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

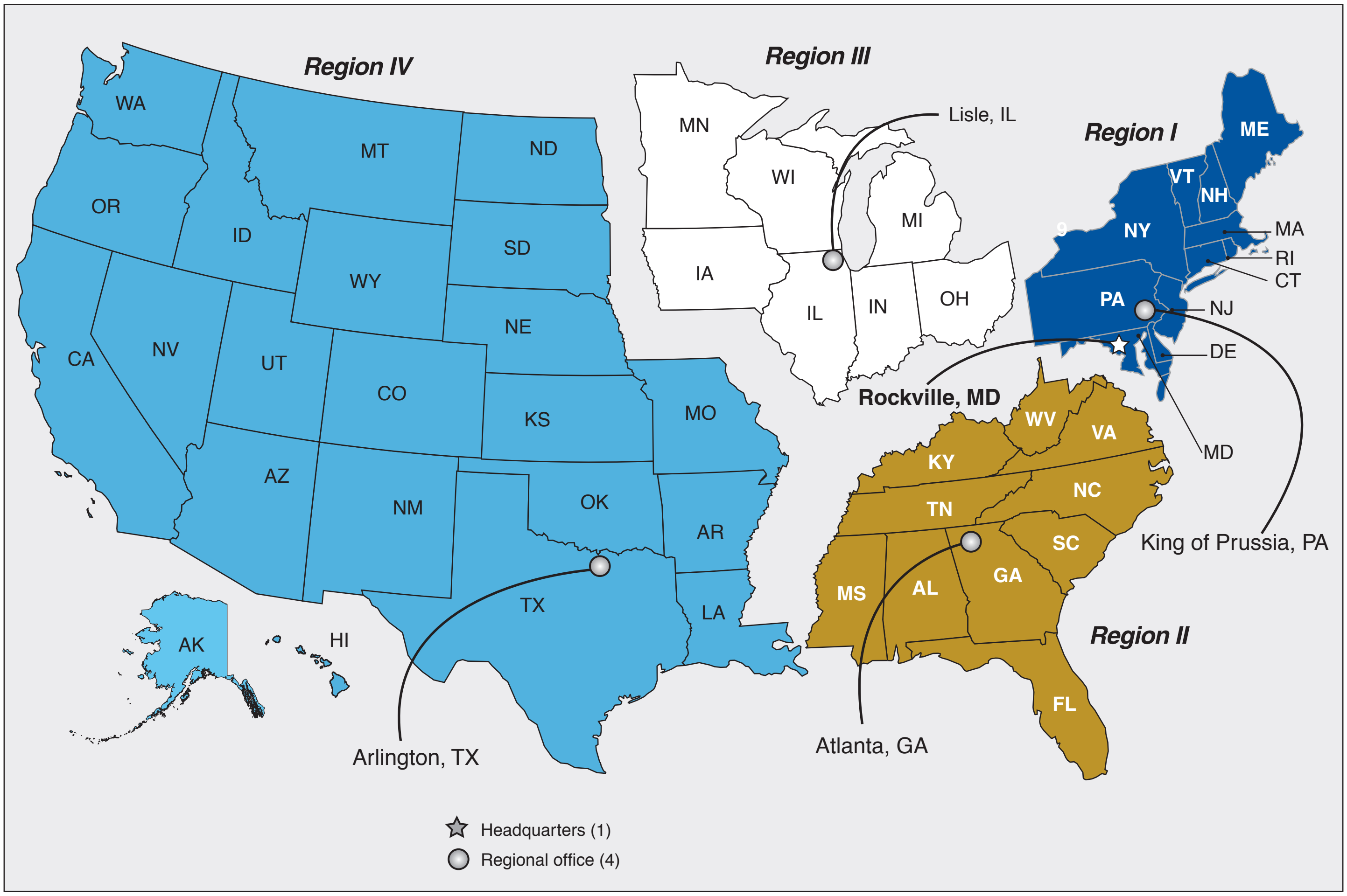
Discussion Group on Environmental Impacts

- 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.

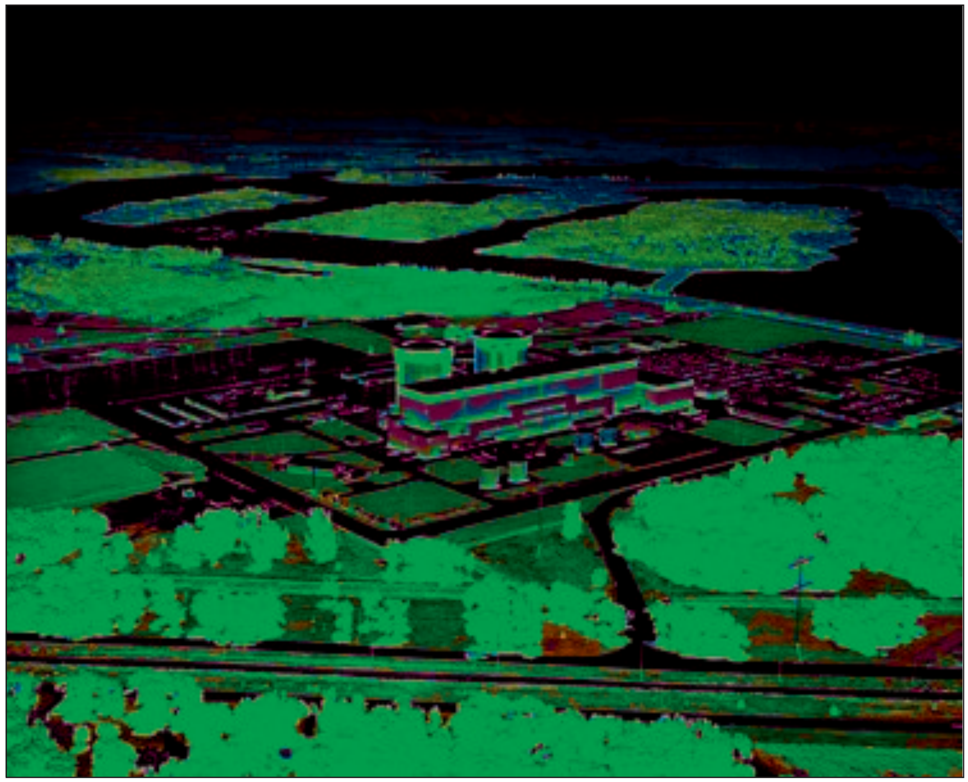
Case Study 1: Braidwood Generating Station

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.

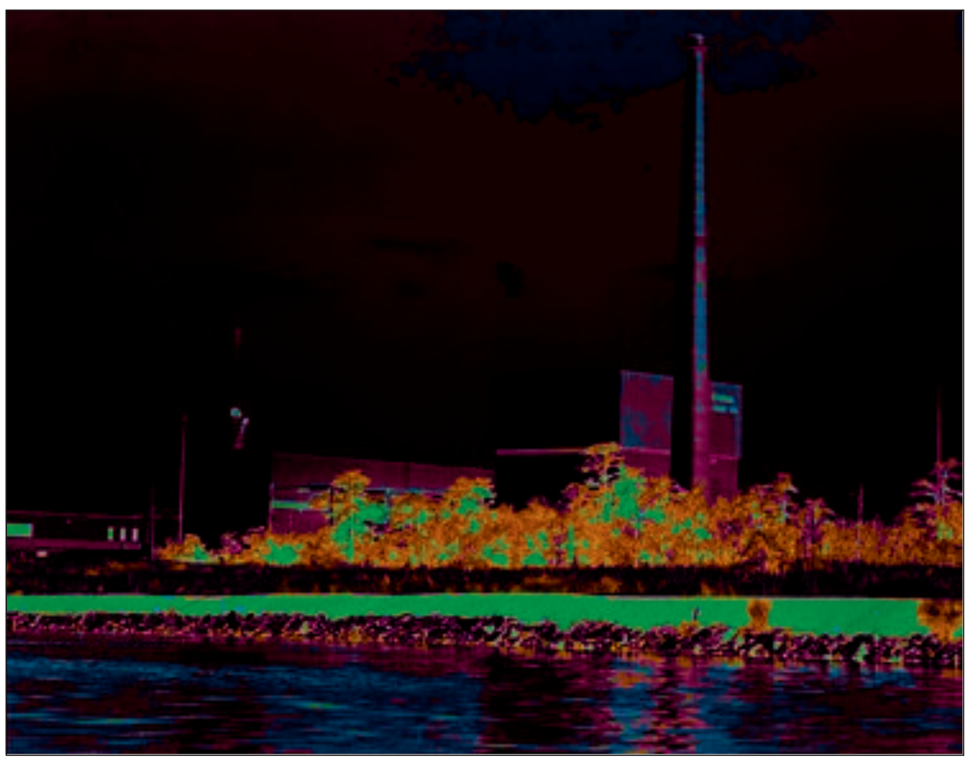
Site Location and Demographics

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.

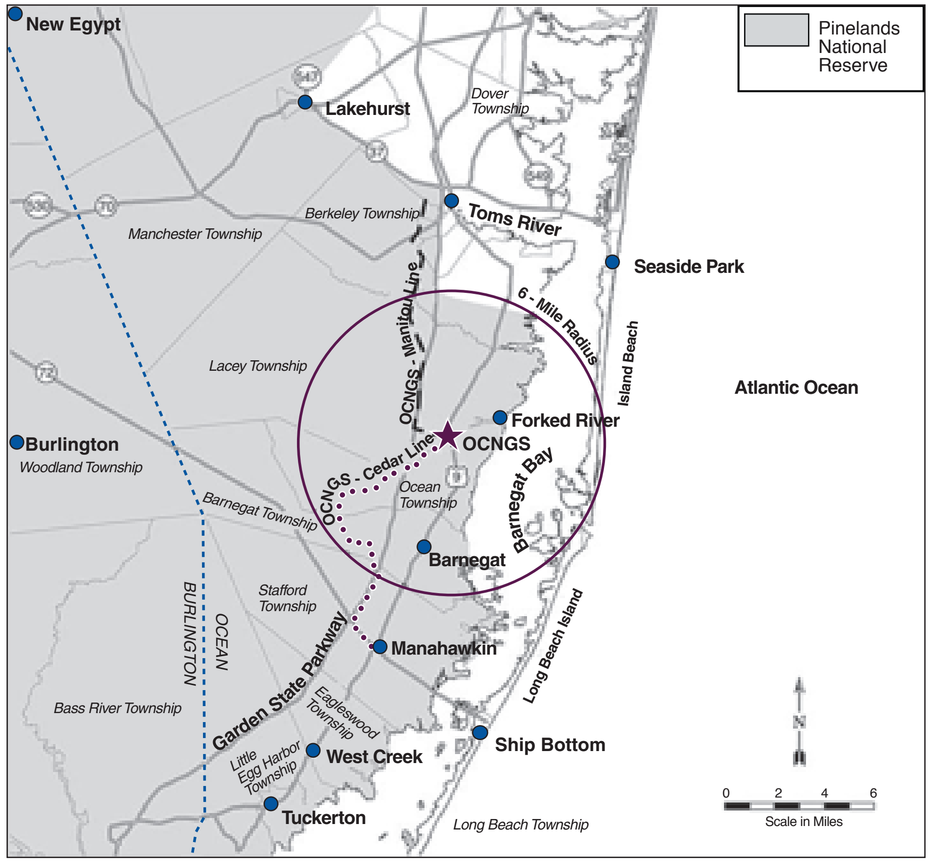
Figure 5: Oyster Creek Generating Station



Source: NRC.

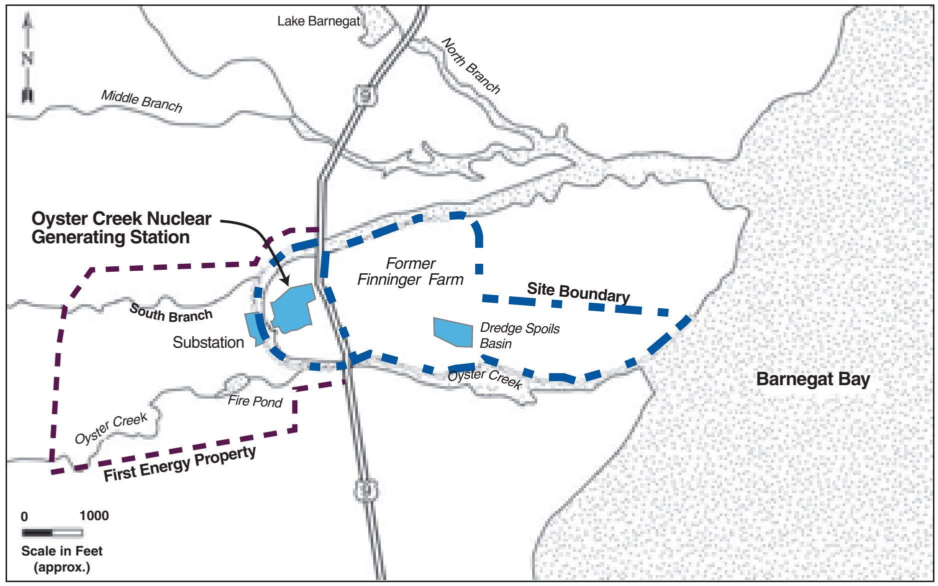
Note: This photograph was not included in the information packet sent to the experts.

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.

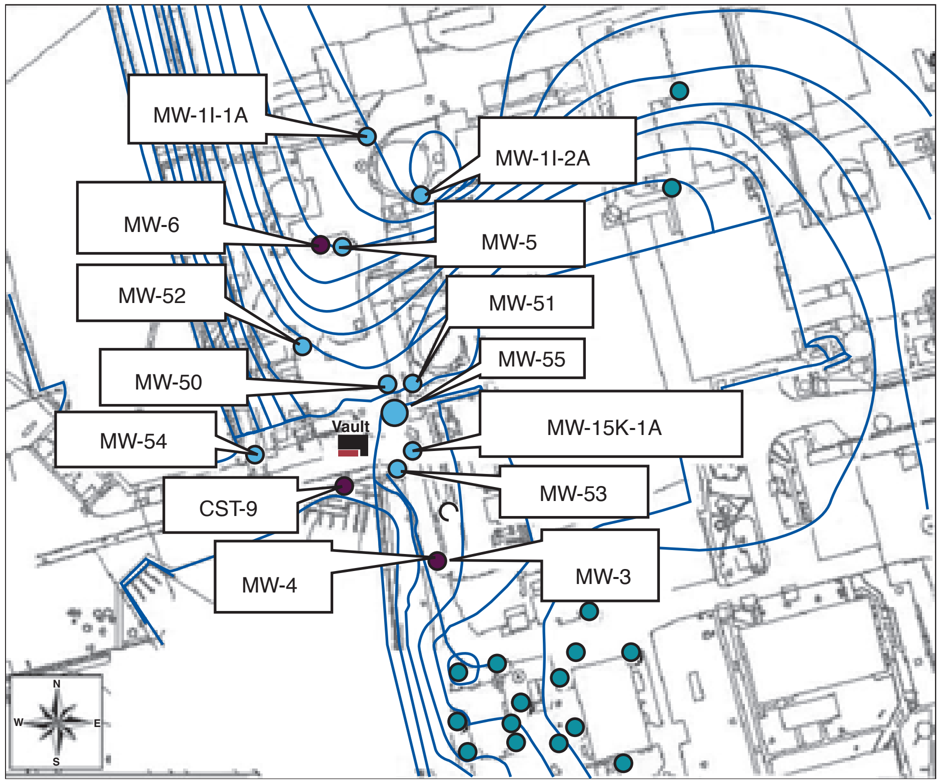
April 2009 Condensate Storage Tank Pipe Leak

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)

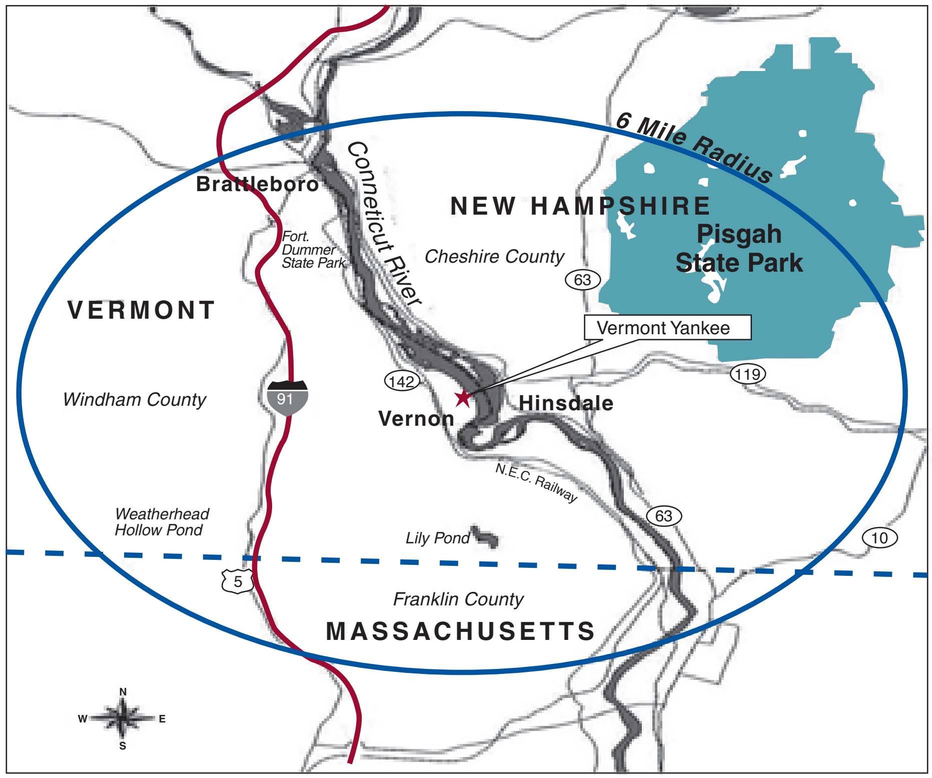
Case Study 3: Vermont Yankee Nuclear Power Station

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

Site Location and Demographics

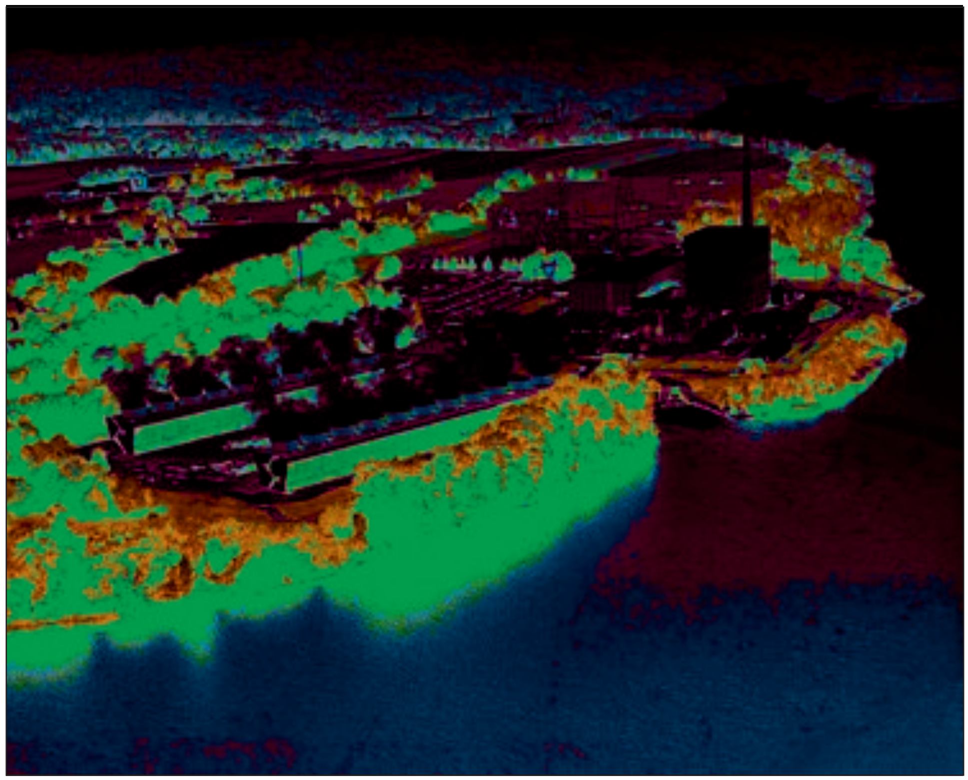
The Vermont Yankee Nuclear Power Station (VYNPS), consisting of one boiling water reactor owned and operated by Entergy, is located in the town of Vernon, Vermont, in Windham County on the west shore of the Connecticut River immediately upstream of the Vernon Hydroelectric Station and dam (see fig. 9). 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.

K. Gianopoulos - 2 -

(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,

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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