processing and water systems to transportation and infrastructure protection.

[28]Aging Management Programs for some license renewals require inspection of nonsafety-related floor drain piping that can potentially contain radioactive materials.

segments of their underground piping based on the potential for and consequences of failure. As a result, systems that are safety-related and systems that contain radioactive materials receive a higher rank. According to the initiative, systems with a higher rank will be prioritized for inspection and testing, so industry stakeholders noted that piping containing radioactive materials would receive more attention under the initiative.

Several Stakeholders Suggested More Stringent On-site Groundwater Monitoring Requirements

Several of the stakeholders we interviewed noted that NRC should have more stringent requirements for licensees to monitor on-site groundwater to quickly detect leaks. Industry stakeholders acknowledged the importance of detecting leaks early to minimize their consequences. A few stakeholders said they would like to see NRC require that licensees install groundwater monitoring wells in the vicinity of potential leaks based on a risk-informed assessment of the underground piping systems that have the highest likelihood of leaking and a current and thorough assessment of the site's hydrogeology. Some stakeholders noted, however, that NRC should allow flexibility for licensees to determine the best approach to detect leaks at their own sites and to adapt their approach on the basis of evolving industry experience.

However, according to stakeholders at NRC, as is the case with inspection requirements, the agency is unlikely to be able to justify changing its groundwater monitoring requirements given the low level of risk associated with reported leaks. Nevertheless, industry and NRC stakeholders noted that components of the industry's voluntary Groundwater Protection Initiative may address some stakeholders' concerns with respect to groundwater monitoring. For example, one of the objectives of the initiative is to establish an on-site groundwater monitoring program by considering placing wells closer to systems with the highest potential for inadvertent releases that could contaminate groundwater. Moreover, many NRC stakeholders noted that the industry initiative goes well beyond what the agency can do in terms of regulations and has already been implemented, whereas establishing new regulations could take years. In fact, a review performed by senior managers at NRC concluded that, in view of the progress being made by industry through the initiative, efforts to amend NRC's regulations to include the initiative are not necessary at this time. Moreover, industry stakeholders told us they do not consider the initiative to be voluntary since all of the power plants' chief nuclear officers committed to its implementation. Other stakeholders, however, told us that the language in the initiative is not strong enough and expressed concern that, because NRC has no authority to enforce the voluntary initiative, industry could move away from it at any point without recourse from NRC.

Some Stakeholders Said That NRC Should Require More Timely Leak Information from Licensees and Should Make It More Accessible to the Public

According to some stakeholders, NRC should require licensees to report information about the level and extent of groundwater contamination from a leak and the licensee's assessment of a leak's impact in a more timely manner. One stakeholder noted that the inability to obtain timely information about leaks could undermine the public's confidence in NRC and licensee conclusions that a leak does not impact public health and safety. NRC currently requires licensees to make information on significant leaks available to the public by providing groundwater sample results and calculations of the radiation dose the public has received in its annual radioactive effluent and environmental reports. Consequently, even though NRC posts on its Web site some information about leaks as it becomes available, up to a year may pass between the time a leak occurs and the time the public receives information supporting the licensee's assessment of the leaks' impact.

In addition, some stakeholders noted that NRC should make information pertaining to leaks more accessible to the public. For example, some of these stakeholders said that NRC could improve the accessibility of information on its Web site. Specifically, one stakeholder said that the site is difficult to navigate, cumbersome, and unnecessarily slow. Another stakeholder noted that staff members at his organization had used NRC's Web site to track information on groundwater contamination at a particular site, but the links they used were no longer available.

Conclusions

The occurrence of leaks at nuclear power plants from underground piping systems is expected to continue as nuclear power plants age and their piping systems corrode. While reported underground piping system leaks to date have not posed discernible health impacts to the public, there is no guarantee that future leaks' impacts will be the same.

Some of our stakeholders noted that a future leak could put the public's health and safety at risk if the leak went undetected for a long period of time. NRC's groundwater monitoring requirements are intended to identify when the public could be or has been exposed through drinking water to radiation doses above certain limits rather than to promptly detect underground piping system leaks. NRC has concluded that, in general, licensees' groundwater monitoring programs implemented under the voluntary groundwater initiative go beyond what the agency requires for groundwater monitoring and could enhance licensees' prevention of and response to potential leaks by detecting them early. However, without regularly evaluating the extent to which the initiative will result in prompt detection of leaks, NRC cannot be assured that groundwater monitoring programs under the initiative will detect leaks before they pose a risk to public health and safety.

In addition, although NRC has acknowledged that the corrosion of underground piping systems, particularly those that are safety-related, is a concern, limitations in the industry's ability to measure the wall thickness of an underground pipe without excavation prevent licensees from determining the structural integrity of underground piping systems. Without being able to identify that an underground piping system's structural integrity has not been compromised by corrosion, the risk to public health and safety is increased. In this context, licensees at nuclear power plants cannot assure that a safety-related pipe will continue to function properly between inspection intervals, thereby protecting the public's health and safety.

Recommendations for Executive Action

To ensure the continued protection of the public's health and safety, we recommend that the Chairman of NRC direct agency staff to take the following two actions:

- Periodically evaluate the extent to which the industry's voluntary Groundwater Protection Initiative will result in prompt detection of leaks and, based upon these evaluations, determine whether the agency should expand its groundwater monitoring requirements.
- Stay abreast of ongoing industry research to develop technologies for structural integrity tests and, when they become feasible, analyze costs to licensees of implementing these tests compared with the likely benefits to public health and safety. Based on this analysis, NRC should determine whether it should expand licensees' inspection requirements to include structural integrity tests for safety-related underground piping.

Agency Comments and Our Evaluation

We provided a draft of this report to NRC for its review and comment. NRC provided written comments, which are reproduced in appendix III, and technical comments, which we incorporated into the report as appropriate. NRC agreed with the information presented in the draft report and said they believe it to be fair and balanced. NRC also agreed with each of the report recommendations and asserted that they have established activities to address the recommendations.

In responding to our recommendation to periodically evaluate the extent to which the industry voluntary Groundwater Protection Initiative will result in prompt detection of leaks and, based on these evaluations, determine whether the agency should expand its groundwater monitoring requirements, NRC stated that "the public can be assured that the NRC will continue to review the status of industry implementation of the initiative and consider regulatory changes as appropriate." Specifically, NRC said that it reviews reported groundwater monitoring results and changes to licensees' programs for identifying and controlling spills and leaks. However, as we reported, the agency has not assessed the adequacy of the licensees' groundwater monitoring programs, which were implemented under the Groundwater Protection Initiative, to promptly detect leaks. Absent such an assessment, we continue to believe that NRC has no assurance that the Groundwater Protection Initiative will lead to prompt detection of underground piping system leaks as nuclear power plants age.

In addition, NRC agreed with our recommendation that it stay abreast of ongoing research on structural integrity tests; analyze the costs and benefits of implementing feasible tests; and, on the basis of this analysis, determine whether it should require structural integrity tests for safety-related piping. Further, NRC pointed out that it has established milestones to periodically assess both the performance of available inspection technology and the need to make changes to the current regulatory framework. Nevertheless, NRC said it "believes there is reasonable assurance that the underground piping systems will remain structurally sound." We believe that structural integrity tests, when feasible, would provide enhanced assurance of underground piping systems' structural soundness and enable more proactive oversight. As we reported, NRC's currently required pipe testing procedures—which provide information about a pipe's function at a particular point in time—do not indicate the presence of degradation in a pipe that could hinder its future performance.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to the appropriate congressional committees, Chairman of NRC, and other interested parties. In addition, this report will be available at no charge on the GAO Web site at http://www.gao.gov.

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

Frank Rusco
Director, Natural Resources and Environment

Appendix I: Objectives, Scope, and Methodology

Our objectives were to (1) determine experts' opinions on the impacts, if any, that underground piping system leaks have had on public health and the environment; (2) assess Nuclear Regulatory Commission (NRC) requirements of licensees for inspecting underground piping systems and monitoring and reporting on leaks from these systems; (3) identify actions the nuclear power industry, licensees, and NRC have taken in response to underground piping system leaks; and (4) identify, according to key stakeholders, what additional NRC requirements, if any, could help prevent, detect, and disclose leaks from underground piping systems.

To determine experts' opinions on the impacts that underground piping system leaks have had on public health and the environment, we worked with the National Academy of Sciences to organize two half-day expert group discussion sessions in January 2011 to discuss (1) issues related to the public health risks associated with radioactive leaks from underground piping systems at nuclear power plants and (2) the environmental resource impacts from the leaks. In addition, we held a half-day plenary discussion session to follow up on questions left open during the public health impacts and environmental impacts group discussion and to discuss the overall characterization of impacts from leaks.

In discussing the public health and environmental impacts of leaks, we asked the experts to consider three case studies of nuclear power plants that have experienced leaks from underground piping systems including Braidwood Generating Station in Illinois, Oyster Creek Generating Station in New Jersey, and Vermont Yankee Nuclear Power Station in Vermont. We compiled information packets on each of the case studies using sources such as NRC inspection reports, licensee environmental and effluent reports, Environmental Impact Statements prepared for license renewal, licensee hydrogeology reports, and licensee groundwater monitoring results and maps (see app. II). The panelists were provided the information packets prior to the panel sessions. We selected these case studies because they included power plants that

- had among the highest detected on-site groundwater tritium concentrations that were associated with underground piping system leaks,
- received a significant amount of publicity surrounding underground piping system leaks, and
- had contaminants from leaks that migrated off-site.

The case studies selected had a range of cooling water sources, included both boiling water reactors and pressurized water reactors, and represented a range of plant ages with start of operations dates from 1969 to 1988.

For the first discussion group on public health impacts from underground piping system leaks, the National Academy of Sciences invited qualified individuals with expertise in toxicology, health physics, public health, risk assessment, dosimetry, nuclear engineering, regulatory issues, and radiobiology. For the second discussion group on the environmental impacts of underground piping system leaks, the National Academy of Sciences invited individuals with expertise in the environmental effects of radiation, fate and transport of radioactive materials, civil engineering, water quality and remediation, hydrogeology, risk assessment, nuclear engineering, and regulatory issues. The invited experts had experience working in academia, consulting, and the federal government. None of the experts were compensated for their work on the discussion groups, and all experts were screened by the National Academy of Sciences for potential conflicts of interest. The following experts participated in the discussion sessions:

Discussion Group on Public Health Impacts

- Jerome Puskin, U.S. Environmental Protection Agency
- Phaedra S. Corso, University of Georgia
- Chris G. Whipple, ENVIRON Corporation
- Lynn R. Anspaugh, University of Utah
- Carl Paperiello, Talisman International, LLC
- David Brenner, Columbia University

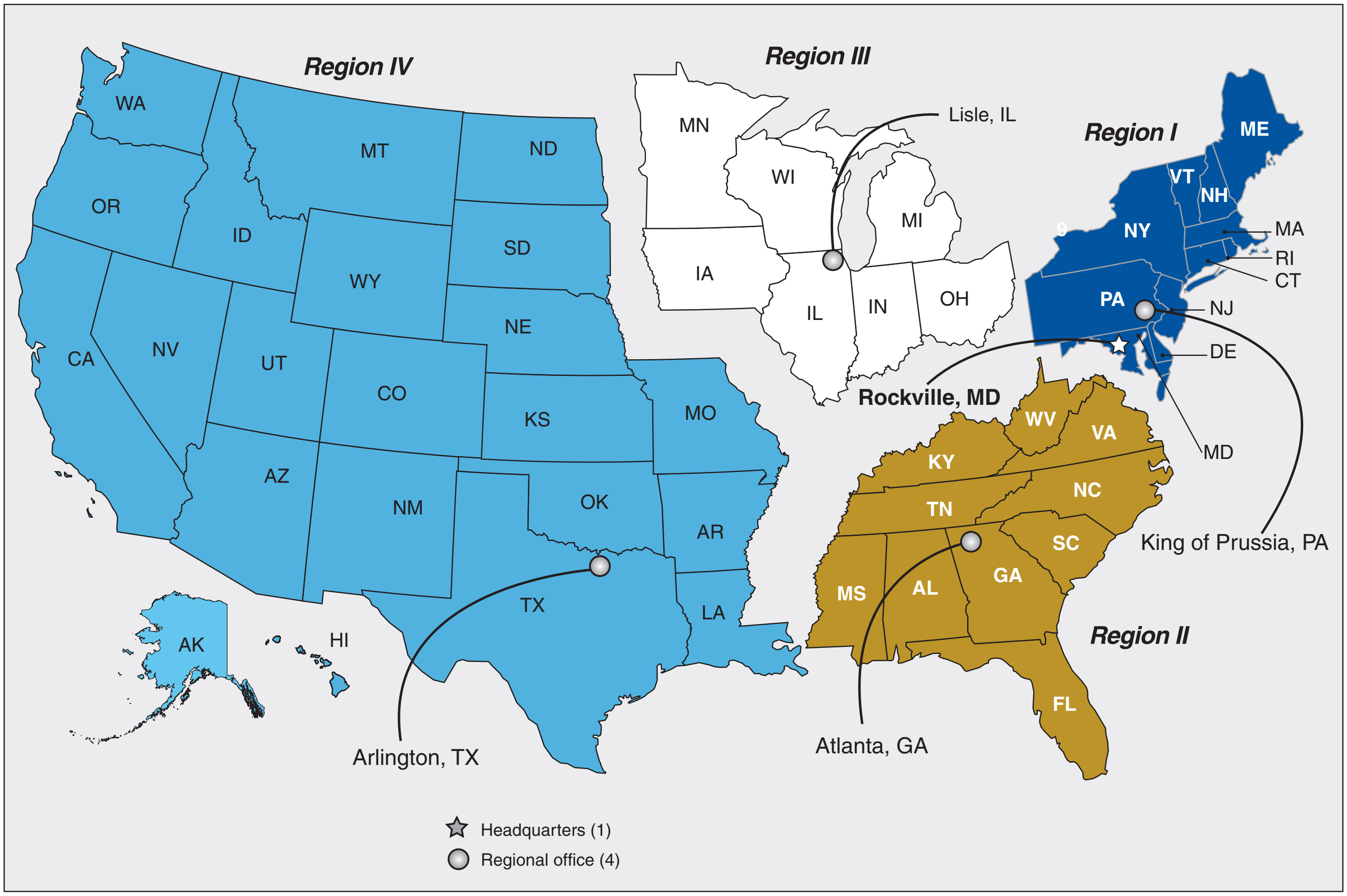
Discussion Group on Environmental Impacts

- Timothy Mousseau, University of South Carolina
- Patricia J. Culligan, Columbia University
- James Clarke, Vanderbilt University

- John Quinn, Argonne National Laboratory
- Chris G. Whipple, ENVIRON Corporation
- Carl Paperiello, Talisman International, LLC

To assess the requirements that NRC places on licensees for inspecting underground piping systems and monitoring and reporting on leaks from these systems, we reviewed and analyzed relevant NRC regulations and requirements, and interviewed NRC officials from the Office of Nuclear Reactor Regulation, Office of General Counsel, Region I, and Region III (a map of the NRC regions is provided in fig. 3).

Figure 3: NRC Regional Offices



Sources: NRC (data); Map Resources (map).

To identify actions the nuclear power industry, licensees, and NRC have taken in response to underground piping system leaks, we conducted site visits at a nonprobability sample[1] of seven nuclear power plants in NRC Regions I and III, which are listed in table 2. During the site visits, we interviewed industry officials and NRC resident inspectors and observed ongoing underground piping system mitigation activities. We selected

[1]Results from nonprobability samples cannot be used to make inferences about a population because, in a nonprobability sample, some elements of the population being studied have no chance or an unknown chance of being selected as part of the sample.

nuclear power plants for their site visits to include plants that had experienced recent reported underground piping system leaks and a nuclear power plant that had not experienced a major reported leak.

Table 2: Nuclear Power Plant Site Visits

Nuclear power plant	State	NRC Region
Braidwood Station	Illinois	III
Dresden Nuclear Power Station	Illinois	III
Indian Point Nuclear Generating Station	New York	I
Oyster Creek Nuclear Generating Station	New Jersey	I
Pilgrim Nuclear Power Station	Massachusetts	I
Seabrook Station	New Hampshire	I
Vermont Yankee Nuclear Power Station	Vermont	I

Source: GAO.

In addition, we gathered and reviewed relevant documents from NRC, including NRC task force reports, policy papers, and an action plan; and industry, including documentation of industry initiatives.

Finally, to determine, according to key stakeholders, what additional NRC requirements, if any, could help prevent and detect leaks from underground piping systems, we identified and interviewed over 30 key stakeholders using a standard set of questions. To ensure a balanced range of perspectives, we selected stakeholders from the following organizations:

- independent consultants and experts;
- advocacy and other interested groups, including Beyond Nuclear, Riverkeeper, Pilgrim Watch, and Union of Concerned Scientists;
- industry and industry groups, including licensees at the nuclear power plants that we visited, the Nuclear Energy Institute, and the Electric Power Research Institute;
- standards-setting organizations, including the American Society of Mechanical Engineers, and NACE International;
- NRC, including officials from Headquarters, Region I, and Region III;

- other federal and state agencies that have worked on issues related to underground piping system leaks and associated groundwater contamination.

We identified stakeholders by performing an Internet and literature search for individuals and organizations that have published relevant reports and studies and by asking previously identified stakeholders for referrals.

Appendix II: Case Studies for Experts' Consideration

We worked with the National Academy of Sciences to convene groups of experts to discuss the impacts that underground piping system leaks have had on public health and the environment. We asked the experts to consider these impacts in the context of three case studies of nuclear power plants that recently experienced leaks from underground piping systems. Prior to the January 2011 discussion groups, the National Academy of Sciences sent the experts information packets that we prepared using NRC and licensee reports to provide background information on these three case studies. This appendix contains excerpts of these case study information packets, excluding their attachments.

Case Study Introduction

We and the National Academy of Sciences are convening expert discussion groups on (1) the public health risks resulting from underground piping system leaks at nuclear power plants and (2) the environmental impacts resulting from underground piping system leaks at nuclear power plants and a plenary session on the overall characterization of leak impacts and further information needs. We would like to obtain the following information from each of the discussion groups:

Public Health Risks Discussion Group:

Information desired:

- the impacts to public health from selected leak case studies, and
- the potential impacts to public health if everything in the case study remained the same, but the tritium concentrations were higher.

Proposed questions for the experts:

1. What is the risk (or risk range) associated with the levels of tritium detected in groundwater at select nuclear power plants if the groundwater was to be used for drinking water (see attached case study information packets)? Please describe the assumptions used and the sensitivity of the risk to these assumptions.
2. How would the risk change if the tritium concentrations were twice the maximum concentration listed above? How would they change if the concentrations were an order of magnitude greater?
3. What additional exposure pathways (other than groundwater) could impact the overall health risk posed to the public by tritium and other

radionuclides released into the environment from the leaks (e.g., Cesium-137, Strontium-90)?

Environmental Resource Impacts Discussion Group:

Information desired:

- the impacts on environmental resources from select leak case studies, and
- the potential impacts to environmental resources if everything in the case studies remained the same, but the tritium concentrations were higher.

Proposed questions for the experts:

1. To what extent have selected leaks from nuclear power plants degraded environmental resources, both on-site and off-site, in a manner that compromises their quality or limits their present or future value or use (see attached case study information packets)?
2. How would the environmental resource impacts change if the contaminant concentrations were twice the concentrations in the examples above? How would they change if the concentrations were an order of magnitude greater?
3. If leaks of similar magnitudes were to occur at other plants, what factors might affect the extent of the resultant environmental impacts or make a particular site more vulnerable to impacts?

Plenary:

Information desired:

- the overall characterization of public health and environmental impacts from leaks, including considerations for cumulative and long-term impacts,
- ability to fully characterize impacts based on the information available from NRC, and
- the additional information that would be required to fully characterize and assess impacts to public health and environmental resources.

We selected three case study nuclear power plants for the experts' consideration: Braidwood, Oyster Creek, and Vermont Yankee. Each of these plants has had a recent underground piping system leak that generated public interest. In addition, the case studies represent some of the highest groundwater tritium concentrations detected at nuclear power plants in association with underground piping system leaks. Summary information about each of the case studies is presented in table 3.

Table 3: Summary of Underground Piping System Leak Case Studies

Nuclear power plant (state)	Reactor type	Year operations began	Maximum detected/reported on-site groundwater tritium concentration	Maximum detected/reported off-site groundwater tritium concentration
Braidwood (IL)	PWR	1988	282,000 pCi/L	1,600 pCi/L
Oyster Creek (NJ)	BWR	1969	4,500,000 pCi/L	None
Vermont Yankee (VT)	BWR	1972	2,500,000 pCi/L	None

Legend: BWR = Boiling Water Reactor; PWR = Pressurized Water Reactor

Source: GAO table based on NRC data.

For each of the case studies, we compiled case study information packets for the panelists that include information on the case study nuclear power plant location and area demographics; a description of the environment near the plant; and information about each of the radioactive leaks, including groundwater tritium concentrations and dose assessment results.

Case Study 1: Braidwood Generating Station

The following information was compiled from NRC reports, licensee-prepared reports to NRC, and Exelon's "Tritium Project" Web site.

Site Location and Demographics

Braidwood Generating Station (see fig. 4)—which consists of two pressurized water reactors owned and operated by Exelon Nuclear—is located in Braceville, Illinois, and covers approximately 4,457 acres of land with a 2,537-acre cooling lake. More broadly, the site is situated in Will County, Illinois, about 20 miles southwest of Joliet, Illinois, and 60 miles southwest of Chicago. In 2009, approximately 685,000 people resided in Will County's 837 square miles, resulting in density of 600 persons/square mile.

Figure 4: Braidwood Generating Station

Source: NRC.

Note: This photograph was not included in the information packet sent to the experts.

Description of the Environment near Braidwood Station

Attachment A,[1] which is an excerpt from a hydrogeologic investigation report for Braidwood, includes a description of the environment near Braidwood including topography, surface water features, geology, hydrogeology, and groundwater flow conditions in the region surrounding the station.

[1]Attachment A, which is not included in this appendix, was an excerpt from a hydrogeologic investigation report prepared for Exelon that included a description of the Braidwood Station.

Surrounding Land Use

Land surrounding the Braidwood site falls mainly into the agricultural, residential, and recreational use categories. Residential lots surround the site to the north and to the east along Smiley Road and Center Street. Further to the north, there are several ponds or small lakes. The center of the Village of Braidwood is approximately 8,000 feet from the site measured from Smiley Road. To the northwest of the site, there are two main highways (Illinois State Highway 53 and Illinois Route 129) running parallel to each other with a railroad (Southern Pacific Railroad) between them. Within the southern portion of the site is the Cooling Lake that is used as a recreational area in the summer for boating and fishing by the Illinois Department of Natural Resources.

A Land Use Survey conducted during August 2005 around the Braidwood Station was performed by Environmental Inc. (Midwest Labs) for Exelon Nuclear to comply with Braidwood Station's *Offsite Dose Calculation Manual*. The purpose of the survey was to document the nearest resident, milk producing animal and garden of greater than 500 ft^2 in each of the sixteen 22½ degree sectors around the site. The results of this survey are summarized in table 4.

Table 4: Braidwood Land Use Survey Results

Distance in miles from the Braidwood Station reactor buildings

Sector	Residence miles	Livestock miles	Milk farm miles
N	0.5	2.6	None
NNE	1.8	None	None
NE	0.7	0.9	None
ENE	0.8	3.3	None
E	0.8	2.3	None
ESE	2.2	2.3	None
SE	2.7	2.7	11.2
SSE	4.5	4.1	None
S	4.2	4.8	None
SSW	1.3	5.3	5.6
SW	0.4	1.2	None
WSW	0.5	3.8	None
W	0.4	1.6	8.7
WNW	0.4	5.4	None
NW	0.4	None	None
NNW	0.4	None	None

Source: Exelon (from NRC).

Underground Piping System Leaks

During March 2005, the licensee was notified by the Illinois Environmental Protection Agency of reports of tritium in wells in a nearby community. Following that notification, the licensee began monitoring groundwater between the community and Braidwood Station and obtained samples from a drainage ditch that was near the community. While no contaminated groundwater was identified, the licensee did measure levels of tritium in the drainage ditch near the Braidwood access road. The licensee performed additional monitoring to identify the source of that tritium contamination.

Between March 2005 and March 2006, the licensee sampled the wells of several homeowners with drinking water wells and installed groundwater monitoring wells to determine the extent of the tritium contamination. On November 30, 2005, the NRC Region III office was notified that the licensee had measured tritium levels as high as 58,000 picocuries per liter (pCi/L) in shallow, groundwater monitoring wells located at the northern edge of the owner-controlled area.

The licensee attributed the contamination to historical leakage of vacuum breakers along the circulating water blowdown line that is routinely used for radioactive liquid releases to the Kankakee River. As an immediate corrective action, the licensee suspended all further releases of liquid radioactive material, while the licensee performed a more comprehensive evaluation of the incidents.

Beginning in December 2005, the NRC performed an independent analysis of split samples taken from some of the licensee's monitoring wells and collected independent samples from some residents nearest to the site boundary. The NRC sample results were consistent with the licensee's results.

The licensee identified tritium levels between 1,400 and 1,600 pCi/L in one residential drinking water well. The tritium levels detected in that well were below the Environmental Protection Agency (EPA) drinking water standard of 20,000 pCi/L. The tritium levels also corresponded to calculated doses that are well below the corresponding NRC dose limits. The remaining residential well samples had no measurable tritium above normal background levels. However, the licensee's monitoring identified an area of contaminated groundwater that extended about 2,000 to 2,500 feet north of the site boundary. Initial measurements by the licensee and independent measurements by the NRC confirmed that gamma-emitting radionuclides and Strontium-90 (Sr-90) were not detected in the contaminated groundwater.

NRC inspectors reviewed the origin of the tritium contamination with the licensee's staff. Based on the information presented and the licensee's measurements, the inspectors confirmed that the measured levels of tritium in the environment were consistent with past leakage of the vacuum breakers on the circulating water blowdown line. That line normally carried nonradioactive water back to the Kankakee River but also served as a dilution pathway for planned liquid radioactive releases. The line was about 5 miles long and contained 11 vacuum breakers that compensated for pressure transients within the line from liquid surges. A map of the blowdown line is included in Attachment B.[2]

The licensee's investigation identified that significant unplanned radioactive releases from three of these vacuum breakers during 1996, 1998, and 2000 and other minor releases between 1996 and 2005 entered the groundwater system. The 1996 event resulted in the leakage of an estimated 250,000 gallons of water. The 1998 and 2000 events each resulted in a leakage of an estimated 3,000,000 gallons of water. Each leak from a vacuum breaker occurred over a period coincident with ongoing, liquid radioactive releases through the blowdown line. NRC inspectors reviewed the licensee's effluent release documents for the time periods described above and confirmed that the intended releases would have met NRC requirements if the releases had been made to the Kankakee River.

The inspectors reviewed the licensee's radiological monitoring and assessments performed during March 2005 through March 2006, to characterize the extent of groundwater contamination from blowdown line vacuum breaker leakage. Specifically, the inspectors reviewed: (1) the licensee's characterization report, which documented the local hydrogeology around the facility through the installation of groundwater monitoring wells on licensee-owned property around the blowdown line; (2) the licensee's sampling and analysis program, which included groundwater and drinking water samples from private wells near the blowdown line; and (3) the licensee's evaluation of blowdown line integrity, which included acoustical monitoring of the line. The inspectors compared the licensee's results to the independent analysis performed by

[2]Attachment B, which is not included in this appendix, contained Braidwood site maps and groundwater tritium plume maps.

the NRC's contract laboratory to evaluate the accuracy of the licensee's measurements (see Attachment C).[3]

NRC inspectors independently estimated the extent and magnitude of the groundwater tritium contamination through NRC's contract analysis of water samples collected from residential drinking wells near the facility and from shallow monitoring wells installed by the licensee. The NRC's contract laboratory analyzed the samples for tritium contamination. In addition, the NRC's contract laboratory analyzed selected samples for other radionuclides using gamma spectroscopy, and analyses have also been performed for Sr-90 and Technetium-99 (Tc-99). The contract laboratory also utilized special techniques to identify "difficult to detect" radionuclides, such as Iron-55 (Fe-55), Nickel-63 (Ni-63), and transuranic elements.

The NRC's results confirmed that tritium was present in one off-site residential well at levels of about 1,300 to 1,500 pCi/L, which is a small fraction of the EPA drinking water standard of 20,000 pCi/L. In all other residential wells, no measurable levels of tritium or other licensed radioactive material above normal background have been detected. In a deeper on-site groundwater well, the NRC measured tritium as high as 282,000 pCi/L. Measurable levels of tritium have been found off-site in shallow monitoring wells and in a pond located near the plant boundary (see Attachment B).

Estimated Off-site Radiation Doses

Exelon released a report in March 2006 that assessed the potential off-site radiation doses that could have been received by members of the public from exposure to tritium that reached the off-site environment around the Braidwood Station following the blowdown line releases. The following paragraphs summarize the results of this study, which is included in its entirety in Attachment D.[4]

Conservative exposure scenarios were evaluated to develop bounding dose estimates—the highest reasonable radiation doses that could have

[3]Attachment C, which is not included in this appendix, contained Exelon's groundwater sample results and NRC's split sample results.

[4]Attachment D, which is not included in this appendix, contained an assessment of the off-site doses from inadvertent releases of water from the blowdown line at Braidwood Station from Exelon's 2005 Annual Effluent Report to NRC.

been received by members of the public. These conservative scenarios were then evaluated in more detail to develop realistic estimates of dose. The methodology of NRC Regulatory Guide 1.109 was used as the basis for estimating doses from all scenarios.

The estimated bounding dose to a member of the public was about 0.16 millirem per year (mrem/yr) from ingestion of drinking water from a residential groundwater well containing tritium from a vacuum breaker release. The highest realistic estimates of radiation dose were from the same drinking water scenario. The estimated maximum realistic dose was 0.068 mrem/yr with an average or expected value about one-half that or 0.034 mrem/yr. When doses from the realistic exposure scenarios were summed, the maximum dose was estimated to be 0.072 mrem/yr. Table 5 lists these dose estimates.

The estimated doses from the vacuum breaker releases at the Braidwood Station are well below the design objective of 6 mrem/yr for the two-unit site provided in Title 10 of the Code of Federal Regulations Part 50 (10 C.F.R. *50*, Appendix I). The doses are even further below the 100 mrem/yr regulatory dose limit for a member of the public provided in 10 C.F.R. 20, Subpart D. The estimated radiation dose represents a negligible increased risk—less than 0.1 percent of the risk from natural background radiation—to members of the public.

Table 5: Doses to the Public from Vacuum Breaker Releases (mrem/yr)

Exposure scenario	Minimum	Average (expected)	Maximum
Drinking well water (2 adults)	~0	0.034[a]	0.068[b]
Eating fish from Exelon Pond (multiple individuals)	0	0.0011	0.0034
Maximum individual summed dose	~0	<0.04	<0.072

Source: Exelon (from NRC).

[a]Based on average individual drinking water ingestion rate of 370 liters per year (L/yr).

[b]Based on maximum individual drinking water ingestion rate of 730 L/yr.

Site Groundwater Contamination

Attachment B includes maps created by Exelon that illustrate the groundwater tritium plumes at Braidwood from 2006 through 2010. Attachment E[5] from Braidwood's 2009 Environmental Report to NRC provides more recent diagrams of groundwater sampling locations and sample results for tritium and Sr-90.

Sources

Hydrogeologic Investigation Report, Braidwood Generating Station, September 2006

Tritium Investigation, Braidwood Station, March 2006

Braidwood 2005 Radioactive Effluent Release Report

Braidwood 2005 Annual Radiological Environmental Operating Report

Braidwood 2009 Annual Radiological Environmental Operating Report

NRC Inspection Report for Braidwood May 25, 2006

Frequently Asked Questions Regarding Clean-Up Efforts at Braidwood

http://www.exeloncorp.com/PowerPlants/braidwood/tritiumproject/resources.aspx

U.S. Census Bureau, State and County QuickFacts, Will County, Illinois (http://quickfacts.census.gov/qfd/states/17/17197.html)

Case Study 2: Oyster Creek Generating Station

The following information was compiled from NRC reports, licensee-prepared reports to NRC, and Exelon's "Tritium Project" Web site.

Site Location and Demographics

The Oyster Creek Generating Station (OCGS) (see fig. 5), consisting of one boiling water reactor owned and operated by Exelon, is located on the Atlantic Coastal Plain Physiographic Province in Ocean County, New

[5]Attachment E, which is not included in this appendix, contained Exelon's 2009 groundwater sampling reports and results for Braidwood.

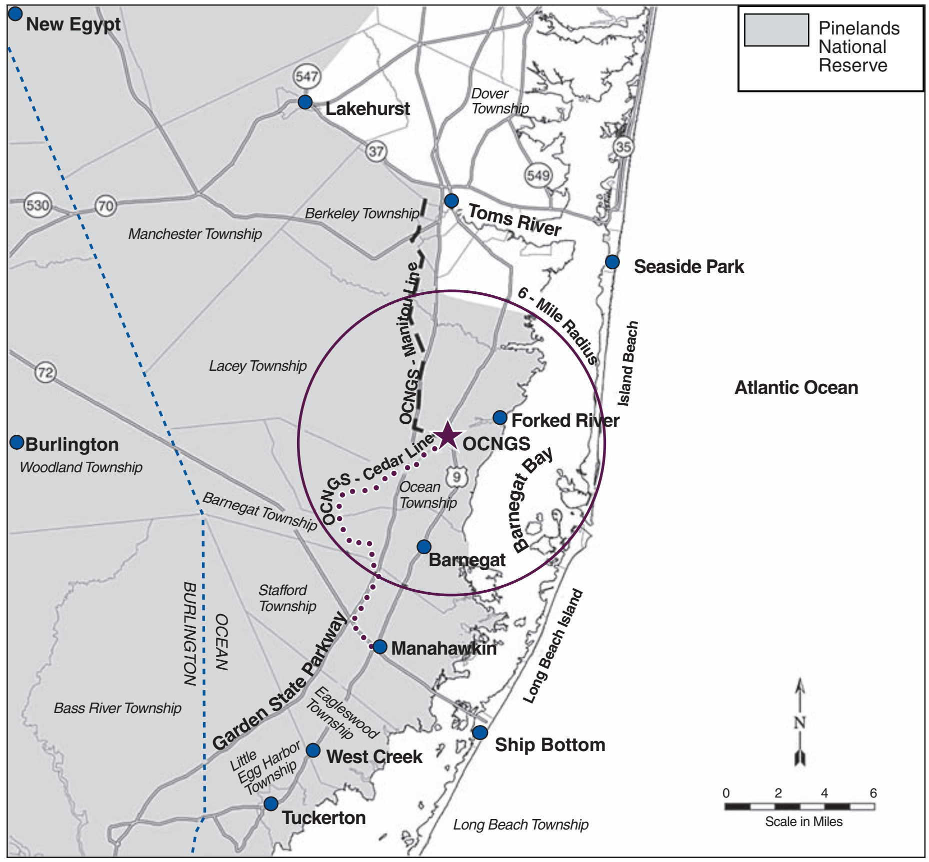
Jersey, about 60 miles south of Newark, 9 miles south of Toms River, and 35 miles north of Atlantic City. As illustrated in figure 6, the site, covering approximately 781 acres, is situated partly in Lacey Township and, to a lesser extent, in Ocean Township. Access is provided by U.S. Route 9, passing through the site and separating a 637-acre eastern portion from the balance of the property west of the highway. The station is about one-quarter mile west of the highway and 1¼ miles east of the Garden State Parkway. The site property extends about 2½ miles inland from the bay; the maximum width in the north-south direction is almost 1 mile (see fig. 7). The site location is part of the New Jersey shore area with its relatively flat topography and extensive freshwater and saltwater marshlands. The South Branch of Forked River runs across the northern side of the site, and Oyster Creek partly borders the southern side.

Figure 5: Oyster Creek Generating Station

Source: NRC.

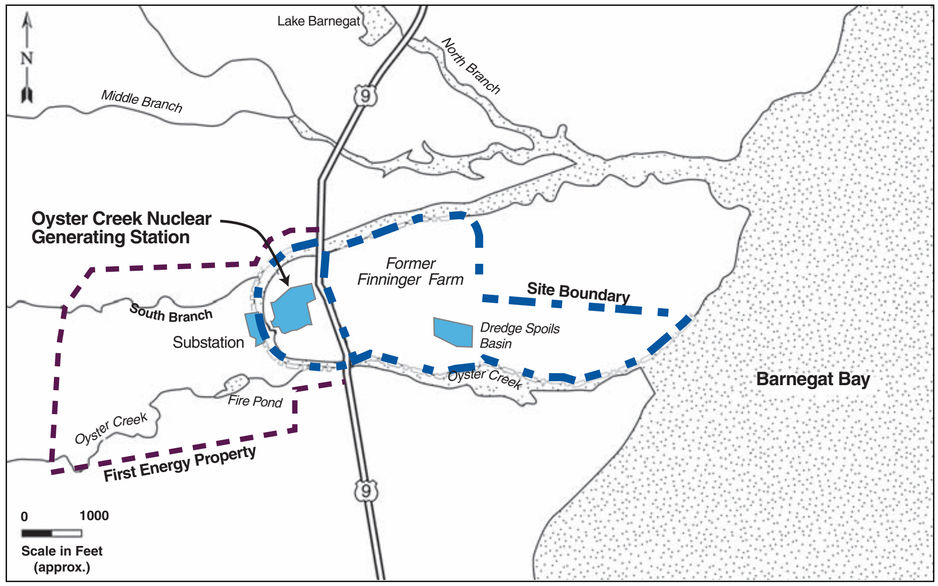
Note: This photograph was not included in the information packet sent to the experts.

Figure 6: Location of Oyster Creek Generating Station



Source: AmerGen (from NRC).

Figure 7: Oyster Creek Generating Station Site Boundary



Source: AmerGen (from NRC).

In 2000, 434,476 people were living within 20 miles of OCGS, resulting in a density of 610 persons per square mile (persons/mi^2). At the same time, 4,243,462 persons were living within 50 miles of the plant, for a density of 1,132 persons/mi.^{2} Land use in the Ocean County is primarily forest (45 percent of total land area), recreation (16 percent), and government (16 percent), with a smaller land area occupied by residential (7 percent), industrial (3 percent), and commercial land uses (1 percent).

Description of the Environment Near Oyster Creek Generating Station

The Generic Environmental Impact Statement for OCGS submitted by NRC as a part of license renewal contains a detailed description of the environment near Oyster Creek Generating Station. An excerpt of this report is enclosed in Attachment A.[6] Aspects of the environment that are described in this excerpt include land use, water use, water quality, air quality, aquatic resources, and terrestrial resources.

[6]Attachment A, which is not included in this appendix, contains an excerpt from Oyster Creek's Generic Environmental Impact Statement prepared for relicensing.

Surrounding Land Use

A Land Use Survey was conducted during 2009 around OCGS. The purpose of the survey was, in part, to determine the location of animals producing milk for human consumption in each of the 16 meteorological sectors out to a distance of 5 miles from the OCGS. None were observed. Another purpose of the survey was to determine the location of gardens greater than 500 square feet in size producing broad leaf vegetation, as well as the closest residence within each of the 16 meteorological sectors. The distance and direction of all locations from the OCGS Reactor Building were determined using Global Positioning System technology. The results of this survey are summarized below.

Table 6: Oyster Creek Generating Station Land Use Survey Results

Distance in miles from the OCGS reactor building		
Sector	**Residence (miles)**	**Garden[a] (miles)**
N	1.1	2.2
NNE	0.6	1.8
NE	0.7	1.0
ENE	1.1	1.2
E	1.2	None
ESE	0.7	0.4
SE	0.6	0.4
SSE	0.9	1.0
S	1.6	1.7
SSW	1.7	4.3
SW	1.7	None
WSW	2.0	None
W	None	None
WNW	None	None
NW	5.3	None
NNW	1.5	2.3

Source: Exelon (from NRC).

[a]Greater than 500 ft^2 in size producing broad leaf vegetation.

Underground Piping System Leaks

There were two underground piping system leaks at OCGS in 2009 that released tritiated water into the environment. The first was identified in April 2009, and the second was identified in August 2009.

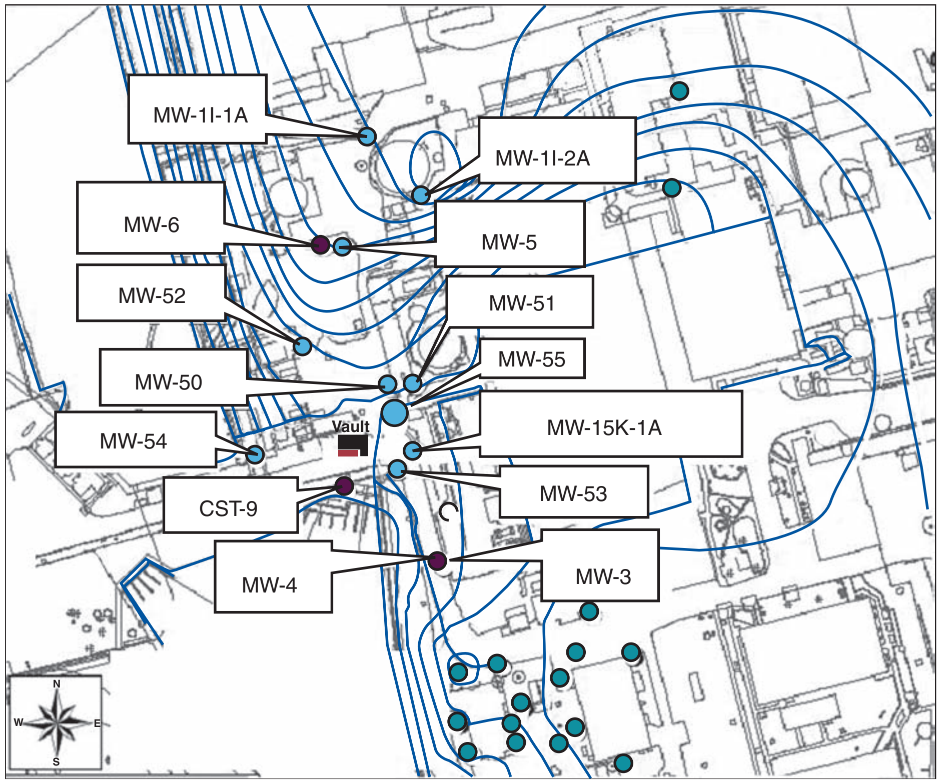
April 2009 Condensate Storage Tank Pipe Leak

On April 15, 2009, in preparation for work inside the Emergency Service Water (ESW) vault, water was found inside the vault. As part of standard practices for water removal, the water was pumped into drums and sampled for gamma emitters, tritium, and pH. Sample analysis identified tritium levels at 102,000 pCi/L. Exelon collected and controlled the water in the vault by pumping it (about 3,000 gallons) into 55-gallon drums for storage and processing.

On April 17, 2009, Exelon received analytical results from monitoring well MW-15K-1A (see fig. 8), which indicated a tritium concentration of about 4.46 million pCi/L. MW-15K-1A is located south of the ESW cable vault. According to Exelon, MW-15K-1A was last sampled on March 10, 2009, as one of about 32 wells routinely sampled and analyzed as part of its on going groundwater monitoring program at OCGS. No tritium or other radionuclides, were detected in any wells above minimum detectable activity (MDA) at that time, including well MW-15K-1A. Additionally, on March 25, 2009, Exelon conducted routine sampling of its on-site potable water sources. The results of the sample indicated no tritium or other radionuclides were detected in the potable water above MDA.

During its investigation of the leak, Exelon installed six additional groundwater monitoring wells (MW-50 through 55) to support characterization of the tritium in the groundwater (see fig. 8). These wells were predominately to the east of the intake structure.

Figure 8: Oyster Creek Well Locations Associated with Buried Pipe Leak



Source: Exelon (from NRC).

Root Cause Analysis

An investigation determined that the release of tritiated water was caused by leaks in the 8-inch and 10-inch carbon steel Condensate System lines. The root cause investigation determined that the piping leaks developed due to a corrosion mechanism known as anodic dissolution. Poor application of pipe coating left the buried pipes susceptible to this corrosion.

Estimated Dose to Public

A bounding calculation of the doses was done. A total of 66 Curies of tritium was assumed to be released to the discharge canal over a 4-month period with a dilution flow of 500,000 gallons per minute (GPM). The total body and organ doses were both 6.06E-04 mrem.

In calculating doses, the licensee considered tritium as the only radionuclide and evaluated the following exposure pathways (and routes of exposure) for liquid effluents:

- drinking water,
- shoreline deposits,
- ingestion of fish, and
- ingestion of shellfish.

The receptors evaluated by the licensee included adults, teenagers, children, and infants. According to Oyster Creek's *Offsite Dose Calculation Manual*, the dose from liquid effluent is calculated to a person at the Route 9 bridge who consumes fish and shellfish harvested at that location.

August 2009 Condensate Transfer Pipe Leak

On August 24, 2009, an 8- to 10-gallon per minute leak was discovered in the condenser bay. The leak was coming from the turbine building west wall penetration housing the Condensate Transfer CH-5 line, the 6-inch Condensate Transfer Main Header. Two leaks were found in the pipe within the wall penetration. A tritium concentration of 1.08E+07 pCi/L was detected.

Root Cause Analysis

The root cause investigation determined the cause of the leak to be galvanic corrosion of the pipe.

Estimated Dose to the Public

A bounding calculation of the doses was done. A total of 2.06 Curies of tritium was assumed to be released to the discharge canal over a 7-day period with a dilution flow of 1E+06 GPM. The total body and organ doses were both 9.36E-06 mrem (see above for a discussion of the radionuclides, pathways, and receptors evaluated in calculating this dose).

Site Groundwater Contamination

The leaks have resulted in groundwater contamination at the site in the form of a tritium plume. Exelon's groundwater geology study indicates that the subsurface water flow containing the tritium plume under the OCGS site is contained within the shallow Cape May aquifer and the somewhat deeper Cohansey aquifer (see the tritium plume maps included in Attachment B).[7] The tritium contamination is slowly moving through the subsurface to the Oyster Creek intake/discharge canal, where it is diluted to nondetectable levels and subsequently discharged into the Barnegat Bay and onward to the Atlantic Ocean. A layer of clay that exists between the Cohansey aquifer and the much deeper Kirkwood drinking water aquifer greatly impedes water movement downward.

Plant-related radioactivity, including tritium, has not been detected at any off-site liquid discharge or groundwater environmental monitoring location. To date, the current on-site groundwater contamination condition at Oyster Creek has not exceeded any regulatory limits for liquid discharge releases.

Sources

Exelon Corporation's Oyster Creek Tritium Project Web site: http://www.exeloncorp.com/PowerPlants/oystercreek/tritiumproject/overview.aspx

Generic Environmental Impact Statement for License Renewal of Nuclear Power Plants, Regarding Oyster Creek Generating Station, January 2007

Oyster Creek Generating Station 2009 Annual Radiological Environmental Operating Report (http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-info.html)

Oyster Creek Generating Station 2009 Radioactive Effluent Release Report (http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-info.html)

Oyster Creek Generating Station Offsite Dose Calculation Manual, Revision 4

Oyster Creek Generating Station–NRC Integrated Inspection Report 2009004

Oyster Creek Generating Station–NRC Inspection Report 2009008 (Underground Piping Leak)

[7] Appendix B, which is not included in this appendix, contained maps of the groundwater tritium plumes at Oyster Creek Generating Station.

NRC Correspondence to the Honorable Senator Menendez (July 19, 2010)

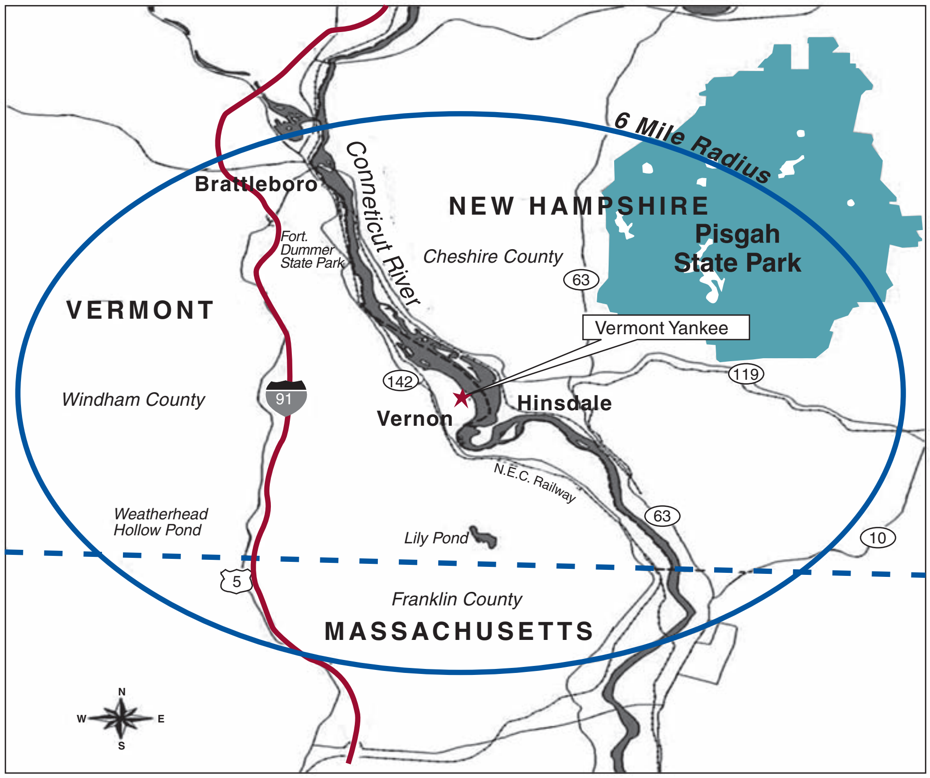
Case Study 3: Vermont Yankee Nuclear Power Station

The following information was compiled from NRC reports, licensee-prepared reports to NRC, and Entergy's Web site.

Site Location and Demographics

The Vermont Yankee Nuclear Power Station (VYNPS), consisting of one boiling water reactor owned and operated by Entergy, is located in the town of Vernon, Vermont, in Windham County on the west shore of the Connecticut River immediately upstream of the Vernon Hydroelectric Station and dam (see fig. 9). The 125-acre site, about 1 mile wide, is owned by Entergy Nuclear Vermont Yankee, LLC, and is situated on the west shore of the Connecticut River across from Hinsdale, New Hampshire, on the east side of the river. The property bounding the site to the north, south, and west is privately owned. VYNPS controls the river water between the northern and southern boundary fences extending out to the state border near the middle of the river. The site is located on Vernon Pond, formed by Vernon Dam and Hydroelectric Station located immediately downstream 0.75 miles from the VYNPS site. VYNPS employs a General Electric boiling water reactor nuclear steam supply system licensed to generate 1593 megawatts-thermal (MWt). The current facility operating license for VYNPS expires at midnight, March 21, 2012. The principal structures at VYNPS include a reactor building, primary containment, control building, radwaste building, intake structure, turbine building, cooling towers, and main stack. Entergy, with approval by the Vermont Public Service Board, is developing an independent spent fuel storage installation for dry cask storage using approximately 1 acre of site land to the north of the plant.

Figure 9: General Location of Vermont Yankee Nuclear Power Station



Source: Entergy (from NRC).

Figure 10: Site Location Photo of Vermont Yankee Nuclear Power Station

Source: NRC.

Note: This photograph differs from the photograph of VYNPS that was included in the information packet sent to the experts.

Description of the Environment near Vermont Yankee Nuclear Power Station

The Generic Environmental Impact Statement for VYNPS submitted by NRC as a part of license renewal contains a detailed description of the environment near VYNPS. An excerpt of this report is enclosed in Attachment A.[8] Aspects of the environment that are described in this excerpt include land use, water use, water quality, air quality, aquatic resources, and terrestrial resources. A brief description of a few of these characteristics is also summarized below.

[8]Attachment A, which is not included in this appendix, contained an excerpt from VYNPS's Generic Environmental Impact Statement prepared for relicensing.

Water Use

VYNPS does not use public water supplies for plant operations but instead relies on surface water from the Connecticut River and groundwater from on-site potable wells. The VYNPS is located on the west bank of Vernon Pool on the Connecticut River, about 0.75 mile upstream of the Vernon Hydroelectric Dam (Vernon Dam). Vernon Pool is the impounded portion of the Connecticut River directly upstream of the dam; it is both the source and receiving water body for the plant's cooling system. The pond covers 2,250 acres when full, and it is about a half-mile wide with a maximum depth of about 40 feet. The Connecticut River has an average daily flow of 10,500 cubic feet per second (cfs) at Vernon Dam. The Vernon Dam, owned and operated by TransCanada, regulates the river discharge to maintain a minimum sustained flow of 1,250 cfs, although under severe drought conditions, flow rates may drop below 1,250 cfs. There are a total of nine hydroelectric dams and three storage dams on the main stem of the Connecticut River upstream of the dam and three hydroelectric dams and one pumped-storage facility downstream of the dam.

Cooling Water

The VYNPS withdraws water daily for its variable cooling system from Vernon Pool on the Connecticut River. Cooling water can be circulated through the system in one of three modes of operation: open-cycle (also called once-through cooling), closed-cycle, or a combination hybrid cycle. The plant has the highest water usage in the open-cycle mode of operation, withdrawing up to 360,000 GPM (802 cfs) from Vernon Pond. In the closed cycle mode, the rate of water pumped is reduced to about 10,000 GPM (22 cfs). The rate of water withdrawn from Vernon Pool in the hybrid-cycle mode falls between that of the open- and closed-cycle modes.

Groundwater

In the vicinity of the major plant structures, groundwater is approximately 20 feet below ground surface. An inventory of potential sources of groundwater contamination within the source protection area (defined as a 500-ft radius) of each potable water supply well at the VYNPS is provided in source water protection plans for each well. The protection plans delineate management practices to reduce the potential risk of contamination of these wells and outline emergency response protocols for spills or other contamination events occurring within the source protection area.

Surface Water

The Vermont Water Resources Board classifies the Connecticut River at the station's point of discharge as Class B water. Class B waters are managed to achieve and maintain a level of quality that supports aquatic biota, wildlife, and aquatic habitat; have aesthetic value; and are suitable for public water supply with filtration and disinfection, for swimming and other water-based recreation, and for crop irrigation and other agricultural uses. Surface water quality is regulated through the EPA's National Pollutant Discharge Elimination System (NPDES) permit program. The State of Vermont has been delegated responsibility by the EPA for administration of the NPDES program in Vermont. In addition to the water quality parameters, the plant is also required to monitor the following:

- river flow rates on an hourly basis at Vernon Dam,
- temperatures on an hourly basis at River Monitoring Station 3 (0.65 mile downstream of the dam) and River Monitoring Station 7 (4 miles upstream of the plant), and
- concentrations of three metals (copper, iron, and zinc) via monthly grab samples.

Terrestrial Resources

About 35 acres (28 percent) of the VYNPS site currently is occupied by buildings and structures. Prior to construction of the station, the site was primarily pasture land with a few mature trees. The remainder of the site supports mowed grass and early successional habitat (66 acres; 53 percent), mixed deciduous and coniferous woodland (20 acres; 16 percent), shrubland (3 acres; 2 percent), and wetland (1 acre; 1 percent). In 2000, 153,409 people were living within 20 miles of VYNPS, for a density of 122 persons per square mile. At the same time, there were 1,513,282 persons living within 50 miles of the plant, for a density of 193 persons per square mile.

Surrounding Land Use

The area within a 5-mile radius of the plant is predominantly rural with the exception of a portion of the town of Brattleboro, Vermont, and the town of Hinsdale, New Hampshire. Between 75 and 80 percent of the area within 5 miles of the station is wooded. The remainder is occupied by farms and small industries. Downstream of the plant on the Connecticut River is the Vernon Hydroelectric Station.

The VYNPS *Offsite Dose Calculation Manual* requires that a Land Use Census be conducted annually between the dates of June 1 and October 1. The census identifies the locations of the nearest milk animal and the nearest residence in each of the 16 meteorological sectors within a distance of 5 miles of the plant. The census also identifies the nearest milk animal (within 3 miles of the plant) to the point of predicted highest annual average relative disposition values due to elevated releases from the plant stack in each of the three major meteorological sectors. The census results are included in table 7.

Table 7: Vermont Yankee Land Use Census Results

2009 Land use census locations[a]		
Sector	**Nearest residence Km (miles)**	**Nearest milk animal Km (miles)**
N	1.4(0.9)	n/a
NNE	1.4(0.9)	*5.5* (3.4) cows
NE	1.3 (0.8)	n/a
ENE	1.0(0.6)	n/a
E	0.9 (0.6)	n/a
ESE	1.9(1.1)	n/a
SE	2.0(1.2)	3.6 (2.2) cows [b]
SSE	2.1 (1.3)	n/a
S	0.6 (0.4)	2.2 (1.4) cows [b]
SSW	0.5 (0.3)	n/a
SW	0.4(0.3)	8.2 (5.1) cows
WSW	0.5 (0.3)	n/a
W	0.6 (0.4)	0.8 (0.5) cows
WNW	1.1 (0.7)	n/a
NW	2.3(1.4)	n/a
NNW	1.7(1.0)	n/a

Source: Exelon (from NRC).

[a]Sectors and distances are relative to the plant stack as determined by a Global Positioning System survey conducted in 1997.

[b]Location of nearest milk animal within 3 miles of the plant to the point of predicted highest annual average D/Q value in each of the three major meteorological sectors.

Underground Piping System Leaks

There were two reported underground piping system leaks at VYNPS in 2010, which released tritiated water into the environment. The leaks were reported on January 7, 2010, and on May 28, 2010. An investigation of the leaks determined the sources and Entergy incorporated corrective actions that included repairing the pipes, excavating contaminated soil, and extracting nearly 300,000 gallons of tritium-contaminated groundwater from the site.

A collection of wells on-site have been used since 1988 for testing groundwater to show compliance with VYNPS's Indirect Discharge Permit from the Vermont Department of Environmental Conservation. A total of 34 wells existed before January 2010. Many of them were used to verify that radioactivity and other contaminants did not pass from two septage spreading fields, one at the northern end of the site, and one at the southern end of the site. Of these 34 wells, 3 of them (GZ-1, GZ-3, and GZ-5) were specifically installed as part of the Nuclear Energy Institute's Groundwater Protection Initiative. The VYNPS shallow monitoring wells were drilled to a depth of about 30 feet with deeper monitoring wells at a depth of 60 to 70 feet. Potable water has traditionally been supplied to various site locations from 4 (350+ feet deep) on-site wells. In early 2010, as an additional safety precaution, use of the Construction Office Building on-site well for drinking water was discontinued.

Root Cause Analysis

An investigation into the release of tritiated water determined the following two root causes:

- inadequate construction and housekeeping practices employed when the Advanced Off-Gas (AOG) Building was constructed in the late 1960s and early 1970s, and when the AOG drain line was added in 1978, and
- ineffective monitoring and inspection of vulnerable structures, systems, and components that eventually leaked radioactive materials into the environment.

Furthermore, corrosion found in two pipes in the AOG pipe tunnel was considered a contributing cause of the leak. The report stated that pipes should not fail. If pipes do fail, the contents should be contained and kept from the environment, and any leaks that occur should be identified promptly.

Two additional identified organizational and programmatic causes included the fact that implementation of the Nuclear Energy Institute (NEI) NEI 07-07, "Industry Groundwater Protection Initiative," was not timely or complete, based upon: (1) Entergy's implementation of the NEI Industry Groundwater Protection Initiative, to date, had not adequately defined fleet, corporate, and VYNPS's accountabilities and (2) inadequate commitment by management to fully implement the NEI Industry Groundwater Protection Initiative. An NRC inspector noted that these organizational and programmatic issues involving groundwater monitoring were previously examined by the NRC (reference Inspection Report No. 05000271/2010006, dated May 20, 2010) and were consistent with the NRC's conclusions in that report.

Estimated Dose to Public and Assessed Safety Significance

Entergy Vermont Yankee is limited to the amount of radiation exposure that can be received if an individual were to stand at the company's property boundary 24 hours a day, 365 days a year. The limit at most nuclear sites is 100 mrem per year at the site boundary. At VYNPS, the limit agreed to by Entergy Vermont Yankee and the Vermont Department of Health is 20 mrem per year. VYNPS and the Vermont Department of Health each collect surveillance data from more than 1,300 different measurements of the air, water, milk, soil, vegetation, sediment, and fish each year.

VYNPS officials wrote a report that describes the course of their 2010 leak events, beginning with the discovery of the tritium leak that was reported by them in January 2010, the search for the source or sources of the leak, the identification of the AOG pipe tunnel leak and the soil contamination that resulted as nuclear reactor water passed from the failed pipes, out the pipe tunnel into the soil, and then into the groundwater. This report was not released to the public, but the Vermont Department of Health summarized major points of interest from this report that relate to public health and environmental protection.

According to the VYNPS report, there was "no nuclear, radiological or personnel safety significance." As evidence of this, it was pointed out that the AOG system is not safety-related and therefore the protection of the reactor and fuel was not jeopardized. The calculated dose from the methods of Vermont Yankee's *Offsite Dose Calculation Manual* was used to demonstrate the lack of radiological safety significance. This dose—0.00095 mrem per year—was compared to the NRC annual dose limit of 100 mrem per year and the EPA annual limit for the maximally exposed individual of 25 mrem per year, as evidence that there was no radiological safety significance.

The maximally exposed member of the public for dose assessment purposes was considered to be a child who consumed fish from the Connecticut River above the Vernon Dam and consumed food products grown with irrigated water from the Connecticut River below the Vernon Dam, and consumed drinking water downstream from the Connecticut River below the Vernon Dam. The child was assumed to consume 6.9 kilograms per year (kg/yr) of fish, 520 kg/yr of vegetables, 26 kg/yr fresh leafy vegetables, 41 kg/yr of meat, 330 L/yr of milk, and 510 L/yr of drinking water.

Site Groundwater Contamination

The 2010 identified leaks have resulted in groundwater contamination at the site in the form of a tritium plume. This condition did not result in any NRC regulatory limits related to effluent releases being exceeded. In 2010, the maximum concentration detected was 2,500,000 pCi/L. Ongoing sample results continue to confirm that no off-site environmental monitoring locations contain detectable levels of plant-related radioactivity, including tritium. See the map of the VYNPS tritium plume included in Attachment B.[9]

Sources

Generic Environmental Impact Statement for License Renewal of Nuclear Power Plants, Regarding Vermont Yankee Nuclear Power Station, August 2007

Vermont Yankee Nuclear Power Station License Renewal Application

Vermont Yankee Nuclear Power Station–Groundwater Monitoring Inspection Report 05000271/2010006

Vermont Yankee Nuclear Power Station–NRC Inspection and Review of Areas Identified in Demand for Information (Inspection Report 05000271/2010007)

Vermont Yankee Nuclear Power Station–NRC Inspection Report 05000271/2010009 (Root Cause Evaluation Report of Buried Piping Leak)

Vermont Department of Health Web site: http://healthvermont.gov/enviro/rad/yankee/graphics.aspx

Vermont Yankee Web site: http://www.safecleanreliable.com/03252010-release.html

[9]Attachment B, which is not included in this appendix, contained a map of the groundwater tritium plume at VYNPS.

Appendix III: Comments from the Nuclear Regulatory Commission

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

May 23, 2011

Ms. Kim Gianopoulos, Assistant Director
Natural Resources and Environment
Government Accountability Office
441 G Street, NW
Washington, D.C. 20548

Dear Ms. Gianopoulos:

I would like to thank you for the opportunity to review and submit comments on the April 2011 draft of the U.S. Government Accountability Office (GAO) report, "Oversight of Underground Piping Systems Commensurate with Risk, but Proactive Measures Could Help Address Future Leaks."

In general, the U.S. Nuclear Regulatory Commission (NRC) agrees with the draft GAO report and believes it to be fair and balanced. The NRC also agrees with each of the report recommendations and has already established activities to address them. In particular, the report recommends that the agency staff "periodically evaluate the extent to which the industry's voluntary Groundwater Protection Initiative will result in prompt detection of leaks and, based upon these evaluations, determine whether the agency should expand its groundwater monitoring requirements." The NRC routinely inspects nuclear power plant licensees using NRC Inspection Procedure 71124.06, "Radioactive Gaseous and Liquid Effluent Treatment," dated December 2, 2009. This procedure requires the NRC to inspect licensee Groundwater Protection Initiative Programs by reviewing reported groundwater monitoring results and changes to the licensee's written program for identifying and controlling contaminated spills or leaks to groundwater. The public can be assured that the NRC will continue to review the status of industry implementation of the initiative and consider regulatory changes as appropriate. We believe these activities are in accordance with the GAO recommendation.

With respect to the second recommendation, considering the compendium of information about degradation of buried piping and direct measurement on samples of buried piping, and given the industry's Groundwater Protection Initiative, which includes risk ranking of piping systems based on potential for, and consequences of, failure as well as follow-on inspections, the staff believes there is reasonable assurance that the underground piping systems will remain structurally sound and thus meet their licensing basis function(s). We agree with GAO's associated recommendation for the NRC to stay abreast of industry research to develop technologies and evaluate costs and benefits to determine whether regulatory requirements should be expanded. The NRC has already established milestones in the staff's Buried Piping Action Plan

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(ML102590171) to periodically assess both the performance of available inspection technology and the need to make changes to the current regulatory framework.

The enclosure provides specific technical comments concerning the NRC's plans and activities related to groundwater protection and buried and underground piping and tanks.

Should you have any questions about these comments, please contact Mr. Jesse Arildsen of my staff at (301) 415-1785 or at Jesse.Arildsen@nrc.gov.

Sincerely,

for

R. W. Borchardt
Executive Director
For Operations

Enclosure:
NRC Technical Comments Regarding
GAO Draft Report, GAO-11-563

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the individual named above, Kim Gianopoulos, Assistant Director; Nancy Crothers; Mark Gaffigan; Cindy Gilbert; Anne Hobson; Karen Keegan; Jonathan Kucskar; Diane Lund; Jaclyn Nidoh; and Timothy Persons made key contributions to this report. Joyce Evans, Jena Sinkfield, and Cynthia S. Taylor provided technical assistance.

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