



# UNACCEPTABLE RISK

*Two Decades of "Close Calls," Leaks and Other Problems  
at U.S. Nuclear Reactors*

**CALPIRG**  
Education Fund

# **Unacceptable Risk**

Two Decades of “Close Calls,” Leaks and Other  
Problems at U.S. Nuclear Reactors

Rob Kerth, Tony Dutzik and Travis Madsen, Frontier Group

Johanna Neumann, U.S. PIRG Education Fund

**CALPIRG Education Fund**

March 2011

# Acknowledgments

The authors sincerely thank Anna Aurilio of Environment America, Peter Bradford, and David Lochbaum of the Union of Concerned Scientists for sparing time from their busy schedules to provide feedback on this document. Thanks also to Susan Rakov and Elizabeth Ridlington of Frontier Group for their editorial review.

Our hearts go out to the people of Japan as they struggle to recover from disaster and rebuild their nation.

The authors bear responsibility for any factual errors. The recommendations are those of CALPIRG Education Fund. The views expressed in this report are those of the authors and do not necessarily reflect the views of our funders or those who provided review.

Copyright 2011 CALPIRG Education Fund

With public debate around important issues often dominated by special interests pursuing their own narrow agendas, CALPIRG Education Fund offers an independent voice that works on behalf of the public interest. CALPIRG Education Fund, a 501(c)(3) organization, works to protect consumers and promote good government. We investigate problems, craft solutions, educate the public, and offer Californians meaningful opportunities for civic participation. For more information about CALPIRG Education Fund or for additional copies of this report, please visit [www.calpirg.org/edfund](http://www.calpirg.org/edfund).

Frontier Group conducts independent research and policy analysis to support a cleaner, healthier and more democratic society. Our mission is to inject accurate information and compelling ideas into public policy debates at the local, state and federal levels. For more information about Frontier Group, please visit [www.frontiergroup.org](http://www.frontiergroup.org).

# Table of Contents

Executive Summary .....	4
Introduction.....	7
Nuclear Power Is Inherently Dangerous.....	8
The Inherent Risks of Nuclear Power .....	8
Health Effects of Radiation Exposure .....	8
How Nuclear Accidents Can Trigger Releases of Radiation .....	8
Potential Causes of Nuclear Accidents .....	9
Human Error .....	9
Mechanical Failure .....	10
Loss of Power .....	11
Natural Disasters and Terrorism.....	11
Causes in Combination.....	12
Close Calls and Radiation Releases at U.S. Nuclear Reactors .....	14
Close Calls.....	14
Leaks of Radioactive Material .....	16
Recent Accident Precursors and Safety System Failures.....	17
Accident Precursors.....	17
Safety System Failures .....	18
Conclusion and Recommendations.....	19
Notes .....	20

# Executive Summary

As the eyes of the world have focused on the nuclear crisis in Fukushima, Japan, Americans have begun to raise questions about the safety of nuclear power plants in the United States.

American nuclear power plants are not immune to the types of natural disasters, mechanical failures, human errors, and losses of critical electric power supplies that have characterized major nuclear accidents such as the one at Fukushima Daiichi power plant in Japan. Indeed, at several points over the last 20 years, American nuclear power plants have experienced “close calls” that could have led to damage to the reactor core and the subsequent release of large amounts of radiation.

These incidents illustrate the inherent dangers of nuclear power to people and the environment, and demonstrate why the United States must move away from nuclear power and toward safer alternatives.

**On four occasions since 1990, the U.S. Nuclear Regulatory Commission (NRC) has rated a reactor event as a “significant precursor” of core damage** – meaning that the chance of an accident that would damage the reactor core, and possibly lead to a large-scale release of radiation, increased to greater than 1 in 1,000. These events had a number of causes, including operator error, primary equipment degradation or failure, failure of emergency backup systems, and loss of offsite power.

- In 2002, in perhaps the most dangerous nuclear incident in the United States since Three Mile Island, workers at the Davis-Besse Nuclear Generating Station in Ohio discovered that boric acid leaking from a cracked nozzle had eroded away six inches of carbon steel on the reactor vessel head, leaving only 3/8 inch of stainless steel to contain the reactor’s highly pressurized steam. Rupture of the vessel head could have resulted in the loss of coolant and damage to the plant’s control rods, creating the conditions for rapid overheating of the reactor core and possible release of radiation.
- In 1996, critical systems at a reactor at Catawba Nuclear Station in South Carolina were without power for several hours when the plant lost outside power at the same time that one of its emergency generators was out of service for maintenance.
- In 1994, workers accidentally allowed 9,200 gallons of coolant to drain from the core of a reactor at Wolf Creek nuclear power plant in Kansas. The plant’s operators estimated that

the condition – had it persisted for five more minutes – could have led to the plant’s fuel rods being exposed and put at risk of overheating.

- In 1991, valves and drain lines in an emergency shutdown system failed at the Shearon Harris nuclear power plant in North Carolina. Had an emergency occurred during that failure, the plant may not have been able to be shut down safely.

**At least one out of every four U.S. nuclear reactors (27 out of 104) have leaked tritium – a cancer-causing radioactive form of hydrogen – into groundwater. Among the accidental releases of radioactive material from U.S. nuclear power plants in the past decade are:**

- The leakage of radioactive material into groundwater at New Jersey’s Salem nuclear power plant – a leak that was discovered in 2002 after it had already been going on for five years. Subsequently, a similar leak of tritium was discovered at New Jersey’s Oyster Creek power plant just one week after the plant received a 20-year license extension.
- The leakage of radioactive tritium into groundwater at the Braidwood Nuclear Generating Station in Illinois.
- The leakage of both tritium and radioactive strontium from the spent fuel pools at the Indian Point Energy Center in New York, which are located just 400 feet from the Hudson River.
- The discovery of tritium in groundwater near the Vermont Yankee nuclear power plant, even though the plant’s owner, Entergy, had stated several times in sworn testimony that the plant had no subterranean pipes capable of leaking radioactive material.

**In recent years, American nuclear power plants have frequently been forced to rely on safety systems to react to unexpected events. However, these safety systems often fail to work as expected.**

- Safety systems are the emergency diesel generators and emergency cooling systems that activate if the reactor loses power or needs to shut down rapidly.
- In 2009, approximately 70 failures in key safety systems were found at U.S. nuclear reactors. That same year, U.S. reactors were required to activate safety systems approximately 24 times. Should these two types of events overlap at the same facility, a serious problem could result.

**To protect the public from the inherent dangers of nuclear power, the United States should take a “time out” on nuclear relicensing and construction until safety problems at nuclear plants are fully addressed, and move away from nuclear power as a major source of America’s energy.**

**Specifically, President Obama should call for:**

- Completion of a comprehensive safety review of all 104 operating U.S. nuclear reactors.
- A moratorium on the relicensing of existing, aging nuclear power plants – some of which share a similar design to the reactors in Fukushima, Japan.
- A moratorium on the licensing of new nuclear reactors.
- Elimination of federal loan guarantees and other subsidies for nuclear power plants. Taxpayers should not be required to subsidize inherently dangerous technologies such as nuclear power – instead, those incentives should be targeted toward low-risk forms of energy such as solar and wind power and improved energy efficiency.

# Introduction

Nuclear power is a high-stakes gamble that threatens public safety.

Think of a Las Vegas slot machine. On any pull of the lever, the chances of getting one “lucky 7” are fairly good. The chances of getting two are smaller. The chances of getting three lucky 7s – delivering a valuable jackpot – are slim. But slots players know that even rare events happen, eventually.

Nuclear power plants are like Vegas slot machines – but with costly and damaging accidents, rather than big payouts, the uncommon yet inevitable result.

There are many things that can go wrong at a nuclear power plant – human error, the failure of a mechanical system, loss of offsite electricity, and the impact of a storm, earthquake or terrorist attack. Most nuclear plants are designed to withstand these challenges individually. But when nuclear power plants are hit with multiple challenges simultaneously – as occurred with the earthquake and tsunami at Fukushima, Japan – or when one challenge cascades into another in unpredictable ways, a manageable situation can become a catastrophe in a heartbeat.

This report reviews a series of incidents over the past 20 years at U.S. nuclear reactors in which one, or even two “unlucky 7s” fell into place. In each of these cases, Americans were spared the kind of nuclear disaster on our soil that has contaminated food and drinking water, threatened the health of workers, and sparked widespread and disruptive evacuations in Japan. But each of them represented a window of opportunity that might – under different circumstances – have led to disaster.

As events in Japan continue to unfold, Americans need to consider what the disaster tells us about the risks of nuclear power in the United States. But we also can learn from the U.S. nuclear industry’s past. The history of mishaps and “close calls” at U.S. nuclear power plants is long. Regardless of the final tally of health and economic impacts from the Fukushima disaster, that record provides more than enough reason to conduct a thorough review of nuclear safety in the United States, and impose a moratorium on the relicensing of existing nuclear power plants and the construction of new ones.



# Nuclear Power Is Inherently Dangerous

Nuclear power is an inherently dangerous technology. Thoughtful reactor design that incorporates redundant safety systems can reduce the dangers of nuclear power, but never eliminate them. There are many opportunities for things to go wrong at a nuclear power plant. Any misstep has the potential to open the door to a more severe accident.

## The Inherent Risks of Nuclear Power

Public exposure to radiation is the primary risk associated with nuclear power. Radiation is dangerous to human health and radioactive materials can remain dangerous for tens to hundreds of thousands of years.

## Health Effects of Radiation Exposure

Nuclear fuel contains radioactive materials including uranium and sometimes plutonium. Nuclear reactions produce radioactive waste products, such as iodine-131 and cesium-137.<sup>1</sup>

There are two ways that radiation can damage human health – immediately, through exposure to large doses of radiation, and over time, through cumulative exposure. Exposure to intense bursts of radiation, such as those that may have been experienced by some workers at the Fukushima plant, has the potential to cause nausea, weakness, hair loss, and, in some cases, death.<sup>2</sup>

Over the long term, exposure to radiation increases the risk of cancer. According to the U.S. National Academy of Sciences, there is no safe level of exposure to radiation.<sup>3</sup> The effects of exposure to even low levels of radiation add up over time, and those cumulative exposures increase the risk of developing cancer later in life.<sup>4</sup>

Radioactive materials also can remain dangerous for a long time. Cesium-137 – one of the radioactive isotopes emitted from the Fukushima nuclear reactors – has a half-life of 30 years, meaning that it takes that long for the isotope to emit half of the radioactivity it will emit over its lifetime, and that cesium-137 released to the environment has the potential to cause harm for a long period of time.<sup>5</sup>

## How Nuclear Accidents Can Trigger Releases of Radiation

Nuclear fuel – whether it is being used to actively generate electricity in a reactor or being stored following use – potentially can release radiation to the environment in an accident.

**Reactor fuel:** Nuclear reactions produce large amounts of heat, which nuclear power plants capture to generate electricity. Even after a nuclear reaction stops, nuclear fuel continues to produce 6 percent as much heat through natural radioactive decay alone, with the amount of decay heat falling off over time.<sup>6</sup> To keep fuel from overheating or catching fire, reactor operators need to maintain a steady flow of coolant to the reactor core. Without coolant, the fuel rods can generate explosive gases, or begin to melt. Coolant loss increases the risk of radiation release, which can occur if operators have to vent radioactive gases to relieve reactor pressure (as was the case at Fukushima), or if the nuclear fuel heats up enough to melt through its containment vessel.

**Spent fuel:** Spent fuel at American nuclear reactors is stored in pools of water on the reactor site for at least five years after use; after that, it may remain in the pools or be transferred to dry casks.<sup>7</sup> In a spent fuel pool, fuel rods are submerged in water that is constantly circulated and cooled. If, as in the case of Fukushima, the flow of fresh water to the spent fuel pool is disrupted, the remaining water in the pool can heat up and eventually boil, leaving the fuel rods exposed. When overheated, the protective cladding on the outside of the fuel rods may crack, exposing the radioactive materials to the elements, and the fuel rods may generate explosive gases, catch fire, and/or melt.

Adding to the risk is the fact that spent fuel pools at American nuclear reactors are not housed within the same type of containment structures that protect reactor cores. In some cases, spent fuel pools are stored in adjacent facilities that lack even the thick concrete walls that provide “secondary containment” against the escape of radioactive materials to the atmosphere. A severe spent fuel pool accident could cause as many as 143,000 cancers within 500 miles.<sup>8</sup> The most likely causes of a spent fuel accident would a crack in the pool caused by an earthquake or the dropping of a cask during the transfer of spent fuel to dry cask storage.<sup>9</sup> Loss of power to the pool could also cause an accident if the pool were left without power for more than four days.<sup>10</sup>

## **Potential Causes of Nuclear Accidents**

There are a variety of potential causes for nuclear accidents. Human error, mechanical failure, loss of power, natural disasters and terrorism all have the potential to trigger nuclear accidents. Often, however, it is the combination of two causes – a natural disaster accompanied by human error or the cascading of one event to another in unexpected ways – that poses the greatest challenge to nuclear safety.

### **Human Error**

“Human error” is often thought of as a bad decision made by one individual at a particular moment in a crisis – pressing the wrong button, perhaps. These types of errors certainly occur. But the construction and operation of nuclear power plants create thousands of opportunities for human beings to make mistakes.

A 2001 study by the U.S. Nuclear Regulatory Commission reviewed 48 nuclear incidents, finding evidence of human error in 37 (77 percent) of those incidents. Each one of those 37 incidents involved multiple errors – an average of more than seven errors per incident. Nor did all of those errors occur during or immediately before the incident. Indeed, errors that occurred prior to the incident – including the failure to address known problems and errors in maintenance and operations – were four times more common than errors that occurred during incident response.<sup>11</sup>

In some cases, human error takes the form of outright negligence or failure to follow proper procedures. For instance, managers failed to inspect the reactor vessel head at Davis-Besse nuclear power plant outside Toledo (see below) and lied to regulators about their inspection program. In other cases, operator error may be a natural result of the challenge of trying to maintain a highly complex system. For instance, the control room operators at Three Mile Island during that plant's accident in 1979 misunderstood the meaning of an indicator light on their control panels, which prevented them from properly diagnosing the problem with the plant for several hours.

## Mechanical Failure

Nuclear plants contain thousands of critical parts. Inevitably, some of those parts fail and need to



*In 2002, corrosion of the vessel head at the Davis-Besse nuclear power plant in Ohio could have led to the loss of coolant from the reactor core and a meltdown. The incident is considered to be the most serious in the United States since Three Mile Island. (Photo: Nuclear Regulatory Commission)*

be replaced. Nuclear power plants are designed to prevent a single predictable failure from threatening the whole reactor. The failure of a single mechanical element, with the entire rest of the plant and crew functioning perfectly, would result in nothing worse than a reactor shutdown and the replacement of the broken part. When latent problems with different mechanical components accumulate over time – or when mechanical components are stressed during reaction to a crisis – mechanical failure can contribute to the creation of a more severe incident.

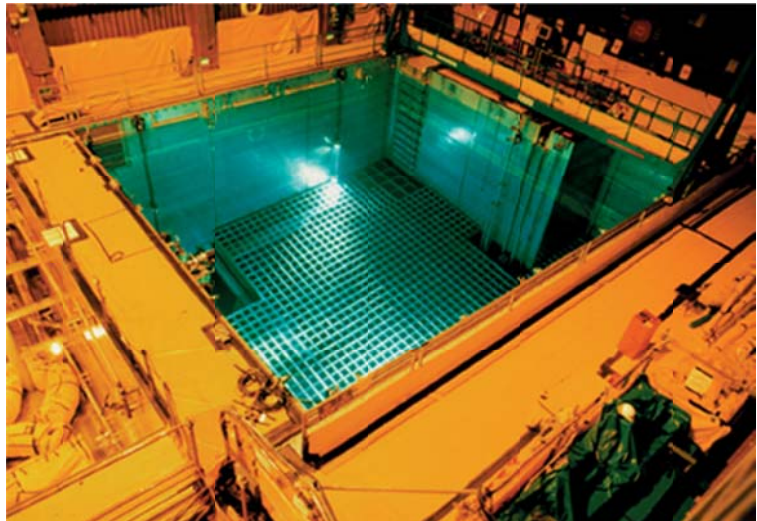
Mechanical failure is to some extent tied in with human error; poor maintenance allows mechanical problems to go undetected. In 2009, two of the six mechanical failures identified as “precursors” of an accident under the NRC’s definition were caused by poor maintenance.<sup>12</sup>

## Loss of Power

The safety systems that allow America’s nuclear power plants to operate and shut down safely require electrical power to operate properly. Vital functions like circulating coolant through the reactor core cannot take place without power, so a plant without power for too long will inevitably become a plant in crisis.

In recognition of this fact, nuclear power plants have multiple sources of power. Reactors produce power themselves, of course, but also have access to power from the electrical grid.

Additionally, all plants are required to have backup diesel generators available for use in emergencies when offsite power is lost, and batteries that provide short-term power in the event that both fail. Loss of a single source of power lowers the margin for error at a plant. Complete loss of power (a “station blackout” event) is an urgent threat.



*Spent fuel pools, such as the one shown above, typically exist outside primary containment structures and are not required to have backup sources of power, increasing the dangers in the event of an accident. (Photo: Nuclear Regulatory Commission.)*

Spent fuel pools, again, generally receive less attention. Spent fuel pools are not required to be hooked up to the same backup power systems – diesel generators and batteries – that are used to keep coolant flowing to operating reactors.<sup>13</sup>

In part, this is justified by the fact that operators generally have several days to restore power to spent fuel pools in the event of the loss of offsite power.<sup>14</sup> If, however, as at Fukushima, grid power is lost for an extended period of time, there may be no backup source of power to fill the gap.

Power losses occur every year at nuclear plants. In 2009, the NRC listed four incidents triggered by loss of offsite power on its list of accident “precursors.”<sup>15</sup> Larger blackouts can leave multiple plants without power over a period of hours. In 2003, eight plants lost power and were forced to shut down during that year’s massive blackout in the northeastern U.S.<sup>16</sup>

## Natural Disasters and Terrorism

Natural disasters – hurricanes, tornadoes, tsunamis and earthquakes – and terrorist attacks have the potential to test the resilience of a nuclear reactor.

Strong tornados pose a serious threat to nuclear power plants. Storms as weak as Category 2 (on the 1 to 5 Fujita Scale) have proven strong enough in the past to knock out offsite power to a reactor. In 1998, the Davis-Besse plant outside Toledo was hit by a Category 2 tornado while at 99 percent power, without any advance warning. Lightning strikes and high winds damaged equipment in the electrical switchyard and knocked down three separate offsite power lines; the plant went without power for 23 hours. Operators struggled with mechanical problems in the emergency power system throughout that time, and one of the site's emergency diesel generators failed just as power was restored.<sup>17</sup>

Beyond knocking out offsite power, tornadoes also could damage unprotected support systems, such as the systems that cool spent fuel pools.<sup>18</sup> A stronger tornado, meanwhile, could pose more serious problems for a plant. Category 4 or 5 tornadoes are strong enough to severely damage a steel reinforced concrete structure, and can fling projectiles with enough force to penetrate thick layers of concrete and steel.<sup>19</sup> Reactor containment buildings or spent fuel pools could be punctured if a storm of this magnitude hit a nuclear plant.

Other natural disasters also threaten nuclear power plants. Although neither floods nor hurricanes are likely to damage reactor buildings themselves, water from floods or hurricane storm surges can enter a plant and short out important electrical equipment. Both floods and hurricanes also threaten the offsite power supply to nuclear plants, raising the possibility of a station blackout.<sup>20</sup>

Finally, nuclear power plants are potential targets for terrorist attacks. A 2006 National Academy of Sciences report found that “successful terrorist attacks on spent fuel pools, though difficult, are possible” and that “under some conditions, a terrorist attack that partially or completely drained a spent fuel pool could lead to ... the release of large quantities of radioactive materials to the environment.”<sup>21</sup>

### **Causes in Combination**

Nuclear power plants are designed to operate or shut down safely in the face of many individual threats that have been anticipated by designers, operators or regulators. Often, however, the threats posed to a nuclear power plant are neither straightforward nor simple – nor can all the various combinations in which they emerge be anticipated.

Threats to nuclear power plants can emerge in combination simultaneously, or one set of threats can cascade in unpredictable ways to create other, more serious threats.

An incident that took place at Braidwood Nuclear Generating Station in Joliet, Illinois, in 2010 illustrates how a series of minor problems can cascade through multiple systems to produce unexpected results. At that plant, operators had been aware for some time that water could spill out of pipes onto the plant's floor under certain conditions, but had regarded it as a problem only for worker safety, not for the plant's operations.<sup>22</sup> On August 16, 2010, a fault in the electrical system led Unit 2 to “trip,” or shut down. As the plant responded to the shutdown, a flow control

system failed, which led to 12,000 gallons of water being pumped onto the floor of the turbine deck through a standpipe. That water, filtering down through holes in the deck, reached an electrical cabinet on a different level of the building and shorted out several pumps for the plant's other reactor, Unit 1. Unit 1 tripped in response to that failure, and, since the pump failure had rendered the usual cooling system ineffective, began to remove decay heat by venting steam, a standard backup cooling system. That steam dislodged a piece of aluminum siding from the reactor building, which fell onto power lines for the reactor's offsite power transformer, but luckily did not cause a short circuit.

The propagation of events through theoretically unconnected systems – in which a flaw in the water circulation systems for one reactor came to threaten the offsite power supply for another reactor – is exemplary of the way in which complex systems are vulnerable to unpredictable accidents.

The Fukushima disaster resulted from both the near-simultaneous emergence of major natural threats –the earthquake and tsunami – as well as the cascading of problems from one reactor to the next. For example, because the Fukushima reactors were in close proximity to one another, radiation releases from the worst-hit reactors made it more difficult for workers to restore the safety of the other reactors.

These potential interactions are too numerous to model or predict fully. As a result, even problems that can be anticipated can lead to unanticipated results.

# Close Calls and Radiation Releases at U.S. Nuclear Reactors

A sampling of incidents at U.S. reactors in the past 20 years shows that American nuclear reactors have experienced a range of problems – many of which could have led to a larger accident. In addition, more than two dozen American nuclear plants have experienced unplanned releases of radiation into the environment. These radiation leaks – while miniscule in comparison to those taking place in Japan – illustrate the potential for mistakes and problems at nuclear reactors to have an impact on the surrounding environment and human health.

## Close Calls

Over the half-century-long history of commercial nuclear power in the United States, there have been numerous incidents in which major releases of radioactive material were narrowly averted. In each of these “close calls” or “near misses,” the precursors for a major accident were in place in the form of the loss of offsite power, the loss of emergency cooling capability, human error, or the failure of a major component. Further errors or failures could easily have turned any one of these events into a catastrophe.

In March 2011, the Union of Concerned Scientists released an illuminating report documenting



*In 1994, coolant was accidentally drained from the reactor at the Wolf Creek nuclear power plant in Kansas. Had workers not stopped the outflow in time, the fuel rods in the reactor core could have quickly become exposed, leading to the potential for a meltdown. (Photo: Nuclear Regulatory Commission)*

14 near-misses at U.S. nuclear power plants in 2010 alone.<sup>23</sup> In this report, we focus on several events over the past two decades that have posed extreme danger – events deemed “significant precursors” by the Nuclear Regulatory Commission. A significant precursor is an event in which the risk of damage to the reactor core exceeds 1 in 1,000 – or 0.1 percent.

Since 1990, four “significant precursors” (out of a total of 17 since 1979) have taken place at U.S. reactors.<sup>24</sup> Each of these events had different causes, ranging from simultaneous unavailability of multiple sources of electric power to long-term

negligence in maintenance and inspections. The four events were:

**Shearon Harris 1, 1991:** At the Shearon Harris 1 plant in North Carolina, valves and drain lines in the safety injection system failed. The safety injection system delivers boric acid and other chemicals that help shut down an ongoing reaction in an emergency. Had an emergency taken place while the components were out of service, a large amount of the safety injection fluid would have been diverted away from the coolant system.<sup>25</sup> The NRC estimated that this led to a 6 in 1,000 risk of core damage.<sup>26</sup>

**Wolf Creek, 1994:** During maintenance operations, with the reactors in a shut-down condition, workers simultaneously opened two valves, unintentionally creating a path for water to flow from the core coolant system to a water storage tank.<sup>27</sup> This configuration remained in place for 66 seconds, during which time 9,200 gallons of coolant drained from the core cooling system to a water storage tank, and the temperature in the cooling system began to rise.<sup>28</sup> Fortunately, operators quickly noticed the problem and stopped the outflow of coolant. In an analysis after the fact, the plant's operators concluded that the loss of coolant, had it continued for five more minutes, would have lowered water levels sufficiently that pumps responsible for circulating coolant through the core could not have functioned. That, in turn, would have allowed coolant to boil off inside the reactor vessel, and exposed the fuel rods within an hour.<sup>29</sup> The NRC estimated that the risk of core damage rose to 3 in 1,000 during this incident.<sup>30</sup>

**Catawba 2, 1996:** Two transformers responsible for delivering outside power to the plant cut out because of improperly installed components, cutting off the plant's offsite power supply. The reactor shut down in response to a drop in the frequency of its electrical power. One of the two emergency diesel generators for the reactor was out of service for maintenance. As a result, an essential set of components lacked any electrical power for a period of several hours. Workers were able to restore power to the reactor after several hours. The NRC estimated that this event led to a 2 in 1,000 risk of core damage.<sup>31</sup>

**Davis-Besse, 2002:** The Davis-Besse nuclear plant, outside Toledo, Ohio, has been one of the nation's most accident-prone nuclear facilities, with six different "significant precursor" events over its lifetime – more than any other reactor in the United States.<sup>32</sup> The most recent of these, which may have been the most serious nuclear incident in the U.S. since Three Mile Island, occurred in 2002. In that year, operators discovered that boric acid leaking through cracks in a control rod nozzle – the tube through which control rods are inserted into the core – had corroded away 6 inches of carbon steel in the reactor vessel head, leaving only 3/8 of an inch of stainless steel to hold back steam at a pressure of 2,500 pounds per square inch (psi). The damage was discovered accidentally during an inspection in 2002, when a worker noticed that a control rod assembly, which should have been held in place by the thick steel, moved when he hit it with his hammer.<sup>33</sup>



Had the stainless steel failed, the core would have immediately lost pressure and begun to vent coolant into its containment vessel. Additionally, the control rods – the mechanism for shutting down the reactor – could have been damaged by the highly pressurized steam and water shooting out of the reactor in the event of a breach.<sup>34</sup> The simultaneous loss of coolant and loss of control rod function would have made rapid overheating in the core possible. Since breaches of the reactor vessel were considered to be all but impossible, the plant's emergency response workers were not trained to deal with them.<sup>35</sup>

Investigators found that the plant's operators had ignored the buildup of boric acid on the vessel head over a period of years, and lied to regulators about the extent of inspections of the area in question. FirstEnergy, the company that owns the plant, paid a \$28 million fine as part of a deal that averted criminal prosecutions for the company and several of its employees.<sup>36</sup>

FirstEnergy ordered a new vessel head from Europe to replace the damaged part, but, since that head would take several years to arrive, temporarily replaced the head with one purchased from an unfinished nuclear plant in Michigan. In 2010, inspections during a reactor shutdown revealed the new reactor head had also developed cracks in its control rod nozzles, which were made of the same crack-prone alloy as the original nozzles. The replacement lid from Europe is due to be installed in 2011.<sup>37</sup>

## Leaks of Radioactive Material

While most of the events described in this report were serious because they threatened to result in a large-scale disaster, a different set of problems at U.S. reactors did not pose a serious threat of core damage but did actually result in the immediate release of radioactive material to the environment.

At least 27 U.S. nuclear reactors, for example, have experienced leaks of tritium – a radioactive form of hydrogen – into groundwater supplies.<sup>38</sup> Tritium leaks are troubling for two reasons – first because they contribute to an increased risk of cancer and other health problems among people who consume tritium-tainted water or food, and second because the recent epidemic of tritium leaks at U.S. nuclear plants have often gone undetected for years, leading to questions about the ability of nuclear plant operators and regulators to protect the public from accidental exposure to radioactive substances.<sup>39</sup>

Recent leaks of radioactive materials from power plants include:

**Salem, 2002:** 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 remediation effort.<sup>40</sup> The leak had been ongoing for at least five years by the time it was discovered.<sup>41</sup>

**Braidwood, 2005:** In December, 2005, investigators found radioactive 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.<sup>42</sup>

**Indian Point, 2005-2006:** Indian Point Energy Center in Buchanan, New York, has one decommissioned and two active reactors, each with a spent fuel pool. 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 Hudson 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 more than 25 times the safe drinking water standard. The leak was eventually traced 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.<sup>43</sup>

**Oyster Creek, 2009:** Oyster Creek Nuclear 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.<sup>44</sup> 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.<sup>45</sup>

**Vermont Yankee, 2010-2011:** Officials from Entergy, the company that operates Vermont Yankee Nuclear Power Plant, had stated several times in sworn testimony that the plant had no subterranean pipes capable of leaking radioactive material.<sup>46</sup> 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.<sup>47</sup> 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.<sup>48</sup>

## **Recent Accident Precursors and Safety System Failures**

Even when radioactive releases or “significant precursors” are not taking place at U.S. reactors, a steady stream of incidents takes place every year.

### **Accident Precursors**

During 2009, the NRC reported 19 “precursors,” or conditions that could lead to an accident. (The presence of a precursor increases the probability of core damage to more than 1-in-1,000,000 – a “significant” precursor increases the risk to greater than 1-in-1,000.) These ranged

from losses of power at five units (two during the same event) to problems involving flammable electrical insulation and poor fire management practices at three reactors on the same site.<sup>49</sup>

### **Safety System Failures**

Safety systems at nuclear reactors are activated frequently in response to unforeseen conditions. In 2009, U.S. reactors were required to activate safety systems approximately 24 times.<sup>50</sup> Safety system activations take place when emergency electric supply or cooling function is needed as a result of triggering events such as the loss of offsite power or an emergency reactor shutdown.

Frequently, however, key safety systems have been found to not work properly. In 2009, approximately 70 failures in key safety systems were found at U.S. nuclear reactors.<sup>51</sup> Safety systems are the emergency diesel generators and emergency cooling systems that activate if the reactor loses power or needs to shut down rapidly. A “safety system failure” is when a subsystem within the safety system does not work properly. Failure of a single redundant component, which would not impair overall system performance, would not be a safety system failure.

## Conclusion and Recommendations

The nuclear industry claims a 30-year plus record of safe operation, dating back to Three Mile Island. A closer look at the industry's safety record, however, reveals several incidents in which the nation barely averted a major nuclear accident – as well as many other incidents in which radioactive materials were released into the environment or specific failures at nuclear plants opened the door for potentially more serious problems to emerge.

The track record of nuclear power in the United States and the recent nuclear crisis in Japan reinforce the notion that nuclear power is an inherently dangerous source of energy – one that poses massive risks to the public. To address the risks posed by nuclear power, President Obama should call for:

- Completion of a comprehensive safety review of all 104 operating U.S. nuclear reactors.
- A moratorium on the relicensing of existing, aging nuclear power plants – some of which share a similar design to the reactors in Fukushima, Japan.
- A moratorium on the licensing of new nuclear reactors.
- Elimination of federal loan guarantees and other subsidies for nuclear power plants. Taxpayers should not be required to subsidize inherently dangerous technologies such as nuclear power – instead, those incentives should be targeted toward low-risk forms of energy such as solar and wind power and improved energy efficiency.

# Notes

---

<sup>1</sup> Iodine-131, a short-lived isotope with a half-life of 8 days, can accumulate in the thyroid, which uses iodine to produce hormones. People exposed to I-131, especially children, are at risk of thyroid cancer. See U.S. Department of Health, National Cancer Institute, *About I-131*, accessed at [www.cancer.gov/cancertopics/causes/i131/abouti131](http://www.cancer.gov/cancertopics/causes/i131/abouti131) on 21 March, 2011.

<sup>2</sup> U.S. Environmental Protection Agency, *Radiation Protection: Health Effects*, downloaded from [www.epa.gov/rpdweb00/understand/health\\_effects.html](http://www.epa.gov/rpdweb00/understand/health_effects.html), 22 March 2011.

<sup>3</sup> National Research Council of the National Academies, *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*, 2006.

<sup>4</sup> Ibid.

<sup>5</sup> 30 years: Argonne National Laboratory, *Cesium: Human Health Fact Sheet*, August 2005.

<sup>6</sup> 6 percent: World Nuclear Association, *Physics of Uranium and Nuclear Energy*, downloaded from [www.world-nuclear.org/education/phys.htm](http://www.world-nuclear.org/education/phys.htm), 22 March 2011.

<sup>7</sup> U.S. Nuclear Regulatory Commission, *Factsheet on Dry Cask Storage of Spent Nuclear Fuel*, 7 May 2009.

<sup>8</sup> R. J. Travis, R. E. Davis, E. J. Grove, and M. A. Azarm, Brookhaven National Laboratory, for U.S. Nuclear Regulatory Commission, *A Safety and Regulatory Assessment of Generic BWR and PWR Permanently Shutdown Nuclear Power Plants*, August 1997.

<sup>9</sup> U.S. National Research Council, *Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report*, 2006.

<sup>10</sup> Ibid.

<sup>11</sup> U.S. Nuclear Regulatory Commission, *Review of Findings for Human Error Contribution to Risk in Operating Events*, August 2001.

<sup>12</sup> U.S. Nuclear Regulatory Commission, *Results, Trends, and Insights of the Accident Sequence Precursor Program*, 29 September 2010.

<sup>13</sup> Paul Gunter, Nuclear Information and Resource Service, *Natural Disasters and Safety Risks at Nuclear Power Stations* (fact sheet), November 2004.

<sup>14</sup> See note 9.

<sup>15</sup> See note 12.

<sup>16</sup> Ibid.

<sup>17</sup> See note 13.

---

<sup>18</sup> U.S. Nuclear Regulatory Commission, *Technical Study of Spent Fuel Accident Risk at Decommissioning Nuclear Power Plants*, October 2000.

<sup>19</sup> “Strong enough ...”: see note 13; “enough force ...”: Ibid.

<sup>20</sup> See note 13.

<sup>21</sup> See note 9.

<sup>22</sup> David Lochbaum, Union of Concerned Scientists, *The NRC and Nuclear Power Plant Safety in 2010: A Brighter Spotlight Needed*, March 2011.

<sup>23</sup> Ibid.

<sup>24</sup> U.S. Nuclear Regulatory Commission, *Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models*, October 2006.

<sup>25</sup> Ibid.

<sup>26</sup> Ibid.

<sup>27</sup> See note 11.

<sup>28</sup> See note 24.

<sup>29</sup> U.S. Nuclear Regulatory Commission, *Loss of Reactor Coolant Inventory and Associated Potential for Loss of Emergency Mitigation Functions While in a Shutdown Condition*, 28 May 1998.

<sup>30</sup> See note 24.

<sup>31</sup> Ibid.

<sup>32</sup> Ibid.

<sup>33</sup> Victor Gilinsky, “Heard About the Near-Accident at the Ohio Nuclear Plant? I’m Not Surprised.” *Washington Post*, 28 April 2002.

<sup>34</sup> Ibid.

<sup>35</sup> Ibid.

<sup>36</sup> U.S. Department of Justice, *FirstEnergy Nuclear Operating Company to Pay \$28 Million Relating to Operation of Davis–Besse Nuclear Power Station* (press release), 20 January 2006.

<sup>37</sup> John Funk, “Problems at the Davis-Besse Nuclear Reactor Near Toledo Are Worse Than Expected,” *Cleveland Plain Dealer*, 15 April 2010.

<sup>38</sup> Associated Press, “A Quarter of U.S. Nuclear Plants Leaking,” *CBSNews.com*, 1 February 2010.

<sup>39</sup> For information on the health risks of tritium, see Nuclear Information and Resource Service, *TRITIUM from Nuclear Power Plants: Its Biological Hazards*, and associated links, downloaded from [www.nirs.org/radiation/tritium/tritiumhome.htm](http://www.nirs.org/radiation/tritium/tritiumhome.htm), 25 March 2011.

---

<sup>40</sup> David Lochbaum, Union of Concerned Scientists, *Petition Pursuant to 10 CFR 2.206 – Enforcement Action – Longstanding Leakage of Contaminated Water*, submitted to Luis A. Reyes, Executive Director for Operations, U.S. Nuclear Regulatory Commission, 25 January 2006.

<sup>41</sup> Ibid.

<sup>42</sup> Ibid.

<sup>43</sup> Greg Clary, “Source of Indian Point Leak Found,” *The Journal News* (Lower Hudson Valley, NY), 11 May 2006.

<sup>44</sup> Abby Gruen, “Exelon Forced to Clean up Tritium Leak at Oyster Creek Nuclear Plant,” *The Star-Ledger*, 7 May 2010.

<sup>45</sup> Ben Leach, “Tritium Found in New Leak at Oyster Creek Nuclear Plant,” *Press of Atlantic City*, 26 August 2009.

<sup>46</sup> John Dillon, “Groups that Challenged Vermont Yankee to be Reimbursed,” *Vermont Public Radio News*, 7 June 2010.

<sup>47</sup> Terri Hallenbeck, “Vermont Yankee Zeroes in on Source of Leak,” *Burlington Free Press*, 6 February, 2010.

<sup>48</sup> Vermont Department of Health, *Investigation into Tritium Contamination at Vermont Yankee Nuclear Power Station*, 28 February 2011.

<sup>49</sup> See note 122.

<sup>50</sup> Based on per-unit safety system actuations from note 12. Total figure calculated by multiplying the per-unit figure by the number of operating U.S. nuclear reactors (104).

<sup>51</sup> Based on per-unit safety system failures from note 12. Total figure calculated by multiplying the per-unit figure by the number of operating U.S. nuclear reactors (104).