Too Close to Home

Nuclear Power and the Threat to Drinking Water

U.S. PIRG Education Fund

Environment America Research & Policy Center

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Executive Summary

The Fukushima Daiichi nuclear disaster, which took place in March 2011, delivered a reminder to the world that nuclear power comes with inherent risks. Over a period of several days, three Japanese nuclear reactors suffered meltdowns. A large amount of radioactive material escaped into the environment over the ensuing months.

Among the risks demonstrated by the Fukushima crisis is the threat of water contamination—including contamination of drinking water supplies by radioactive material. In the wake of the Fukushima accident, drinking water sources as far as 130 miles from the plant were contaminated with radioactive iodine, prompting cities such as Tokyo to warn against consumption of the water by infants.

In the United States, 49 million Americans receive their drinking water from surface sources located within 50 miles of an active nuclear power plant —inside the boundary the Nuclear Regulatory Commission uses to assess risk to food and water supplies.

Airborne contamination in the wake of a nuclear accident is not the only threat nuclear power poses to water supplies. Leakage of radioactive material into groundwater is a common occurrence at U.S. nuclear power plants, even if the amount of radioactivity released is tiny compared to that released at Fukushima. In addition, U.S. nuclear power plants draw their cooling water supplies from critical waterways nationwide—making those water supplies the natural destination for spilled or dumped radioactive liquid, and putting them at risk of contamination in a Fukushima-type accident.

Because of the inherent risks of nuclear power, the United States should ensure that all currently operating nuclear power plants are, at the latest, retired at the end of their operating licenses and the nation should move toward cleaner, safer solutions such as energy efficiency and renewable energy for our future energy needs.

The Fukushima nuclear accident contaminated a large area, and threatened drinking water over an even larger area.

- The Japanese government required residents of communities within 12.4 miles (20 kilometers) of the plant to evacuate, and encouraged voluntary evacuation for residents within 18.6 miles (30 kilometers (km)) of the plant.

- The U.S. government urged its citizens to leave areas within 50 miles of the plant.

- Months after the accident, citizens continue to find "hotspots" of radiation outside the evacuation zone. The Japanese government has evacuated some areas outside the initial evacuation boundary. Many areas within the boundary may be uninhabitable for decades.

- Airborne radiation contaminated drinking water supplies outside the evacuation zone, including 130 miles away in Tokyo. The village of Iitate, 28 miles from the plant, kept a warning in place regarding drinking water consumption through May 10.

- A large amount of radioactive water escaped into the ocean, through leaks and the dumping of 11,500 tons of seawater that was used to cool the reactor during the emergency.

According to data from the U.S. Environmental Protection Agency, Americans in 35 states drink water from sources within 50 miles of nuclear power plants. New York has the most residents drawing their drinking water from sources near power plants, with the residents of New York City and its environs making up most of the total. Pennsylvania has the second most, including residents of Philadelphia, Pittsburgh, and Harrisburg.

The Indian Point plant in New York is close to the water supplies of the greatest number of people; 11 million New York, Connecticut, and New Jersey residents drink water from sources near the plant. Twenty-one different nuclear plants sit within 50 miles of the drinking water sources serving more than 1 million people. Of these plants, six share the same General Electric Mark I design as the crippled reactors at Fukushima.

Table ES-1: Top 10 States by Population Relying on Water Intakes within 50 Miles of Nuclear Plants

Rank	State	Total Population Relying on Water Sources within 50 miles of Nuclear Plants
1	New York	9,974,602
2	Pennsylvania	6,651,752
3	Massachusetts	4,821,229
4	North Carolina	3,753,495
5	New Jersey	3,286,373
6	Ohio	2,844,794
7	California	2,362,188
8	Virginia	2,022,349
9	Michigan	1,521,523
10	Connecticut	1,511,605

A total of 12 million Americans draw their drinking water from sources within 12.4 miles (20 km) of a nuclear plant. All land within 20 km of the Fukushima Daiichi plant has been mandatorily evacuated to protect the public from exposure to radiation. Some areas within, and even outside, that radius may remain uninhabitable for decades.

Major cities, including New York, Boston, Philadelphia, San Diego, Cleveland and Detroit receive their drinking water from sources within 50 miles of a nuclear plant. New York City receives its drinking water from within 20 km of the Indian Point nuclear station.

Water contamination is not only a threat in the event of a major nuclear accident. 75 percent of U.S. nuclear plants have leaked tritium, a radioactive form of hydrogen that can cause cancer and

Table ES-2: Top 10 Plants by Population Receiving Drinking Water from Intakes within 50 Miles

Rank	Plant	State	Population
1	Indian Point	New York	11,324,636
2	Seabrook	New Hampshire	3,921,516
3	Limerick	Pennsylvania	3,901,396
4	*Vermont Yankee*	Vermont	3,114,882
5	Salem / *Hope Creek*	New Jersey	2,900,971
6	San Onofre	California	2,295,738
7	Perry	Ohio	2,132,775
8	Beaver Valley	Pennsylvania	1,878,905
9	Shearon Harris	North Carolina	1,686,425
10	McGuire	North Carolina	1,646,516

(Italics indicate reactors with GE Mark I containments.)

Table ES-3: Top 10 Plants by Population Receiving Drinking Water from Intakes within 12.4 Miles (20 km)

Rank	Plant	State	Population
1	Indian Point	New York	8,359,730
2	Limerick	Pennsylvania	923,538
3	McGuire	North Carolina	895,538
4	Surry	Virginia	422,300
5	Oconee	South Carolina	378,899
6	Three Mile Island	Pennsylvania	262,149
7	Peach Bottom	Pennsylvania	243,368
8	Shearon Harris	North Carolina	206,414
9	Waterford	Louisiana	103,818
10	Beaver Valley	Pennsylvania	80,626

genetic defects. Tritium can contaminate groundwater and drinking water, and has been found at levels exceeding federal drinking water standards near U.S. nuclear power plants.

- A tritium leak from the spent fuel pool at New York's Indian Point Energy Center, discovered in 2005, went undetected long enough for radioactive water to reach the Hudson River.
- Tritium leaking from underground pipes at Braidwood Nuclear Generating Station in Illinois reached nearby drinking water wells; the leak was discovered in fall 2005.

Table ES-4: Largest Water Systems with Intakes within 50 Miles of Nuclear Plants

	System	State	Population Served
1	New York City System	NY	8,000,000
2	MWRA (Boston and Southeastern MA)	MA	2,360,000
3	Philadelphia Water Department	PA	1,600,000
4	Cleveland Public Water System	OH	1,500,000
5	City of San Diego	CA	1,266,731
6	City of Detroit	MI	899,387
7	Aqua Pennsylvania Main System (Philadelphia Suburbs)	PA	820,000
8	Charlotte-Mecklenburg Utility	NC	774,331
9	United Water NJ (Bergen County)	NJ	773,163
10	City of Fort Worth	TX	727,575

Table ES-5: Largest Water Systems with Intakes within 12.4 Miles (20 km) of Nuclear Plants

	System	State	Population Served
1	New York City System	NY	8,000,000
2	Aqua Pennsylvania Main System (Philadelphia Suburbs)	PA	820,000
3	Charlotte-Mecklenburg Utility	NC	774,331
4	City of Newport News	VA	406,000
5	Greenville Water System	SC	345,817
6	United Water of New York (Rockland County)	NY	270,000
7	Town of Cary	NC	149,000
8	Chester Water Authority	PA	124,649
9	Harford County D.P.W.	MD	104,567
10	United Water of Pennsylvania (Dauphin County)	PA	97,645

The Fukushima nuclear reactor used seawater as a source of emergency cooling for the stricken reactors, with large releases of radioactivity to the Pacific Ocean. U.S. nuclear reactors draw their cooling water from a variety of important waterways, including:

- The Atlantic and Pacific oceans and the Gulf of Mexico.
- Three of the five Great Lakes (Michigan, Erie and Ontario).
- Key inland waterways such as the

Mississippi, Ohio, Delaware, Columbia, Susquehanna and Missouri rivers.

The inherent risks posed by nuclear power suggest that the United States should move to a future without nuclear power.

The nation should:

- Retire existing nuclear power plants, at the latest, at the end of their current operating licenses.
- Abandon plans for new nuclear power plants.
- Adopt policies to expand energy efficiency and production of energy from clean, renewable sources such as wind and solar power.

In the meantime, the United States should reduce the risks nuclear power poses to water supplies by:

- Completing a thorough safety review of U.S. nuclear power plants and requiring plant operators to implement recommended changes immediately.
- Ensuring that emergency plans account for the potential impacts of drinking water contamination to residents outside the current 50-mile boundary used in planning.
- Requiring nuclear plant operators to implement regular groundwater tests in order to catch tritium leaks.
- Enforcing laws against tritium leaks by fining plant operators for unauthorized releases of radioactive materials.
- Require that nuclear waste be stored as safely as possible, preferably by using hardened dry cask storage (which reduces the risk associated with spent fuel pools).
- Requiring plants to take steps—such as construction of on-site storage capacity for contaminated water—to prevent the release of radioactive water in the event of an accident. Plant operators should have a plan to contain the amount of water that they anticipate using to flood the reactor in a worst-case scenario.

Introduction

Nuclear power plants rely on water.

Water is the medium by which the heat unleashed from a nuclear reaction is harnessed to generate steam to turn a turbine and create electricity. Water also plays a critical role in cooling both nuclear power plants and spent nuclear fuel.

Nuclear power plants, however, aren't friendly to the water resources on which they rely. Nuclear power plants with "once-through" cooling systems draw vast amounts of water from aquatic ecosystems and return that water to those ecosystems, usually at a higher temperature. The cooling water intakes for nuclear power plants can ingest large numbers of aquatic organisms and can trap sea turtles and other larger animals against their intake screens. Plants with cooling towers take in less water and pose a lesser danger to aquatic organisms, but send a greater share of the water they do use up in steam.

Over the past year, America and the world have come to appreciate anew the threats nuclear power can pose to drinking water supplies and precious waterways.

In March 2011, authorities in Tokyo warned parents not to allow infants to drink tap water. The water—drawn from a source 130 miles away from the stricken Fukushima Daiichi nuclear power plant—contained elevated levels of radioactive iodine, a short-lived substance capable of causing thyroid damage.

While the advisories in Tokyo and other communities outside the Fukushima evacuation zone were lifted shortly thereafter, longer-lived radioactive substances—such as cesium-137—have continued to be detected in drinking water, though not at levels that would trigger immediate health warnings.

In the wake of the discovery of radioactive iodine in the Tokyo drinking water supply, the authors of this report requested information from the U.S. Environmental Protection Agency (EPA) on the location of drinking water intakes within 20 kilometers and 30 kilometers of U.S. nuclear power plants (the evacuation zones used by Japanese authorities) and within 50 miles (the zone from which the U.S. government urged its citizens to evacuate following the Fukushima disaster, and the radius that the Nuclear Regulatory Commission (NRC) uses to plan for the risk of food and water contamination in a nuclear accident).

The locations of drinking water intakes

are protected information for homeland security reasons. However, EPA management agreed to identify public drinking water systems whose surface water intakes are within the designated radii. The data produced from this EPA analysis form the basis of much of this report.

The months since the Fukushima disaster have only underscored the concerns Americans should have about the potential for radioactive contamination of water. The recent revelations of widespread, routine releases of radioactive tritium from U.S. nuclear power plants, coupled with the discharge of vast amounts of radioactivity through cooling water from the Fukushima plant to the Pacific Ocean, demonstrate that while radioactive contamination of water is not the only public health concern posed by nuclear power plants, it is a significant one.

The Fukushima Disaster Threatened Drinking Water Supplies

The Meltdowns at Fukushima: What Happened?

On March 11, 2011, a massive earthquake—9.0 on the Richter scale—occurred underwater off Japan's east coast. The earthquake, in turn, triggered a tsunami that rapidly inundated areas near the ocean.

One of Japan's nuclear power plants, Fukushima Daiichi, stands along the coast in the area hit by the tsunami. The plant shut down and went to emergency power as soon as the earthquake occurred, but lost power to its emergency systems as the tsunami flooded its underground generators and electrical rooms, and knocked down the power lines that provided off-site emergency power to the facility. Without emergency cooling, fuel rods inside the plant's reactors began to heat up, boiling off much of the water inside the reactor vessels.

Within days, and perhaps hours (since the plant has not yet been brought back under control, experts have not had the chance to examine it and develop an exact understanding of how the accident proceeded), three reactors at the plant melted down, and in at least one case molten nuclear fuel melted through the reactor's pressure vessel, breaching the first level of containment surrounding it.[1] In fact, the entire core of one of the reactors may have melted through the reactor vessel and eaten some way into the concrete underlying the reactor vessel.[2] As operators vented steam and gases from the pressure vessels to pump in more water, a series of hydrogen explosions took place, damaging the reactor buildings and possibly the containment structures at several reactors.[3] (Those explosions took place despite the fact that the Fukushima plant was equipped with the same "hardened" vents that U.S. nuclear plants rely on to prevent hydrogen accumulation.[4])

Rising pressure in the reactor vessels forced the operators to vent radioactive steam to the atmosphere on a number of occasions. Radioactivity at the site periodically spiked, indicating that other leaks were allowing material to escape from the damaged reactors. On one occasion, workers had to withdraw from the plant to protect their health when radiation levels rose too high for even short-term exposure.[5]

A large amount of radioactive material also escaped into the ocean, through both intentional dumps and uncontrolled leaks of radioactive water. Damage from the earthquake allowed radioactive water to escape into the plant grounds and the ocean. One particularly large leak poured highly radioactive water from Reactor #2 into the ocean for five days in early April before operators managed to seal it.[6] Within the plant, workers discovered pools of heavily radioactive water. In one case, two workers walked through water with 10,000 times the normal level of radioactivity found in coolant water; both had to be treated for severe burns from the radiation.[7] Unable to contain all the radioactive water that leaks and the cooling process were producing, the plant's operators were forced to release 11,500 tons of contaminated water (about 2.8 million gallons, or enough water to fill a one-acre pond to a depth of eight and a half feet) in order to free storage space for even more radioactive waste.[8] At times, the level of radioactive iodine present in seawater near the plant rose to 1,250 times the legal limit.[9] The French nuclear monitoring agency, in an October 2011 report, stated that the Fukushima disaster was the greatest single instance of nuclear contamination of the ocean, raising cesium-137 levels in global seawater to above the levels that prevailed during atmospheric nuclear testing in the 1960s.[10]

Investigators have not yet pinpointed all the sources of radioactive releases, or the exact amounts of radioactivity involved, but the Fukushima plant clearly released a large amount of radiation into the ocean and atmosphere—with the ocean receiving a larger portion of the radiation.[11] Efforts to contain and clean up the disaster continue at the plant; as of November 2011, none of the three reactors have been brought fully under control, and workers continue to detect previously unknown instances of extremely high radiation outside the reactor vessels.[12]

How Nuclear Fuel Threatens Drinking Water

Nuclear fuel is an extremely hazardous substance. Reactor fuel rods contain not only uranium, but also other radioactive isotopes produced by the process of atomic fission. Several of those radioisotopes are present in large quantities, and move through the environment in a way that makes it likely for people to be exposed to them through food and drinking water if released in an accident.

Radiation comes in several forms, all of which damage cells and DNA. Electromagnetic radiation—in the form of either gamma rays or x-rays—can travel through the air and harm people who spend time near a radiation source.[13] Alpha and beta radiation—particles emitted from atomic nuclei—cannot travel very far but do severe damage to cells if they are released from within the body, which can happen after a person drinks contaminated water or inhales contaminated dust.[14] Acute exposure—likely only in the case of severe radioactive accidents—results in immediate sickness, and possibly death.[15] Longer term exposure raises the risk of cancer and other illnesses, such as anemia and cataracts.

A small number of radionuclides pose the greatest threat of contamination through food and water:

- **Radioactive Iodine:** Uranium fission produces iodine-131, a short-lived radioisotope with a half-life (the amount of time it takes for half of a radioactive substance to break down) of 8 days, as a by-product. Iodine-131 dissolves easily in water,

Radioactive Half-Lives

Because radioisotopes break down at different rates, they remain hazardous in the environment for different lengths of time. The decay rate of radioisotopes is measured in half lives—the amount of time it takes for half of the radionuclides in a given sample to decay.

For instance, iodine-131 has a half life of 8 days. If you started with a sample of 1,000 I-131 atoms, 8 days later 500 of those atoms would remain, while the other 500 would have decayed into stable, non-radioactive isotopes. After another 8 days, 250 would be left; 8 days after that, 125.

Although each case of contamination is different, a common rule of thumb is that a radioactive element remains a threat for 10 half-lives, after which it has presumably decayed enough to release only very small amounts of radiation.[16]

and can escape into cooling water from cracked fuel rods.[20] People can be exposed to radioactive iodine by drinking contaminated water or eating contaminated food. In the human body, iodine concentrates in the thyroid gland. Exposure to radioactive iodine can cause short-term thyroid problems, which lead to hormone imbalance, and increase the risk of thyroid cancer over the longer term.[21] Radioactive iodine released during the Chernobyl accident led to elevated rates of thyroid cancer in the nearby population, particularly in children under 10.[22]

- **Radioactive Cesium:** Another fission product that travels easily through the environment and into the body is cesium-137. Cesium-137 remains in the environment for a relatively long period of time, with a half-life of 30 years (lingering cesium-137 from atmospheric nuclear weapons testing accounts for an appreciable portion of the background radiation to which people are regularly exposed).[23] It dissolves in water, and can be ingested with drinking water or food. It disperses throughout the body, and increases the long-term risk of cancer.[24]

- **Radioactive Strontium:** Strontium-90 is a third fission product that can travel through the environment and threaten human health. Strontium-90 has a half life of 29 years, and emits radiation in the form of beta particles (which cause damage when released from within the body). Because it is chemically similar to calcium, 20 to 30 percent of the strontium a person consumes is incorporated into his or her bones and remains in the body over the long term, increasing the risk of bone cancer.[25]

- **Tritium:** Tritium is a radioactive isotope of hydrogen that is produced in reactors. Unlike the other elements described, which dissolve into water, tritium is actually incorporated into water molecules in place of ordinary hydrogen. Tritium has a half life of

12.3 years. It can cause cancer and raise the risk of genetic abnormalities in future generations.[26] It does not accumulate in the body, but poses a threat if it is consumed regularly over a period of time.[27]

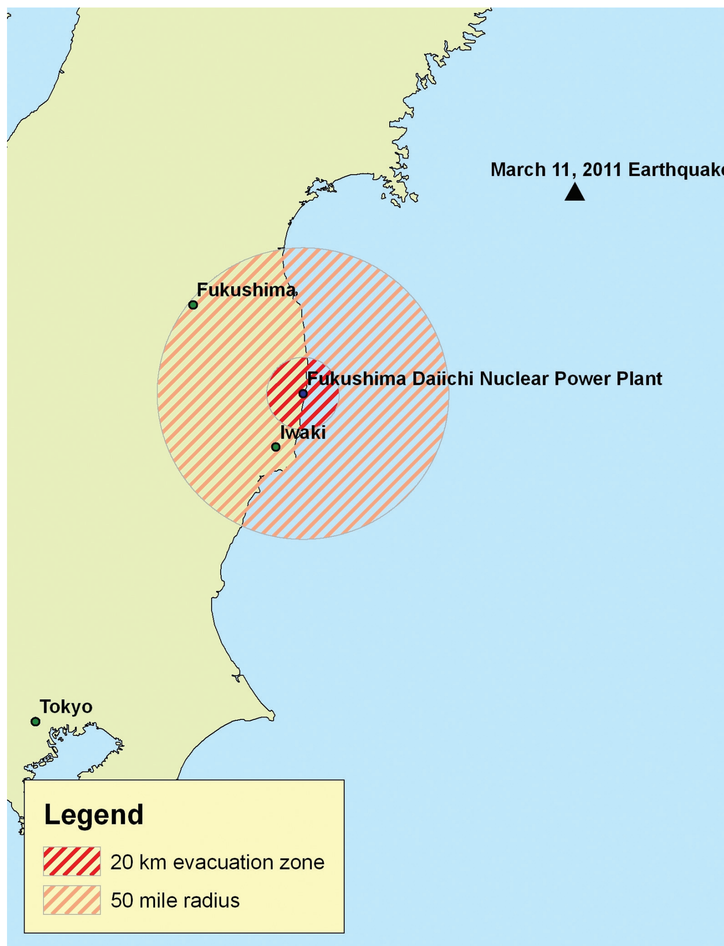
Impacts of the Fukushima Disaster on Water Resources

The Fukushima nuclear disaster led to restrictions on consumption of drinking water in areas near the plant.[28] All areas within 12.4 miles (20 km) of the plant were evacuated, but drinking water supplies at even greater remove were contaminated by radioactive iodine from the power plant during the days and weeks following the initial accident.

Estimates vary as to the exact amount, but a significant quantity of radiation was clearly released into the air during the several months following the Fukushima accident. About 80 percent of the radioactive material released did not land in Japan, due to prevailing winds that pushed most of the material released out to sea.[29] The airborne radiation that did head toward land forced the evacuation of a 12-mile radius area surrounding the plant, with radiation "hotspots" as far away as the city of Date—over 40 miles from the plant, more than three times as far away as the boundary of the main evacuation zone—requiring evacuation.[30] Locations where radiations levels exceeded the recommended maximum annual dose for civilians were detected as far away as the outskirts of Tokyo.[31]

The largest city to have its water supply affected by the Fukushima disaster was Tokyo, which provides drinking water to 12 million people through its metropolitan water system. On March 22—11 days after the earthquake and tsunami—radioactive iodine was detected at the Kanamachi water treatment plant, a facility 130 miles from Fukushima Daiichi, which treats water from the Tone River system.[32] The radioactive isotope was present at over twice the level the Japanese government deems safe for infant consumption.[33] By March 25, concentrations fell back to levels not believed to cause immediate health problems.[34]

Other cities experienced contamination for longer periods of time. Several communities had safety warnings in place through April 1, and the village of Iitate in Fukushima Prefecture, 28 miles from



Airborne radioactive particles from the Fukushima power plant affected drinking water quality in Tokyo, well outside the 50 mile radius used to plan for contamination around U.S. nuclear plants.

the plant, kept a warning against infant consumption of municipal water in place through May 10.[35]

Each of these communities, however, is beyond the 20 kilometer evacuation zone. Drinking water within the evacuation zone surrounding the plant has not been tested, since the residents who would consume it have been evacuated, but areas within the zone have been found to have radiation levels as high as 25 times the safe threshold, and may be uninhabitable for decades.[36]

The impacts of the Fukushima disaster, moreover, were not limited to water contamination resulting from airborne releases of radioactivity. The use of seawater to provide emergency cooling for the reactors and spent fuel pools at the plant resulted in the discharge of large amounts of radioactivity to the Pacific Ocean. At times, the level of radioactive iodine present in seawater near the plant rose to 1,250 times the legal limit.[37] Radioactive substances have been detected in soil samples from the seabed both near the nuclear reactor and as much as 18.6 miles (30 kilometers) away, as well as in animal plankton and fish.[38]

The events at Fukushima lead to legitimate questions about the potential impact of a similar accident in the United States, as well as to the impact of other events that can lead to radioactive contamination of water supplies.

U.S. Nuclear Power Plants and Their Threats to Water

Nuclear accidents of the scale of the Fukushima disaster are rare events, but the occurrence of such a disaster within the United States would have devastating impacts. Millions of Americans draw their drinking water from sources near nuclear power plants, while the discharge of radioactivity from a stricken reactor to the waterways on which reactors rely for cooling would impose lasting damage to critical waterways. In addition, Americans have reason to be concerned about the continued release of radioactive tritium to groundwater at U.S. nuclear reactors—releases that, while they pose only a tiny fraction of the danger imposed by a Fukushima-type accident, are steadily ongoing and signal deep reason for concern about the safety of the nation's aging nuclear fleet.

Airborne Releases of Radioactive Substances in the Event of an Accident

Airborne radioactive releases—the source of the contamination that entered Tokyo's drinking water—can take place in a number of different ways.

- **Deliberate releases of steam**: Operators attempting to cool a reactor may be forced to vent steam to the atmosphere to relieve pressure inside the reactor vessel.
- **Accidents involving spent fuel pools**: Spent fuel pools at nuclear plants contain large amounts of radioactive material kept outside of protective containment structures. If water drains from those pools, fuel rods can catch fire, lofting radioactive material into the atmosphere.
- **Breaches of containment**: If a meltdown or explosion breaches the airtight reactor vessel and containment building that active nuclear fuel is held in, radioactive material can escape in steam or ejected material.

Once in the air, radioactive elements can travel significant distances before coming to land. Areas near the plant are likely to receive the heaviest concentrations, although weather patterns can cause deposition to be uneven.[39]

Rainstorms can increase the risk that airborne radioactive releases pose to drinking water supplies. By capturing airborne particles and washing particles deposited on land into waterways, they can cause a sudden infusion of radionuclides into bodies of water, including rivers and reservoirs that provide the source for drinking water systems.

According to data provided by the U.S. Environmental Protection Agency (EPA), **approximately 49 million Americans receive their drinking water from sources within 50 miles of a nuclear power plant**—the "ingestion pathway emergency planning zone" used

Table 1: Top 10 Nuclear Plants by Population Receiving Drinking Water from Intakes within 50 Miles

Rank	Plant	State	Total Population
1	Indian Point	New York	11,324,636
2	Seabrook	New Hampshire	3,921,516
3	Limerick	Pennsylvania	3,901,396
4	Vermont Yankee	Vermont	3,114,882
5	Salem / Hope Creek	New Jersey	2,900,971
6	San Onofre	California	2,295,738
7	Perry	Ohio	2,132,775
8	Beaver Valley	Pennsylvania	1,878,905
9	Shearon Harris	North Carolina	1,686,425
10	McGuire	North Carolina	1,646,516

Table 2: Top 10 Nuclear Plants by Population Receiving Drinking Water from Intakes within 12.4 Miles (20 km)

Rank	Plant	State	Total Population
1	Indian Point	New York	8,359,730
2	Limerick	Pennsylvania	923,538
3	McGuire	North Carolina	895,538
4	Surry	Virginia	422,300
5	Oconee	South Carolina	378,899
6	Three Mile Island	Pennsylvania	262,149
7	Peach Bottom	Pennsylvania	243,368
8	Shearon Harris	North Carolina	206,414
9	Waterford	Louisiana	103,818
10	Beaver Valley	Pennsylvania	80,626

Table 3: Ten Largest Drinking Water Systems with Intakes within 50 Miles and 12.4 Miles (20 km) of Nuclear Plants

	20 km			50 miles		
	System	State	Population Served	System	State	Population Served
1	New York City System	NY	8,000,000	New York City System	NY	8,000,000
2	Aqua Pennsylvania Main System (Philadelphia suburbs)	PA	820,000	MWRA (Boston and Southeastern MA)	MA	2,360,000
3	Charlotte-Mecklenburg Utility	NC	774,331	Philadelphia Water Department	PA	1,600,000
4	City of Newport News	VA	406,000	Cleveland Public Water System	OH	1,500,000
5	Greenville Water System	SC	345,817	City of San Diego	CA	1,266,731
6	United Water of New York (Rockland County)	NY	270,000	City of Detroit	MI	899,387
7	Town of Cary	NC	149,000	Aqua Pennsylvania Main System (Philadelphia Suburbs)	PA	820,000
8	Chester Water Authority	PA	124,649	Charlotte-Mecklenburg Utility	NC	774,331
9	Harford County D.P.W.	MD	104,567	United Water NJ (Bergen County)	NJ	773,163
10	United Water of Pennsylvania (Dauphin County)	PA	97,645	City of Fort Worth	TX	727,575

by the NRC in planning for food and water contamination in the event of an accident.[40]

Approximately 12 million Americans receive their water from a source within 20 kilometers of a nuclear plant—a radius that corresponds with the evacuation zone around the Fukushima Daiichi plant, and an area in which many residents may not be able to resettle for years, if not decades.[41] Any drinking source within 50 miles of a nuclear power plant is at clear risk of contamination in the event of an accident; sources within 20 km are at the highest risk of contamination, are likely to receive the heaviest doses of radiation, and may remain contaminated for longer than more distant sources.

The Indian Point nuclear plant in New York sits within 50 miles of drinking water sources serving 11 million people, more than any other plant, and within 12.4 miles (20 km) of water sources serving 8 million people. (See Table 1.)

Twenty-one nuclear plants sit within 50 miles of the drinking water sources of 1 million or more people.[42] Of those plants, six are boiling water reactors using General Electric Mark I containment structures—the same type of reactor and containment that failed at Fukushima.[43] Regulators have been aware since the 1970s that the Mark I structure is particularly vulnerable to releasing nuclear material in the event of a meltdown, as happened at Fukushima.[44]

It is important to note that large cities often draw their water supplies from sources far away from the cities themselves. The Vermont Yankee nuclear power plant, for example, sits roughly 84 miles from Boston. However, Boston's water supply comes from the Quabbin Reservoir in western Massachusetts, which is well within 50 miles of the Vermont Yankee plant. (The owners of Vermont Yankee, an aging plant which has suffered repeated leaks, a cooling tower collapse, a fire, and other equipment failures since 2004, are currently suing the state of Vermont in an attempt to continue operating past 2012.[45])

The largest city to draw its drinking water supply from a source near a nuclear power plant is New York City, where the Delaware Aqueduct draws from reservoirs and pumping stations close to Indian Point Energy Center. Notable among these are the Chelsea pumping station, less than 12.4 miles (20 km) from the plant, and the West Branch Reservoir, 16.7 miles from the plant.[46] Other cities depend on water sources near particularly high-risk plants; San Onofre Nuclear Generating Station, near the city of San Diego's water supply, sits near a fault line, and recent research has suggested that the earthquake risk at the site could be much higher than the plant's designers prepared for.[47] Other major cities with drinking water sources located near power plants include Boston, Philadelphia and Cleveland, where populations of 2.3 million, 1.6 million, and 1.5 million, respectively, rely on drinking water sources with intakes located within 50 miles of nuclear facilities.[48]

Residents of 35 states draw their drinking water from sources within 50 miles of nuclear plants. Some of those states do not contain a plant themselves, but border states with nuclear power plants. Maine and Indiana, for instance, have no operating nuclear plants within their borders, but obtain drinking water from sites proximate to nuclear power plants in other states.

Table 4: Top 10 States by Population Receiving Drinking Water from Intakes within 50 Miles and 12.4 Miles (20 km) of Nuclear Plants

	20 km		50 miles	
	State	Population Affected	State	Population Affected
1	New York	8,406,192	New York	9,974,602
2	Pennsylvania	1,414,196	Pennsylvania	6,651,752
3	North Carolina	1,101,952	Massachusetts	4,821,229
4	South Carolina	456,966	North Carolina	3,753,495
5	Virginia	426,532	New Jersey	3,286,373
6	Maryland	117,719	Ohio	2,844,794
7	Louisiana	104,730	California	2,362,188
8	Massachusetts	93,444	Virginia	2,022,349
9	Michigan	92,752	Michigan	1,521,523
10	Ohio	92,031	Connecticut	1,511,605

Releases of Radioactivity to Cooling Water Sources in the Event of an Accident

Nuclear power plants rely on nearby sources of water for cooling. About 40 percent of U.S. nuclear reactors, like the reactors at Fukushima, use once-through cooling systems, in which large volumes of water are taken from the ocean, a river or a lake, circulated through the plant, and then returned to the original water body, often at higher temperature.[49] The remainder of U.S. plants use recirculating cooling systems—incorporating either cooling towers or cooling ponds—that reduce the amount of water needed for routine cooling.

During the Fukushima disaster, emergency responders used large quantities of seawater—pumped into the plant directly, sprayed from fire trucks, and even at one point dropped from above by helicopter—in a desperate attempt to cool the reactors and their spent fuel pools. Contaminated seawater then leaked and was dumped back into the ocean, carrying radioactivity from the plant with it.

Most of the radioactive material was released during the early stages of the Fukushima accident in the form of contaminated water that leaked or was deliberately dumped into the ocean.[50]

U.S. nuclear power plants draw their cooling water from a wide variety of sources. Some, like Fukushima, are on the coastline and draw cooling water from the sea. Others sit on inland waterways or one of the Great Lakes. Still others rely on groundwater or wastewater supplies for cooling. Of the nation's 66 nuclear plants, 44 draw their cooling water from inland bodies of water, while 22 draw on the Great Lakes, ocean water or another source.

The release of radioactivity to cooling water sources—as occurred at Fukushima—has the potential, therefore, to harm important water bodies nationwide. The waterways that U.S. nuclear power plants rely on for cooling water include:

- The Atlantic and Pacific oceans and the Gulf of Mexico.
- Three of the five Great Lakes (Michigan, Erie and Ontario).
- Key inland waterways such as the Mississippi, Ohio, Delaware, Columbia, Susquehanna and Missouri rivers.

Table 5 includes a complete list of cooling water sources for U.S. nuclear power plants.

Tritium Leaks Can Threaten Drinking Water Near Reactors

Even in the absence of a nuclear disaster, radionuclides can escape from nuclear plants and make their way into nearby groundwater and drinking water. These leaks, while less dramatic—and with far less dire impact on public health than the radioactive releases from the Fukushima disaster—can go undetected for months or years, allowing significant levels of radioactive material to accumulate outside of plant boundaries.

The most common radionuclide found to have leaked from nuclear plants is tritium, a radioactive form of hydrogen. In a few cases, more hazardous isotopes have also escaped; strontium-90 was found outside Indian Point Energy Center in 2005, and cesium-137 was found outside Fort Calhoun Nuclear Generating Station in 2007.[55] (Indian Point, which sits alongside the Hudson River, is 25 miles away from New York City.[56]) All of these isotopes are dangerous in drinking water. Tritium, if ingested over time in sufficient quantities, can raise the long-term risk of cancer.[57]

Table 5: Cooling Water Sources of U.S. Nuclear Plants[51]

Nuclear Plant	State	Name of Water Source
Browns Ferry	AL	Wheeler Reservoir
Joseph M. Farley	AL	Chattahoochee River
Arkansas Nuclear One	AR	Lake Dardanelle
Palo Verde	AZ	Sewage effluent
Diablo Canyon	CA	Pacific Ocean
San Onofre	CA	Pacific Ocean
Millstone	CT	Long Island Sound
Crystal River	FL	Gulf of Mexico
St. Lucie	FL	Atlantic Ocean
Turkey Point	FL	Biscayne Bay
Edwin I. Hatch	GA	Altamaha River
Vogtle	GA	Savannah River
Duane Arnold	IA	Cedar River
Braidwood	IL	Kankakee River cooling lake
Byron	IL	Rock River (cooling tower)
Clinton	IL	Salt Creek
Dresden	IL	Kankakee River
LaSalle	IL	Illinois River cooling lake
Quad Cities	IL	Mississippi River
Wolf Creek	KS	Wolf Creek cooling lake
River Bend	LA	Mississippi River[52]
Waterford	LA	Mississippi River
Pilgrim	MA	Atlantic Ocean
Calvert Cliffs	MD	Chesapeake Bay
Donald C. Cook	MI	Lake Michigan
Fermi	MI	Lake Erie
Palisades	MI	Lake Michigan
Monticello	MN	Mississippi River
Prairie Island	MN	Mississippi River
Callaway	MO	Missouri River[53]
Grand Gulf	MS	Mississippi River (cooling tower)[54]
Brunswick	NC	Cape Fear River
Harris	NC	Harris Reservoir

Tritium leaks have occurred with great regularity at U.S. nuclear plants. An investigation by the Associated Press found that leaks have occurred at 75 percent of U.S. plants, and that a great number of them have taken place in the past five years.[58] On at least three occasions, tritium leaks from nuclear plants have contaminated nearby well water.[59]

As plants have aged, the risk of tritium leaks has risen, since aging equipment

Table 5: Cooling Water Sources of U.S. Nuclear Plants[51] (continued)

Nuclear Plant	State	Name of Water Source
McGuire	NC	Lake Norman
Cooper	NE	Missouri River
Fort Calhoun	NE	Missouri River
Seabrook	NH	Atlantic Ocean
Oyster Creek	NJ	Barnegat Bay
Hope Creek	NJ	Delaware River
Salem	NJ	Delaware River
Indian Point	NY	Hudson River
James A. Fitzpatrick	NY	Lake Ontario
Nine Mile Point	NY	Lake Ontario
R. E. Ginna	NY	Lake Ontario
Davis-Besse	OH	Lake Erie
Perry	OH	Lake Erie
Beaver Valley	PA	Ohio River
Limerick	PA	Schuylkill & Delaware rivers
Peach Bottom	PA	Susquehanna River
Susquehanna	PA	Susquehanna River
Three Mile Island	PA	Susquehanna River
Catawba	SC	Lake Wylie
H. B. Robinson	SC	Black Creek (Lake Robinson)
Oconee	SC	Keowee River
V. C. Summer	SC	Broad River
Sequoyah	TN	Chickamauga Reservoir (Tennessee River)
Watts Bar	TN	Chickamauga Reservoir (Tennessee River)
Comanche Peak	TX	Squaw Creek Reservoir
South Texas Project	TX	Colorado River
North Anna	VA	North Anna River
Surry	VA	James River
Vermont Yankee	VT	Connecticut River
Columbia Generating Station	WA	Columbia River
Kewaunee	WI	Lake Michigan
Point Beach	WI	Lake Michigan

has had more time to develop leaks and weaknesses.[60] Much of the U.S. nuclear fleet was built during the 1970s, and is now approaching or exceeding 40 years of operation. When leaks occur, meanwhile, they can be difficult to detect and repair. Plants have miles of underground piping, some encased in concrete and difficult to access, which can corrode over time and begin to leak contaminated water.[61] The

Government Accountability Office found in a 2011 report that current tests used to check underground pipes at nuclear plants cannot detect degradation, making it impossible to assess their condition.[62]

Among the most significant tritium leaks of the past 10 years:

- In 2002, radiation was discovered on the shoes of workers at Salem Nuclear Power Plant in New Jersey. A leak there was eventually traced to a blocked pipe in a system servicing the spent fuel pool, which had allowed contaminated water to build up behind the concrete walls of the spent fuel pool. That water had leaked into nearby groundwater, raising radiation levels above safe thresholds and requiring the plant's owners to undertake a significant cleanup effort.[63] The leak had been ongoing for at least five years by the time it was discovered.[64]

- In December, 2005, investigators found tritium in a drinking water well at a home near Braidwood Nuclear Generating Station in Illinois. Levels of tritium above the safe drinking water standard were found near the plant, and much higher levels were detected on the plant grounds. The leak was eventually traced to a pipe carrying normally non-radioactive water away for discharge.[65]

- Indian Point Energy Center in Buchanan, New York, has two active reactors and one decommissioned reactor, each with a spent fuel pool on the site. In 2005, investigators discovered first radioactive tritium and then radioactive strontium in groundwater between the spent fuel pools and the Hudson River. The pools sit 400 feet from the river; levels of strontium above the safe drinking water standard were first discovered 150 feet from the river. Closer to the plant, test wells showed levels of strontium over 25 times the safe drinking water standard. The leak was eventually pinpointed to the spent fuel pool for the decommissioned Indian Point 1 reactor, where a drain system designed to contain a known leak at the pool was apparently failing to contain all radioactive releases.[66]

- Officials from Entergy, the company that operates Vermont Yankee Nuclear Power Plant in southeastern Vermont, had stated several times in sworn testimony that the plant had no subterranean pipes capable of leaking nuclear material.[67] In early 2010, however, investigators discovered radioactive tritium in groundwater near the plant. Initial findings were small, but test wells eventually revealed concentrations of up to 2.7 million picocuries/liter in certain areas—135 times the federal safety standard for drinking water.[68] The leak was eventually traced to underground steam pipes. In early 2011, test wells again detected elevated levels of tritium, suggesting further contamination from an as-yet-undiscovered leak.[69]

- Oyster Creek Generating Station in New Jersey is the nation's oldest continuously operating nuclear plant. In April 2009, just over a week after the plant received a license extension to allow it to continue operating for another 20 years, operators at Oyster Creek discovered a tritium leak within the plant grounds. The leak released approximately 180,000 gallons of contaminated water, some of which eventually reached the Cohansey Aquifer underlying the plant.[70] A second leak, discovered in August of that year, produced tritium concentrations 500 times the safe drinking water limit at sites on the plant grounds.[71]

Policy Recommendations

Nuclear power is inherently risky. The Fukushima nuclear accident demonstrated the dangers that nuclear power can pose to public health and our environment. With 49 million Americans drawing their drinking water from areas within 50 miles of nuclear power plants—and with three-quarters of all U.S. nuclear power plants already leaking radioactivity into groundwater supplies—it is time for the U.S. to move toward cleaner, safer and cheaper alternatives for our energy needs.

The inherent risks posed by nuclear power—coupled with its cost—mean that the United States should move to a future without nuclear power.

The nation should:

- Retire existing nuclear power plants, at the latest, at the end of their current operating licenses.
- Abandon plans for new nuclear power plants.
- Adopt policies to expand energy efficiency and production of energy from clean, renewable sources such as wind and solar power, such as tax incentives and a renewable energy standard.
- Eliminate subsidies for nuclear power.

In the meantime, the United States should reduce the risks nuclear power poses to water supplies by:

- Completing a thorough safety review of U.S. nuclear power plants and requiring plant operators to implement recommended changes immediately.
- Ensuring that emergency plans account for the potential impacts of drinking water contamination to residents outside the current 50-mile boundary used in planning.
- Requiring nuclear plant operators to plan for the containment and disposal of contaminated water produced in the process of a nuclear accident.
- Require that nuclear waste be stored as safely as possible, preferably by using hardened dry cask storage (which reduces the risk associated with spent fuel pools).

- Require nuclear plant operators to test groundwater for tritium contamination regularly.[72]

- Enforce laws against tritium leaks—which call for plant operators to pay a fine for any unauthorized release of radioactive material—to provide an additional incentive for plant operators to prevent such leaks.

Appendix A: Data Tables

Table A-1: Total Population Receiving Drinking Water from Intakes within 50 Miles of Each US Nuclear Plant

Plant	State	Total Population Receiving Drinking Water from Intakes within 50 Miles of Plant
Browns Ferry	Alabama	619,428
Palo Verde	Arizona	124,500
Arkansas Nuclear	Arkansas	475,437
San Onofre	California	2,295,738
Diablo Canyon	California	66,450
Millstone	Connecticut	893,827
Saint Lucie	Florida	124,700
Vogtle	Georgia	398,523
Braidwood	Illinois	283,767
Dresden	Illinois	382,267
La Salle	Illinois	283,443
Quad Cities	Illinois	245,971
Clinton	Illinois	157,835
Duane Arnold	Iowa	84,403
Wolf Creek	Kansas	63,947
Waterford	Louisiana	1,449,287
River Bend	Louisiana	13,803
Pilgrim	Massachusetts	1,206,352
Fermi	Michigan	1,580,621
Palisades	Michigan	389,057
D.C. Cook	Michigan	254,584
Monticello	Minnesota	873,838
Prairie Island	Minnesota	478,021
Grand Gulf	Mississippi	9,116
Callaway	Missouri	31,346
Fort Calhoun	Nebraska	579,626
Cooper	Nebraska	3,490
Seabrook	New Hampshire	3,921,516
Salem	New Jersey	2,900,971
Hope Creek	New Jersey	2,900,971
Oyster Creek	New Jersey	1,076,424

Table A-1: Total Population Receiving Drinking Water from Intakes within 50 Miles of Each US Nuclear Plant (cont'd.)

Plant	State	Total Population Receiving Drinking Water from Intakes within 50 Miles of Plant
Ginna	New York	815,873
FitzPatrick	New York	548,848
Nine Mile Point	New York	548,848
Indian Point	New York	11,324,636
Shearon Harris	North Carolina	1,686,425
McGuire	North Carolina	1,646,516
Brunswick	North Carolina	215,985
Perry	Ohio	2,132,775
Davis-Besse	Ohio	1,550,459
Limerick	Pennsylvania	3,901,396
Beaver Valley	Pennsylvania	1,878,905
Three Mile Island	Pennsylvania	1,155,630
Peach Bottom	Pennsylvania	1,059,176
Susquehanna	Pennsylvania	848,626
Catawba	South Carolina	1,370,934
Oconee	South Carolina	799,932
Summer	South Carolina	487,462
Robinson	South Carolina	151,010
Sequoyah	Tennessee	659,341
Watts Bar	Tennessee	551,341
Comanche Peak	Texas	1,243,514
South Texas	Texas	2,751
Vermont Yankee	Vermont	3,114,882
North Anna	Virginia	1,138,798
Surry	Virginia	883,551
Columbia Generating Station	Washington	188,312
Kewaunee	Wisconsin	202,581
Point Beach	Wisconsin	202,581

(Note: Some plants do not appear in this list, since no surface water systems in the EPA's registry were within 50 miles of those plants. In some cases, groundwater-based drinking systems may be located near those plants; this report does not deal with those systems.)

Table A-2: Total Population Receiving Drinking Water from Sources within 12.4 miles (20 km) of U.S. Nuclear Plants

Plant	State	Total Population Receiving Drinking Water from Intakes within 12.4 Miles of Plant
Browns Ferry	Alabama	26,130
Arkansas Nuclear	Arkansas	38,930
Diablo Canyon	California	1,200
Millstone	Connecticut	56,473
Braidwood	Illinois	5,604
Dresden	Illinois	5,604
Wolf Creek	Kansas	2,679
Waterford	Louisiana	103,818
Pilgrim	Massachusetts	37,316
D.C. Cook	Michigan	27,397
Palisades	Michigan	32,418
Fermi	Michigan	60,334
Grand Gulf	Mississippi	912
Fort Calhoun	Nebraska	7,512
Seabrook	New Hampshire	47,785
Salem	New Jersey	6,199
Hope Creek	New Jersey	6,199
Ginna	New York	17,062
FitzPatrick	New York	29,400
Nine Mile Point	New York	29,400
Indian Point	New York	8,359,730
Shearon Harris	North Carolina	206,414
McGuire	North Carolina	895,538
Davis-Besse	Ohio	16,885
Perry	Ohio	59,946
Susquehanna	Pennsylvania	40,620
Beaver Valley	Pennsylvania	80,626
Peach Bottom	Pennsylvania	243,368
Three Mile Island	Pennsylvania	262,149
Limerick	Pennsylvania	923,538
Summer	South Carolina	8,303
Oconee	South Carolina	378,899
Watts Bar	Tennessee	2,359
Sequoyah	Tennessee	56,145
Comanche Peak	Texas	11,750
Vermont Yankee	Vermont	31,543
Surry	Virginia	422,300
Columbia Generating Station	Washington	49,319
Point Beach	Wisconsin	13,354

Table A-3: Total Population Receiving Drinking Water from Intakes within 50 Miles of Nuclear Plants by State

State	Population Receiving Drinking Water From Intakes Within 50 Miles of Nuclear Plants
Alabama	586,253
Arkansas	475,437
Arizona	124,500
California	2,362,188
Connecticut	1,511,605
Florida	124,700
Georgia	577,361
Iowa	278,996
Illinois	652,804
Indiana	219,766
Kansas	63,947
Louisiana	1,471,531
Massachusetts	4,821,229
Maryland	208,442
Maine	94,948
Michigan	1,521,523
Minnesota	935,100
Missouri	31,346
North Carolina	3,753,495
Nebraska	518,302
New Hampshire	374,368
New Jersey	3,286,373
New York	9,974,602
Ohio	2,844,794
Oregon	15,410
Pennsylvania	6,651,752
Rhode Island	63,499
South Carolina	1,185,917
Tennessee	803,424
Texas	1,246,265
Virginia	2,022,349
Vermont	31,440
Washington	172,902
Wisconsin	202,581
West Virginia	65,426
Total	**49,274,575**

Table A-4: Total Population Receiving Drinking Water from Intakes within 12.4 Miles (20 km) of Nuclear Plants by State

State	Population Receiving Drinking Water From Intakes Within 12.4 Miles of Nuclear Plants
Alabama	26,130
Arkansas	38,930
California	1,200
Connecticut	56,473
Illinois	5,604
Kansas	2,679
Louisiana	104,730
Massachusetts	93,444
Maryland	117,719
Michigan	92,752
North Carolina	1,101,952
Nebraska	7,512
New Hampshire	11,000
New Jersey	6,199
New York	8,406,192
Ohio	92,031
Pennsylvania	1,414,196
South Carolina	456,966
Tennessee	58,504
Texas	11,750
Virginia	426,532
Vermont	12,200
Washington	49,319
Wisconsin	13,354
West Virginia	3,186
Total	**12,610,554**

Appendix B: Methodology

Data on the proximity of U.S. nuclear power plants to drinking water intakes were supplied by the U.S. Environmental Protection Agency (EPA) to Frontier Group in June 2011. The EPA identified drinking water intakes for public drinking water systems within 20 kilometers and 50 miles of U.S. nuclear power plants, using geographic data for nuclear power plants from the U.S. Nuclear Regulatory Commission and data on the location of drinking water intakes, the names of drinking water systems, and the population served by those systems from the Safe Drinking Water Information System (SDWIS) from fall 2010.

The totals for the number of consumers for each drinking water source include only the primary sources of drinking water for each drinking water system. Secondary sources of drinking water are not included in the tables in this report, though they may be included in supplemental data that accompanies this report (but with the number of potentially affected customers listed as zero).

Detailed metadata, as supplied by the EPA, are available upon request to the authors.

Note that drinking water intakes may be within the designated radius of more than one nuclear reactor. Also note that the data do not include intakes that are downstream of or within the same watershed as waterways within the given radius if the intakes themselves are outside the radius.

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