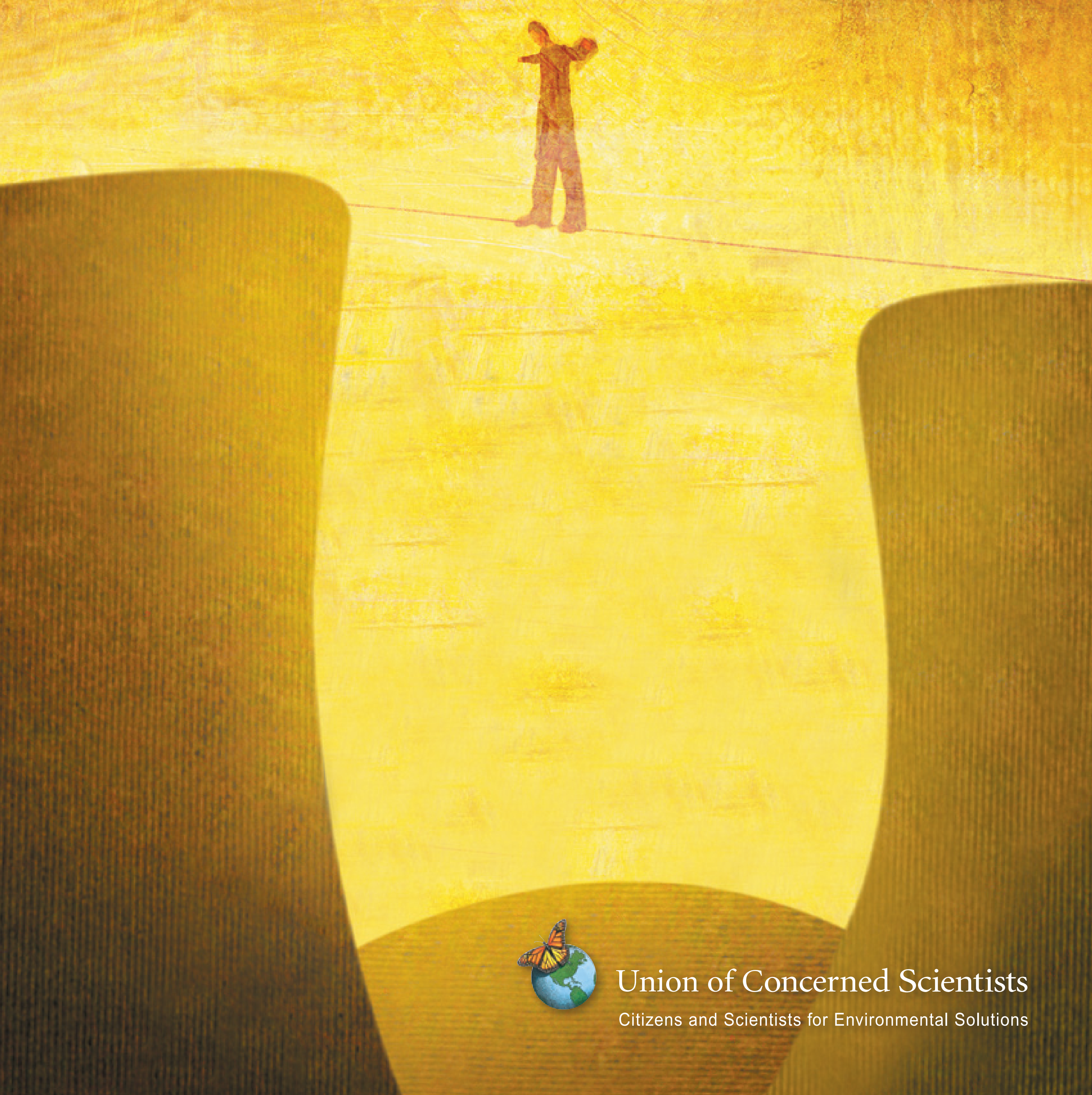
WALKING A NUCLEAR TIGHTROPE

Unlearned Lessons of Year-plus Reactor Outages



Union of Concerned Scientists

Citizens and Scientists for Environmental Solutions

WALKING A NUCLEAR TIGHTROPE

Unlearned Lessons of Year-plus Reactor Outages

David Lochbaum

Union of Concerned Scientists

September 2006

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The Union of Concerned Scientists is a nonprofit partnership of scientists and citizens combining rigorous scientific analysis, innovative policy development, and effective citizen advocacy to achieve practical environmental solutions.

The UCS Global Security Program seeks to bring about a safer world by eliminating the risks posed by nuclear arsenals and nuclear terrorism, improving nuclear power plant safety, preventing the deployment of anti-satellite and spaced-based weapons, and enhancing international dialogue on security issues.

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COVER ILLUSTRATION: Getty Images, Catalano Design

DESIGN: Catalano Design

Printed on recycled paper with soy-based inks

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Acknowledgments

The author is grateful for the constructive feedback from peer reviews by Drs. Kymn Harvin, Paul Blanch, Jim Riccio, and David Wright.

The author also appreciates the permission granted by Dr. Bill Corcoran to use his quality assurance graphic in Chapter 4 and, more importantly, for Bill's long campaign to have nuclear plant managers embrace the quality assurance requirements outlined in Appendix B to Title 10 of the Code of Federal Regulations, Part 50.

Last but not least, the author acknowledges the fine technical editing performed by Bryan Wadsworth and Heather Tuttle.

Executive Summary

On March 28, 1979, the Unit 2 reactor at the Three Mile Island (TMI) nuclear power plant in Pennsylvania suffered a partial core meltdown. It was the worst accident—so far—in the history of commercial nuclear power in the United States. The fact that this event occurred more than a quarter-century ago is often cited as evidence that nuclear power is safer today.

But is it safe enough? A car speeding through a school zone at 90 miles per hour (mph) is safer if it slows to "only" 75 mph, but it isn't safe enough. Children in the school zone are at just as great a risk.

Is nuclear power in the United States safe enough today just because a reactor has not experienced a meltdown since 1979? The answer is a resounding no. In the 27 years since the TMI meltdown, 38 U.S. nuclear power reactors had to be shut down for at least one year while safety margins were restored to minimally acceptable levels. Seven of these reactors experienced two year-plus outages.

Though these reactors were shut down before they experienced a major accident, we cannot assume we will continue to be so lucky. The number and length of these shutdowns testifies to how serious and widespread the problem is.

A History of Neglect

The vast majority of these extended outages were caused not by broken parts but a general degrading of components to the point that safe operation of the plant required a shutdown for broad, system-wide maintenance. Federal regulations require plant owners to maintain corrective action programs (CAPs, often referred to as quality assurance progams) that find and fix problems, but a review of year-plus outages demonstrates that existing CAPs are inadequate. In each case, it took considerable time and cost to find and fix the many problems these inadequate CAPs had either overlooked or improperly "corrected," and to address the flaws in the programs themselves. In other words, it took longer than one year for plant owners to get back on the right side of the law and make the reactor safe enough to operate.

Nuclear power is clearly not safe enough when so many reactors have to be shut down for a year or more before they can be restarted under the minimum conditions considered acceptable by federal safety regulations. Extended outages are prima facie evidence of how far safety margins have been allowed to erode, making nuclear power more dangerous and costly than necessary. Furthermore, extended outages caused by inadequate CAPs also indicate that plant owners have violated federal regulations many times and in many places.

Waking Up the Watchdog

The Nuclear Regulatory Commission (NRC), which oversees safety at U.S. nuclear power reactors, simply must do a better job of monitoring reactor safety levels so it can intercede before safety margins erode to the point that it takes a year or more to restore them to acceptable levels. Specifically, the NRC must improve its performance in terms of:

- assessing the adequacy of CAPs;
- communicating with plant owners about CAP failures identified at other reactors;
- integrating all available reactor data so NRC staff around the country can "connect the dots" about potential problems at similar reactors; and

- reducing the frequency of safety performance declines that could lead to year-plus outages.

The U.S. Congress, which oversees the NRC, must ensure that the reforms listed above are completed effectively and expeditiously. These reforms are imperative if our country's 104 existing nuclear power reactors are to be considered truly safe enough. And completion of these reforms should be a prerequisite for the construction of any new federally subsidized nuclear power reactors. Otherwise, the next safety problem at a nuclear power plant may not just represent a potential extended outage—it may pose a threat far worse than a speeding car headed straight toward a busy school zone.

Introduction

The Nuclear Regulatory Commission (NRC), an agency within the executive branch of the federal government, has almost exclusive responsibility for setting and enforcing safety standards for U.S. nuclear power plants. How well is the agency meeting its responsibility? Some observers point to the fact that no U.S. reactor has experienced a meltdown since Three Mile Island in 1979 as proof the NRC is effective. Others see evidence to the contrary in the growing frequency of near-misses, including the serious problems discovered in 2002 at the Davis-Besse plant in Ohio.

Meltdowns are too high a threshold by which to measure the NRC's performance; this would be like assessing an individual's health based on whether he or she had a pulse. And "near-miss" is too subjective a measure (i.e., how near is near?). Better insights come from the occasions when reactors must remain shut down for a year or more to restore safety levels.

Year-plus outages represent prima facie evidence of how far safety levels have been allowed to drop below acceptable levels; an effective regulator should be capable of monitoring these levels and interceding before year-plus outages are required. **Chapter 1** explains in more detail why year-plus reactor outages provide meaningful insights into the NRC's effectiveness.

To be candid, two assumptions the Union of Concerned Scientists (UCS) made when beginning the research for this report proved false, revealing that the situation was actually worse than we expected. First, based on earlier work we had done for our May 2004 report *Nuclear Power in the 21st Century: The Risk of a Lifetime*, we assumed there had been a total of about two dozen year-plus outages in the United States. Second, we assumed that no reactor other than Davis-Besse had experienced more than one such outage. Instead, our research identified a total of 51 outages lasting a year or more and 10 facilities that experienced more than one such outage.

Where the Problems Begin

Chapter 2 summarizes the who, what, where, when, and why for all of these extended outages. In addition, a case study providing more detailed information and extensive citations for each outage is available on the UCS website at *www.ucsusa.org/clean_energy/nuclear_safety.*

UCS reviewed the 51 year-plus reactor outages to gain insights into past practices that should be continued or expanded to lessen the chances of future extended outages. We also identified things the NRC should begin doing or should do differently with the same goal in mind. These insights are presented in **Chapter 3** and provide the foundation for the conclusions and recommendations offered in Chapter 6.

The primary lesson to be learned from year-plus outages is that the most common contributing factor is inadequate quality assurance, otherwise known as corrective action. **Chapter 4** describes how the NRC assesses the effectiveness of corrective action programs, why the NRC's efforts have been unsuccessful, and what needs to be done to fix this problem.

Next, **Chapter 5** examines the NRC's performance in addressing year-plus outages. This performance is characterized by specific occasions in which the agency's actions were commendable, and occasions when its actions were condemnable. The former category dispels any notion that the NRC is incapable of ever becoming an effective guardian of public health and safety, but the latter illustrates why the NRC needs specific reforms to transform itself into such a guardian.

Answers Are within Reach

Finally, **Chapter 6** provides recommendations that would not only help the NRC address the findings presented in Chapters 3 and 4, but also help Congress ensure that the NRC becomes a more effective watchdog. It is the job of the NRC to monitor safety performance at nuclear power plants, but it is the job of Congress to monitor the NRC's performance. With that in mind, we examine the role played by Congress in the past and the role it should play in a future where the risk of disaster at nuclear power plants is minimized.

Implementation of our recommendations would enable the NRC to better monitor safety margins, reducing the likelihood that safety could erode to the point that plant owners need a year or more to fix the problem. Or worse, that a neglected safety problem triggers a potentially catastrophic reactor meltdown.

Chapter 1

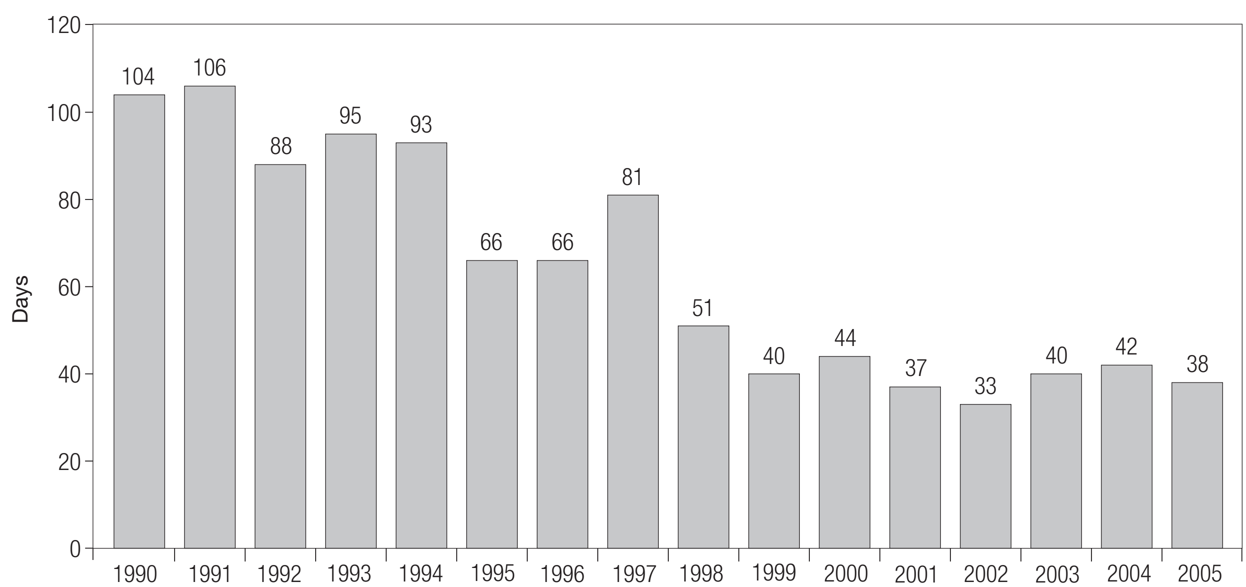
The Relevance of Year-plus Outages

UCS reviewed those occasions when U.S. nuclear power reactors restarted following outages* lasting a year or more. We selected this performance measure because, while relatively brief nuclear reactor outages are commonplace (many are planned for maintenance and refueling operations), year-plus outages are not. Since outages are very costly for a plant, an extended outage suggests the seriousness of the problems leading to it.

The average length of refueling outages, which occur relatively frequently and continue to account for most outage time at U.S. reactors, declined from 104 days in 1990 to 38 days in 2005 (Figure 1). As a result, a year-long reactor outage in 1990 was equivalent to more than 3.5 average refueling operations, but a year-long outage today is equivalent to more than nine refueling operations.

These comparisons suggest the extent to which safety margins had eroded prior to year-long outages and the cost of restoring the necessary margins—plant owners must expend the time and labor equivalent of several back-to-back refueling outages to climb out of the hole.

Figure 1. Average Length of Refueling Outages



Source: Nuclear Energy Institute. 2006. Online at *http://www.nei.org/documents/U.S._Nuclear_Refueling_Outage_Days_Average.pdf.*

* "Outage" refers to the time in which a nuclear reactor is not providing power to the electrical grid. Since a nuclear power reactor's sole purpose is to generate electricity, plant owners have ample reason to minimize the number and duration of outages.

Rolling the Dice?

An occasional year-plus outage might be expected. Nuclear power plants are complex industrial enterprises that can be plagued by failures of large components that take time to repair. But 51 year-plus outages in the past 40 years is unacceptable. The NRC and its predecessor, the Atomic Energy Commission (AEC), have licensed a grand total of 130 nuclear power reactors,† 41 of which have experienced one or more year-plus outages. A one-in-three chance of incurring a year-plus outage was not supposed to be part of the bargain when these reactors were built and licensed.

Some observers have argued that the fact no U.S. nuclear power reactor has experienced a meltdown since 1979 (during which time 45 year-plus outages have occurred) demonstrates the status quo is working successfully. That's as fallacious as arguing that the levees protecting New Orleans were fully adequate prior to Hurricane Katrina by pointing to the absence of similar disasters between 1980 and 2004. The frequency of year-plus outages instead shows how unprepared we are for severe challenges. Hopefully, we won't need a nuclear Katrina to spur the nuclear industry and the federal government into action.

† This total excludes the Shoreham reactor in New York, which was licensed by the NRC but never operated above five percent of its generating capacity (i.e., it never had a chance to experience an outage of any length), and the Shippingport reactor in Pennsylvania, which was licensed by the AEC and re-licensed by the NRC but functioned more as a test reactor than a power reactor.

Chapter 2

The Nature of Year-plus Outages

The year: 1966. *The Sound of Music* won the Oscar for Best Picture. The first episode of *Star Trek* was broadcast. The U.S. Supreme Court protected the rights of persons accused of crimes with its ruling in the *Miranda v. Arizona* case. The Medicare program began. Walt Disney died. And the Enrico Fermi nuclear generating station north of Detroit, MI, shut down after a partial meltdown of its reactor core. The Detroit Edison Company removed the damaged fuel, repaired the reactor, and restarted the plant in 1970. It marked the first time a U.S. nuclear power reactor experienced an outage lasting longer than one year, but in the ensuing four decades, 40 additional reactors would experience a total of 50 year-plus outages (Table 1, p. 8).

This report considers three categories of year-plus outages:

- **Damage recovery** outages result from a significant event at the reactor (such as an accident) that causes extensive damage and requires the reactor to be shut down for repair for an extended period.
- **Component replacement/repair** outages result from the degradation of a major reactor component, such as an aging steam generator, that must be replaced or repaired before it fails. In this case, the length of the outage is determined by the time required to replace or repair this component.
- **Safety restoration** outages result from cumulative, systemic degradation of reactor components. A year-plus outage of this kind is not needed to fix damage caused by an accident or to replace or repair a major component, but to fix dozens or even hundreds of equipment problems that have accumulated over time.

The vast majority—more than 70 percent—of year-plus shutdowns have been safety restoration outages.

Table 1. Year-plus Reactor Outages (Listed Chronologically by Outage Start Date)

Reactor	Owner	Location	Date Commercial Operation Began	Outage Dates	Reactor Age at Start of Outage (in years)	Outage Length (in years)	NRC Region	Reactor Type	Outage Category
Fermi Unit 1	Power Reactor Development Corporation	Newport, MI	8/7/66	10/5/1966-7/18/70	0.2	3.8	III	LMFBR	Damage Recovery
Palisades	Consumers Power Company	South Haven, MI	12/31/71	8/11/73-10/1/74	1.6	1.1	III	PWR	Safety Restoration
Browns Ferry Unit 2	Tennessee Valley Authority	Athens, AL	3/1/75	3/22/75-9/10/76	0.1	1.5	II	BWR	Damage Recovery
Browns Ferry Unit 1	Tennessee Valley Authority	Athens, AL	8/1/74	3/22/75-9/24/76	0.6	1.5	II	BWR	Damage Recovery
Surry Unit 2	Virginia Electric and Power Company	Surry, VA	5/1/73	2/4/79-8/19/80	5.8	1.5	II	PWR	Component Replacement/ Repair
Three Mile Island Unit 1	General Public Utilities	Middletown, PA	9/2/74	2/17/79-10/9/85	4.5	6.6	I	PWR	Safety Restoration
Turkey Point Unit 3	Florida Power & Light Company	Florida City, FL	12/14/72	2/11/81-4/11/82	8.2	1.2	II	PWR	Component Replacement/ Repair
San Onofre Unit 1	Southern California Edison Company	San Clemente, CA	1/1/68	2/26/82-11/28/84	14.2	2.8	V	PWR	Safety Restoration
Nine Mile Point Unit 1	Niagara Mohawk Power Corporation	Lycoming, NY	12/1/69	3/20/82-7/5/83	12.3	1.3	I	BWR	Component Replacement/ Repair
Indian Point Unit 3	New York Power Authority	Buchanan, NY	8/30/76	3/25/82-6/8/83	5.6	1.2	I	PWR	Component Replacement/ Repair
Oyster Creek	General Public Utilities	Forked River, NJ	12/1/69	2/12/83-11/1/84	13.2	1.7	I	BWR	Component Replacement/ Repair
St. Lucie Unit 1	Florida Power & Light Company	Ft. Pierce, FL	12/21/76	2/26/83-5/16/84	6.2	1.2	II	PWR	Component Replacement/ Repair
Browns Ferry Unit 3	Tennessee Valley Authority	Athens, AL	3/1/77	9/7/83-11/28/84	6.5	1.2	II	BWR	Component Replacement/ Repair
Pilgrim	Boston Edison Company	Plymouth, MA	12/1/72	12/10/83-12/30/84	11.0	1.1	I	BWR	Component Replacement/ Repair
Peach Bottom Unit 2	Philadelphia Electric Company	Delta, PA	7/5/74	4/28/84-7/13/85	9.8	1.2	I	BWR	Component Replacement/ Repair
Fort St. Vrain	Public Service Company of Colorado	Plattville, CO	7/1/79	6/13/84-4/11/86	5.0	1.8	IV	HTGR	Component Replacement/ Repair

LMFBR = liquid metal fast breeder reactor
PWR = pressurized water reactor
BWR = boiling water reactor
HTGR = high-temperature gas-cooled reactor

Table 1. Year-plus Reactor Outages (Listed Chronologically by Outage Start Date) *continued*

Reactor	Owner	Location	Date Commercial Operation Began	Outage Dates	Reactor Age at Start of Outage (in years)	Outage Length (in years)	NRC Region	Reactor Type	Outage Category
Browns Ferry Unit 2	Tennessee Valley Authority	Athens, AL	3/1/75	9/15/84-5/24/91	9.5	6.7	II	BWR	Safety Restoration
Browns Ferry Unit 3	Tennessee Valley Authority	Athens, AL	3/1/77	3/9/85-11/19/95	8.0	10.7	II	BWR	Safety Restoration
Browns Ferry Unit 1	Tennessee Valley Authority	Athens, AL	8/1/74	3/19/85-?	10.6	21.0 plus	II	BWR	Safety Restoration
Davis-Besse	Toledo Edison Company	Oak Harbor, OH	7/31/78	6/9/85-12/24/86	6.9	1.5	III	PWR	Safety Restoration
Sequoyah Unit 2	Tennessee Valley Authority	Soddy-Daisy, TN	6/1/82	8/22/85-5/13/88	3.2	2.7	II	PWR	Safety Restoration
Sequoyah Unit 1	Tennessee Valley Authority	Soddy-Daisy, TN	7/1/81	8/22/85-11/10/88	4.1	3.2	II	PWR	Safety Restoration
Rancho Seco	Sacramento Municipal Utility District	Clay Station, CA	4/18/75	12/26/85-4/11/88	10.7	2.3	V	PWR	Safety Restoration
Pilgrim	Boston Edison Company	Plymouth, MA	12/1/72	4/11/86-6/15/89	13.4	3.2	I	BWR	Safety Restoration
Peach Bottom Unit 2	Philadelphia Electric Company	Delta, PA	7/5/74	3/31/87-5/22/89	12.7	2.1	I	BWR	Safety Restoration
Peach Bottom Unit 3	Philadelphia Electric Company	Delta, PA	12/23/74	3/31/87-12/11/89	12.3	2.7	I	BWR	Safety Restoration
Nine Mile Point Unit 1	Niagara Mohawk Power Corporation	Lycoming, NY	12/1/69	12/19/87-8/12/90	18.0	2.6	I	BWR	Safety Restoration
Surry Unit 2	Virginia Electric and Power Company	Surry, VA	5/1/73	9/10/88-9/19/89	15.4	1.0	II	PWR	Safety Restoration
Palo Verde Unit 1	Arizona Public Service Company	Tonopah, AZ	1/28/86	3/5/89-7/5/90	3.1	1.3	V	PWR	Safety Restoration
Calvert Cliffs Unit 2	Baltimore Gas & Electric Company	Lusby, MD	4/1/77	3/17/89-5/4/91	12.0	2.1	I	PWR	Safety Restoration
Calvert Cliffs Unit 1	Baltimore Gas & Electric Company	Lusby, MD	5/8/75	5/5/89-10/4/90	14.0	1.4	I	PWR	Safety Restoration
FitzPatrick	New York Power Authority	Scriba, NY	7/28/75	11/27/91-1/23/93	16.3	1.2	I	BWR	Safety Restoration
Brunswick Unit 2	Carolina Power & Light Company	Southport, NC	11/3/75	4/21/92-5/15/93	16.5	1.1	II	BWR	Safety Restoration
Brunswick Unit 1	Carolina Power & Light Company	Southport, NC	3/18/77	4/21/92-2/11/94	15.1	1.8	II	BWR	Safety Restoration
South Texas Project Unit 2	STP Nuclear Operating Company	Bay City, TX	6/19/89	2/3/93-5/22/94	3.6	1.3	IV	PWR	Safety Restoration
South Texas Project Unit 1	STP Nuclear Operating Company	Bay City, TX	8/25/88	2/4/93-2/25/94	4.4	1.1	IV	PWR	Safety Restoration

LMFBR = liquid metal fast breeder reactor
PWR = pressurized water reactor
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Table 1. Year-plus Reactor Outages (Listed Chronologically by Outage Start Date) *continued*

Reactor	Owner	Location	Date Commercial Operation Began	Outage Dates	Reactor Age at Start of Outage (in years)	Outage Length (in years)	NRC Region	Reactor Type	Outage Category
Indian Point Unit 3	New York Power Authority	Buchanan, NY	8/30/76	2/27/93-7/2/95	16.5	2.3	I	PWR	Safety Restoration
Sequoyah Unit 1	Tennessee Valley Authority	Soddy-Daisy, TN	7/1/81	3/2/93-4/20/94	11.7	1.1	II	PWR	Safety Restoration
Fermi Unit 2	Detroit Edison Company	Newport, MI	1/23/88	12/25/93-1/18/95	5.9	1.1	III	BWR	Damage Recovery
Maine Yankee	Maine Yankee Atomic Power Company	Wiscasset, ME	12/28/72	1/14/95-1/18/96	22.0	1.0	I	PWR	Component Replacement/ Repair
Salem Unit 1	Public Service Electric & Gas Company	Salem, NJ	6/30/77	5/16/95-4/20/98	17.9	2.9	I	PWR	Safety Restoration
Salem Unit 2	Public Service Electric & Gas Company	Salem, NJ	10/13/81	6/7/95-8/30/97	13.6	2.2	I	PWR	Safety Restoration
Millstone Unit 2	Northeast Utilities	Waterford, CT	12/26/75	2/20/96-5/11/99	20.2	3.2	I	PWR	Safety Restoration
Millstone Unit 3	Northeast Utilities	Waterford, CT	4/23/86	3/30/96-7/1/98	9.9	2.3	I	PWR	Safety Restoration
Crystal River Unit 3	Florida Power Corporation	Crystal River, FL	3/13/77	9/2/96-2/6/98	19.5	1.4	II	PWR	Safety Restoration
Clinton	Illinois Power Company	Clinton, IL	11/24/87	8/5/96-5/27/99	8.8	2.7	III	BWR	Safety Restoration
LaSalle County Unit 2	Commonwealth Edison Company	Marseilles, IL	10/19/84	9/20/96-4/11/99	11.9	2.6	III	BWR	Safety Restoration
LaSalle County Unit 1	Commonwealth Edison Company	Marseilles, IL	1/1/84	9/22/96-8/13/98	12.7	1.9	III	BWR	Safety Restoration
Donald C. Cook Unit 2	Indiana Michigan Power Company	Bridgman, MI	7/1/78	9/9/97-6/25/00	19.2	2.8	III	PWR	Safety Restoration
Donald C. Cook Unit 1	Indiana Michigan Power Company	Bridgman, MI	8/23/75	9/9/97-12/21/00	22.0	3.3	III	PWR	Safety Restoration
Davis-Besse	FirstEnergy Nuclear Operating Company	Oak Harbor, OH	7/31/78	2/16/02-3/16/04	23.5	2.1	III	PWR	Safety Restoration

LMFBR = liquid metal fast breeder reactor
PWR = pressurized water reactor
BWR = boiling water reactor
HTGR = high-temperature gas-cooled reactor

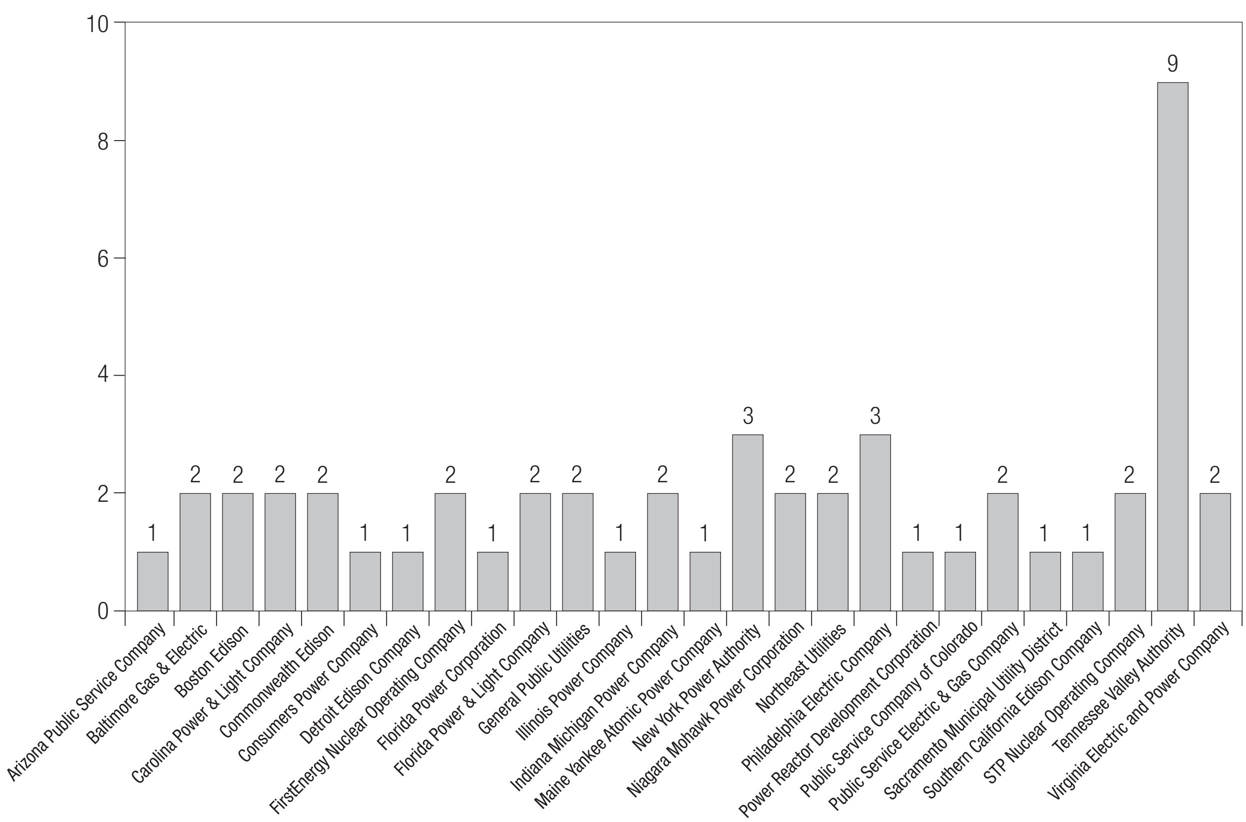
Ownership and Fleet Size

Twenty-six companies owned the nuclear power reactors experiencing year-plus outages (Figure 2). The Tennessee Valley Authority (TVA) has experienced more of these outages than the next three companies combined.

However, considering only the raw number of year-plus outages may be unfair to TVA because it owned and operated a larger fleet of nuclear reactors than most companies and therefore had more opportunities for extended outages.

Figure 3 (p. 12) instead plots the percentage of each company's fleet that has experienced year-plus outages. By this measure, Boston Edison leads the way with 200 percent—it owned a single reactor that experienced two year-plus outages. TVA shared second place with the New York Power Authority.

Figure 2. Year-plus Outages by Reactor Owner



Geography

As depicted in Figure 4, reactors that have experienced year-plus outages can be found from sea to shining sea and plenty of points in-between.

Figure 5 shows that Alabama tops the list of states with the most year-plus reactor outages (six), followed closely by Michigan and New York with five each.

As in the case of reactor ownership, the raw numbers of outages by state may be unfair to Alabama because it had a larger fleet of operating reactors than many other states.

Figure 6 (p. 14) therefore plots the percentage of a state's reactors that have experienced year-plus outages. By this measure, Alabama still ranks worst, with a year-plus outage rate of 120 percent—the state's five nuclear reactors experienced a total of six extended outages. Colorado, Maine, Maryland, Massachusetts, and Tennessee share a year-plus outage rate of 100 percent.

As depicted in (Figure 7, p. 15), most year-plus reactor outages have occurred in NRC Region I (Northeast) followed by Regions II (Southeast), III (Midwest), and IV and V

Figure 3. Percent of Reactor Fleet Experiencing Year-plus Outages

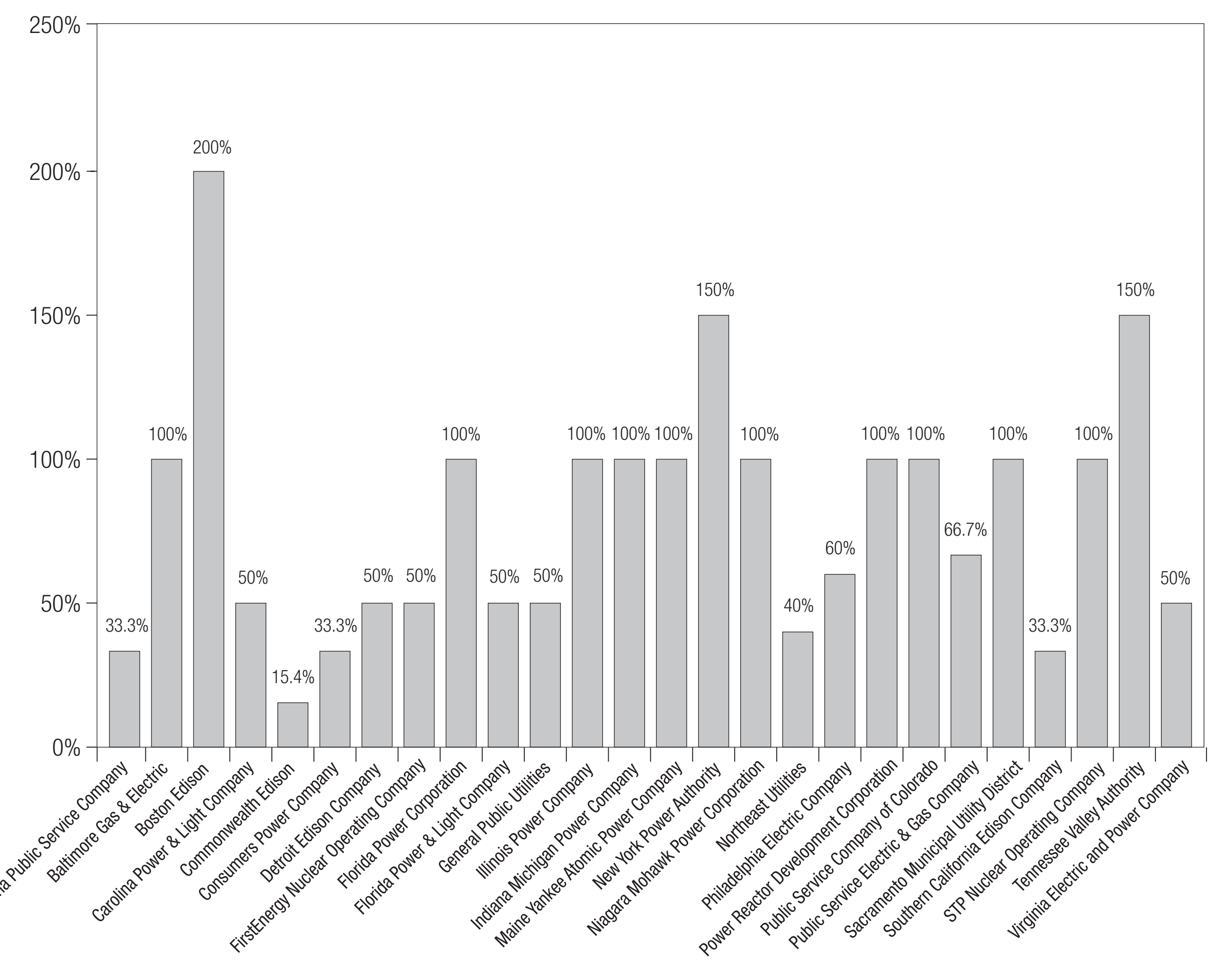
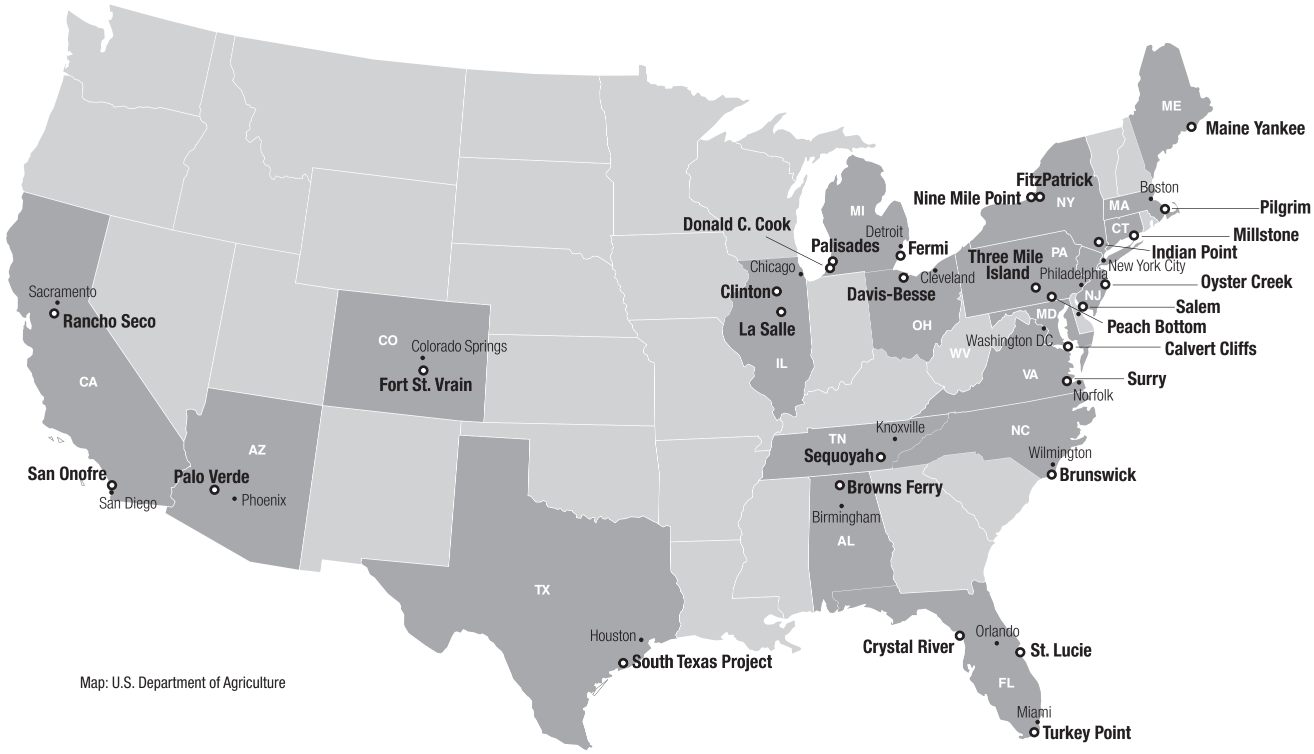
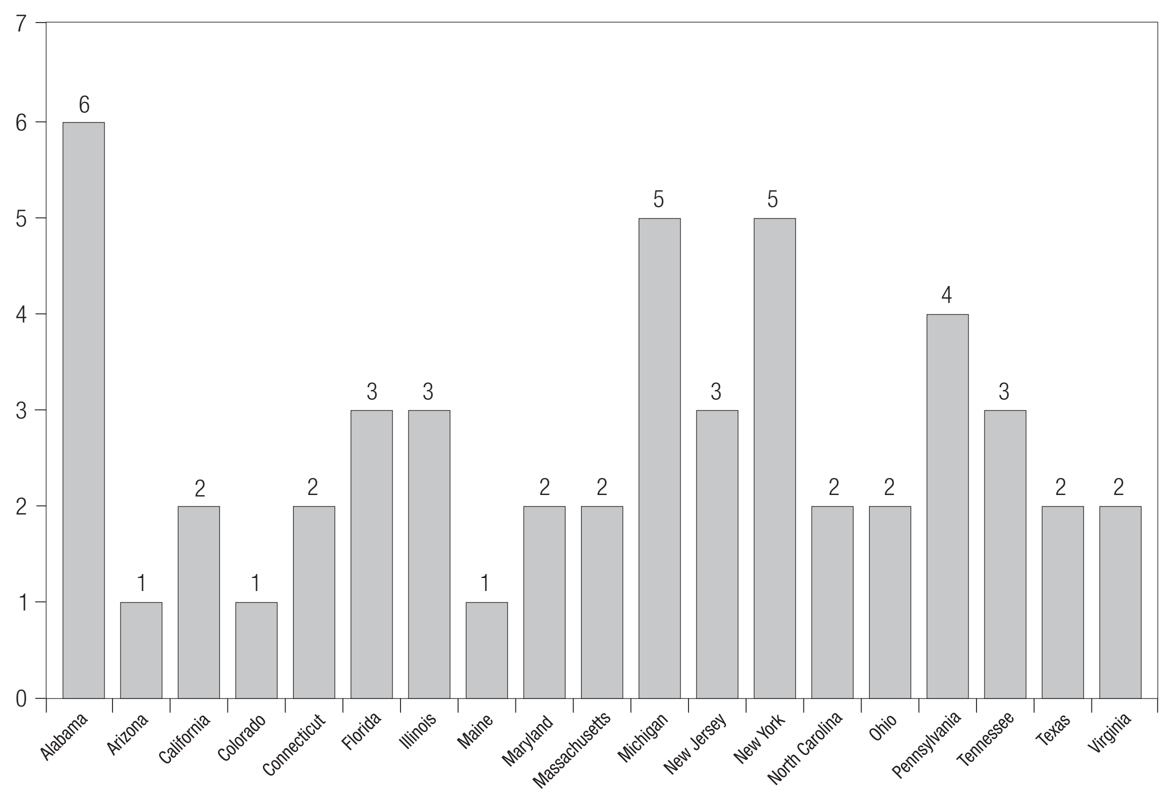


Figure 4. Location of Reactors Experiencing Year-plus Outages



Map: U.S. Department of Agriculture

Figure 5. Year-plus Reactor Outages by State



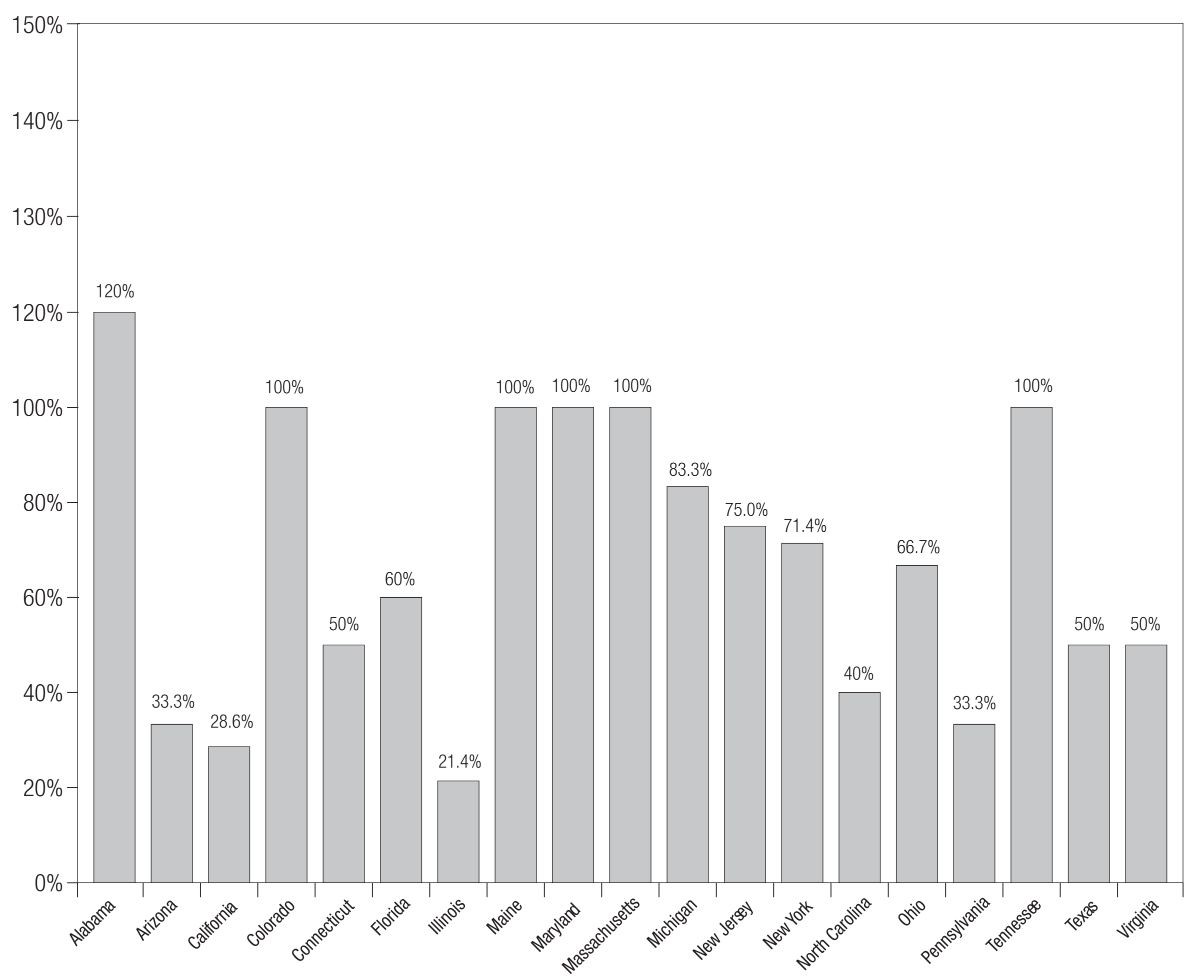
(Southwest and West). The Northeast has the oldest reactors in the country as well as the highest energy consumption; the Southeast has the Tennessee Valley Authority (with its large number of nuclear power plants).

Technology and Time

Most of the nuclear power plants in the United States feature pressurized water reactors. The next most popular type is the boiling water reactor. The country's sole liquid metal fast breeder reactor and one of its two high-temperature gas-cooled reactors have experienced year-plus reactor outages, resulting in a higher outage rate for those reactor types than the more common pressurized water reactor or boiling water reactor (Figure 8).

Figure 9 demonstrates that there is no particular age at which nuclear reactors are more likely to experience extended outages. Three year-plus outages occurred during the first year of operation, but even reactors that have been operating for more than 20 years have had to shut down for a year or more.

Figure 6. Percent of Reactors Experiencing Year-plus Outages (by State)



NOTE: Total can exceed 100% if the number of outages is greater than the total number of reactors in the state.

Figure 7. Percent of Reactors Experiencing Year-plus Outages (by NRC Region)

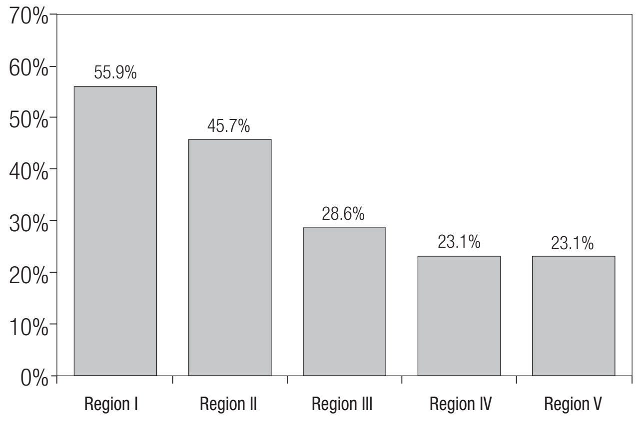


Figure 8. Percent of Reactors Experiencing Year-plus Outages (by Reactor Type)

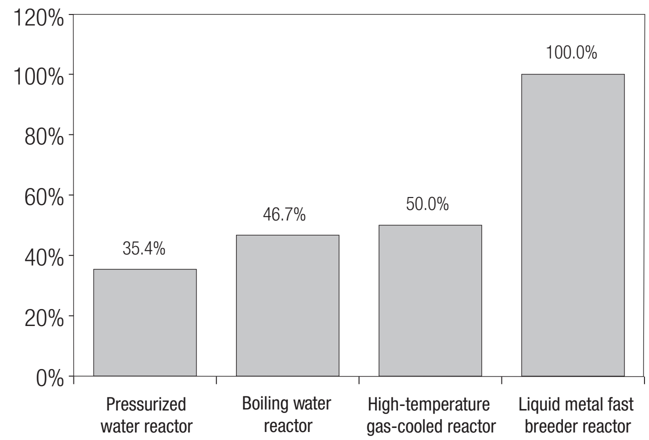
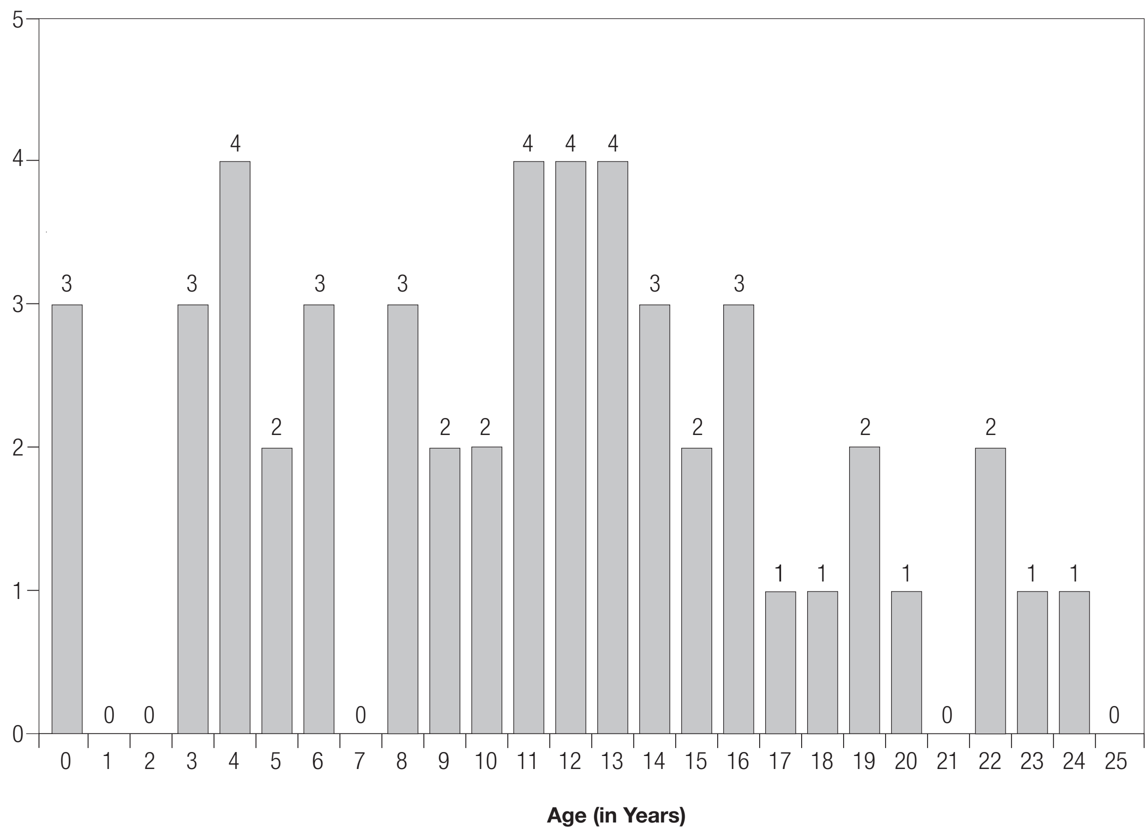


Figure 9. Reactors Experiencing Year-plus Outages (by Age at Start of Outage)



Similarly, the number of year-plus reactor outages per decade (Figure 10) shows that the problem has not disappeared with the passage of time.

The Causes

More than 70 percent of all year-plus reactor outages were the result of broad, programmatic breakdowns that allowed safety margins to deteriorate to unacceptable levels (Figure 11). About 22 percent were necessitated by the replacement and repair of large components. The remaining eight percent were the result of events that caused extensive damage to the plants.

The Costs

Based on information supplied by the U.S. Department of Energy (DOE),[1] UCS estimated the lost revenue for each year-plus reactor outage (Figure 12). We multiplied the outage duration by several factors: the electrical output of the reactor, the average capacity factor for reactors in that decade, and the average price of electricity for that period.

We also attempted to estimate the total costs associated with all 51 year-plus outages, but publicly available reports do not consistently break out labor, equipment, and other costs associated with the generation of replacement power during an extended outage.

Estimating lost revenue allows relative comparisons across time and reactor size. Suffice it to say that, through bad management and ineffective regulatory oversight, year-plus outages have cost ratepayers and stockholders nearly $82 billion in lost revenue (in 2005 dollars) over time. Regardless of cause, location, reactor type, and owner, these outages also accounted for nearly 135 reactor years (or 3.4 reactor lifetimes) of downtime.

Figure 10. Reactors Experiencing Year-plus Outages (by Decade)

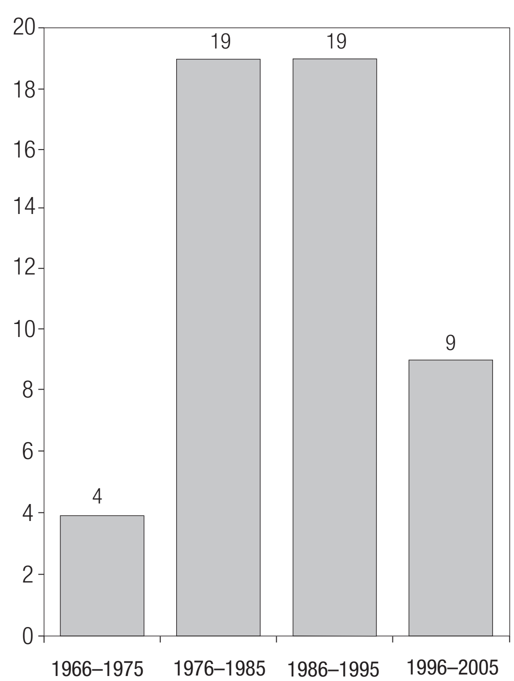


Figure 11. Reactors Experiencing Year-plus Outages (by Cause)

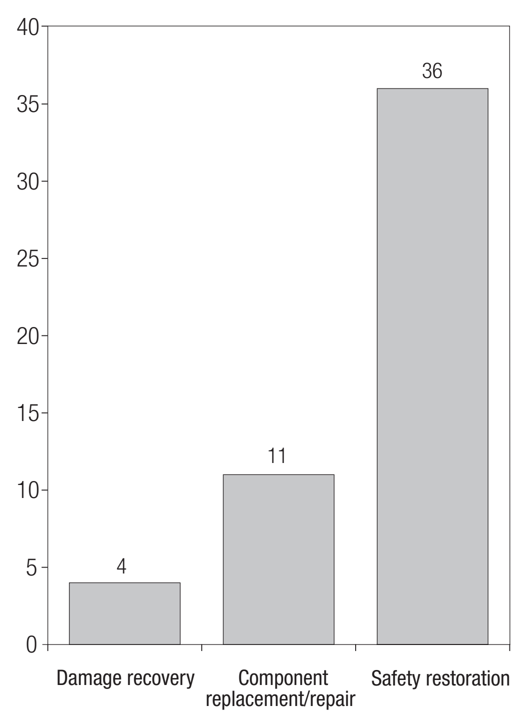


Figure 12. Total Costs of Year-plus Reactor Outages

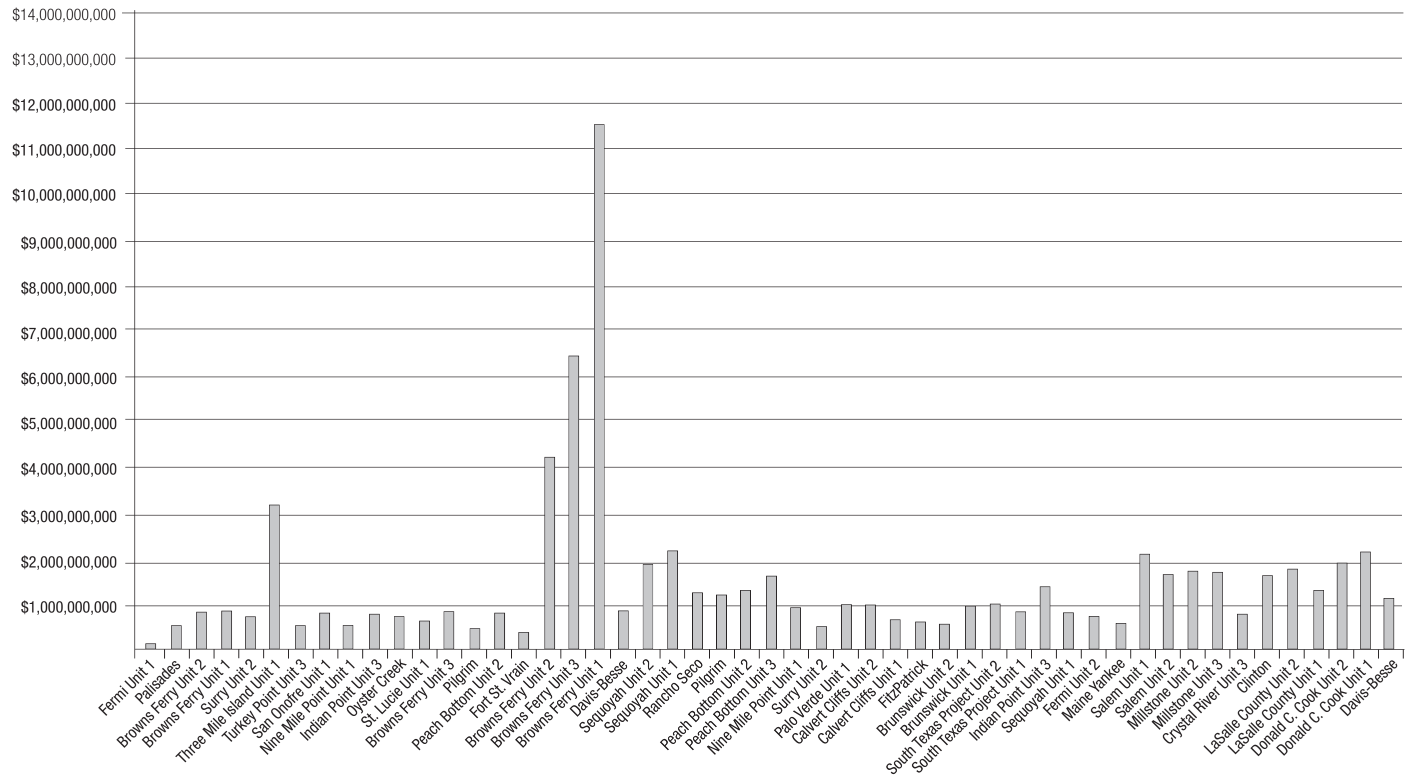


Table 2. Year-plus Reactor Outage Milestones

First year-plus outage	Fermi Unit 1 (Newport, MI)	October 1966
Most recent year-plus outage	Davis-Besse (Oak Harbor, OH)	February 2002
Shortest year-plus outage	Maine Yankee (Wiscasset, ME)	1 year, 4 days
Longest year-plus outage	Browns Ferry Unit 1 (Athens, AL)	21 years and counting
Youngest reactor to experience a year-plus outage	Browns Ferry Unit 2	Less than one month
Oldest reactor to experience a year-plus outage	Davis-Besse	23.5 years
Reactors with most year-plus outages	Browns Ferry Unit 1 Browns Ferry Unit 2 Browns Ferry Unit 3 Davis-Besse Indian Point Unit 3 (Buchanan, NY) Nine Mile Point Unit 1 (Lycoming, NY) Peach Bottom Unit 2 (Delta, PA) Pilgrim (Plymouth, MA) Sequoyah Unit 1 (Soddy-Daisy, TN) Surry Unit 2 (Surry, VA)	2 each

CHAPTER 3

The Lessons of Year-plus Outages

First and foremost, the fact that the 51 year-plus nuclear power reactor outages since 1966 have not led to a major accident is an enduring legacy of the "defense-in-depth" approach to nuclear safety practiced by the NRC and its predecessor, the AEC:

> *The NRC's approach to protecting public health and safety is based on the philosophy of defense-in-depth. Briefly stated, this philosophy (1) requires the application of conservative codes and standards, which create substantial safety margins in the design of nuclear plants; (2) requires high quality in the design, construction, and operation of nuclear plants to reduce the likelihood of malfunctions, including the use of automatic safety system actuation features; (3) recognizes that equipment can fail and operators can make mistakes, thus requiring redundancy in safety systems and components to reduce the chances that malfunctions or mistakes will lead to accidents that release fission products from the fuel; and (4) recognizes that, in spite of these precautions, serious fuel damage accidents can happen, thus requiring containment structures and other safety features to prevent the release of fission products off site.*[2]

Despite inept management, widespread equipment degradation, and/or significant design flaws that resulted in extended reactor downtime, the public has not been physically harmed by a year-plus outage.** Nuclear power plants are far from being houses of cards. The "substantial safety margins" and "redundancy" built into them by the AEC's original requirements have helped prevent them from toppling even when safety margins were badly eroded.

However, Edwin C. Triner, director of the AEC's Office of Program Analysis–Regulation, expressed a different fear in a letter to his boss in 1974:

> *I am very concerned that we are currently establishing patterns of excessive tolerance that will make strong action increasingly difficult to take and will haunt us in future years when the population of and dependence on nuclear facilities have greatly increased.*[3]

Triner's warning was both justified and unheeded; 49 of the 51 year-plus reactor outages occurred *after* he made this statement.

Lesson 1: Owners Are Given Too Much Leeway

The frequency with which plant owners have had to shut down their reactors for a year or more just to restore the minimum safety margins is itself a sign of the "excessive tolerance" that has allowed safety to erode to dangerous levels. More

** The same cannot be said of the public's psyche or pocketbook.

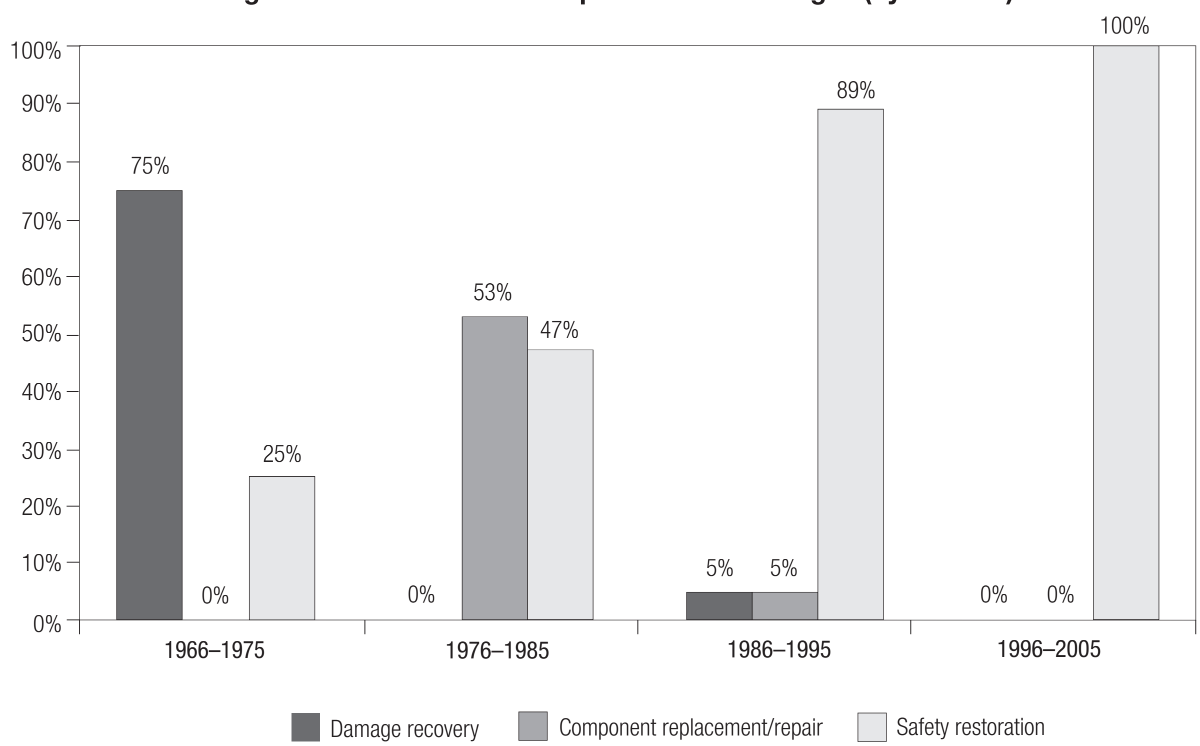
specifically, 36 of the 51 year-plus outages were caused by broad, programmatic breakdowns that forced plant owners to first fix their flawed practices and then undo the damage inflicted on their plants by years of operating with the flawed practices.

The reasons for year-plus reactor outages by decade provide useful insights. For example, Figure 13 shows the early prevalence of year-plus outages related to events that caused extensive damage (such as the March 1975 fire that damaged cables and equipment at Browns Ferry Units 1 and 2 in Alabama and knocked the reactors out of service for more than a year). These damage recovery outages have largely been eliminated. Similarly, year-plus component replacement/repair outages, which are needed to replace or repair major components that have degraded (such as recirculation pipes at Massachusetts' Pilgrim facility in 1983 and steam generator tubes at Maine Yankee in 1993) were prevalent several decades ago and have been largely eliminated. These types of year-plus outages did not disappear by themselves—the NRC applied considerable regulatory attention to such incidents and successfully reduced their frequency.

However, year-plus safety restoration outages necessitated by systemic breakdowns (resulting from flawed operating practices and badly eroded safety margins) are another matter. This type of extended outage, which reflects the "patterns of excessive tolerance" that Edwin Triner warned the AEC about in 1974, is booming. As explained in greater detail in Chapter 4, this trend is the result of the NRC not applying effective regulatory attention to systemic breakdowns, thereby allowing such incidents to proliferate.

Until the nuclear power industry and the NRC can successfully demonstrate that they have stopped the significant safety margin erosion caused by systemic failures, it would be imprudent public policy to cause further erosion by

Figure 13. Reasons for Year-plus Reactor Outages (by Decade)



supporting cost-cutting measures such as extended power uprates, "best-estimate" or "realistic" analyses in place of conservative analyses, and 20-year operating license extensions. Time and again, the "substantial safety margins" originally established by the AEC have protected the public from harm, and the NRC must call a halt to the ongoing march of nuclear power reactors deeper and deeper into those margins.

Lesson 2: Problems Are Not Spotted Soon Enough

Another compelling insight arising from our review of year-plus reactor outages is the lack of a comparable review by the NRC. Though the agency often conducted a post-mortem analysis of its own performance and that of the plant owner in respect to an individual extended outage, such as those done for the Millstone (Connecticut) and South Texas Project outages, it never attempted a broader assessment seeking to identify recurring themes among similar outages.

More than 20 years ago, Congress had to pass legislation forcing the NRC to conduct a broader assessment of recurring problems at nuclear power plants under construction. As related by the General Accounting Office (GAO):

> *The concerns regarding the quality of nuclear power plant construction prompted the Congress to direct NRC to study existing and alternative approaches for improving quality and quality assurance activities at construction sites. NRC's study, commonly referred to as the "Ford Amendment" study after its principal sponsor, Senator Wendell Ford of Kentucky, was conducted between November 1982 and April 1984, and included the development of six case studies of nuclear power plant construction projects that had experienced or did not have major quality-related problems.*[4]

The NRC ultimately reported back to Congress:

> *The staff concluded that the root cause for the major quality-related problems in design and construction was the failure or inability of some utility management to effectively implement a management system that ensured adequate control over all aspects of the project.*[5]

Nevertheless, the problem of poor quality during construction was never fully resolved. The last U.S. nuclear power reactor to enter service—Watts Bar in Tennessee—was licensed by the NRC in December 1995 after two decades of troubled, costly construction. The GAO evaluated the performance of TVA, the plant's owner, in 1991 and reported:

> *TVA has been unable to maintain adequate productivity levels for construction at its nuclear power plants and efficiency levels for modification work at its fossil and hydro plants. For example, according to the President of its Generating Group, TVA has been unable to complete construction of the Watts Bar Nuclear Plant, in part because of poor productivity.*[6]

It should come as no surprise, then, that quality assurance problems born by ineffective management and nurtured by inadequate regulatory oversight did not disappear when nuclear power reactors moved beyond the construction phrase. Our review of the 51 year-plus reactor outages during the past four decades finds that the same poor oversight by the NRC has combined with management failures to produce conditions so abysmal that extended outages are necessary to restore safety levels.

Lesson 3: The Public Is Being Ignored

The nuclear power industry and the NRC often blame the public for unnecessarily extending the duration of licensing proceedings. As a result, the NRC recently revised its regulations, such as Title 10 of the Code of Federal Regulations (CFR), Part 2, to restrict public involvement in these proceedings. Yet the case studies we have compiled for each of the 51 year-plus outages (see *www.ucsusa.org/clean_energy/nuclear_safety*) provide scant evidence to support this charge. In a small number of cases, such as Maine Yankee and Michigan's Donald C. Cook, actions by the public did prolong the outages, but the record also clearly demonstrates that the public did not trump up baseless accusations or entangle the restart in pointless legal wrangling.

As noted above, most extended outages are the result of poor management and overly tolerant regulatory oversight. It is therefore patently unfair to punish the public for the NRC's failures and those of its licensees. The agency should take swift steps to remove these unwarranted restrictions and restore the public to its meaningful role in licensing proceedings.

The other lessons we have learned from year-plus outages follow in descending order of importance and specificity.

Lesson 4: Corrective Action Programs (CAPs) Are Not Adequately Assessed

More than 70 percent of year-plus outages have been caused by broad, programmatic breakdowns. Such breakdowns cannot, and did not, occur without a corresponding failure of the programs that were already in place to find and fix problems. Having an effective CAP is not simply prudent public policy and sound business practice; it is also a federal requirement (under Appendix B to 10 CFR Part 50). Nevertheless, the industry and the NRC have a poor track record of evaluating the health of these vital, mandatory programs.

The most recent—but far from the only—example is Ohio's Davis-Besse. In March 2001, the NRC gave high marks to the CAP at Davis-Besse:

> *The team concluded that the licensee effectively identified, evaluated, and corrected plant problems. Problem identification was determined to be effective based on a low condition report initiation threshold and effective Quality Assurance audits and self assessments. . . . Root cause evaluations used structured techniques and were effective in identifying one or more root causes. Corrective actions specified appropriately matched the identified causes and were effective in preventing recurrence of significant conditions adverse to quality.*
>
> *The inspectors conducted interviews with plant staff to assess whether there were impediments to the establishment of a safety conscious work environment. . . . No significant findings were identified during the assessment of safety-conscious work environment. Plant staff interviewed indicated a willingness to identify safety issues. The low threshold for initiating CRs* [corrective responses]*, the increasing number of CRs, and management support for using the CR process observed during the daily management meeting also supported a safety conscious work environment.*[7]

Less than a year later, workers at Davis-Besse discovered significant degradation of the reactor vessel head. The NRC sent another team to inspect the CAP, which this time flunked:

> *This report documents a special corrective action program implementation team inspection. The inspection was conducted to assess the adequacy of the licensee's implementation of the facility's corrective action program. . . . Two Green findings associated with two cited violations, one Severity Level IV Non-Cited Violation (NCV), and twenty-six (26) Green findings associated with 26 NCVs were identified.*

In an effort to identify adverse trends and problem areas, the licensee performed a collective review of approximately 600 relatively significant CRs. . . . The licensee's review efforts identified numerous discrepancies involving an inadequate CAP, inadequate configuration control, degraded hardware conditions, inconsistent and potentially non-conservative assumptions in design basis and licensing basis documents, deficient or unavailable calculations, and non-conservative operating and test procedures which did not reflect design and licensing basis documents.

During the inspection, the [NRC] *team reviewed approximately 150 CRs. Of these, the team determined that approximately 120 had weaknesses or deficiencies, of some type. As a result of the team's findings, the licensee initiated approximately 120 additional CRs to document and address the team's findings. Overall, the team determined that approximately 80 percent of the CRs actually reviewed by the team had weaknesses or deficiencies to some degree.*[8]

The CAP at Davis-Besse was no worse in 2004 than it had been in 2001. What changed was the NRC's perception of the program. A near-disaster showed just how far from reality the agency's original conclusion had wandered. It is imperative that the gap between perception and reality with respect to CAP effectiveness be minimized if future extended outages—or worse, accidents—are to be avoided. The next chapter probes this topic further.

Lesson 5: Problems Are Allowed to Recur

Michigan's Palisades nuclear power reactor was shut down from August 1973 until October 1974 due (at least initially) to a leak in a steam generator tube. Though that problem had been corrected by spring 1974, the AEC inspected the site and concluded the reactor was not ready to be restarted. The first item on the AEC's list of concerns was an inadequate quality assurance program.

This same problem has been on nearly all of the NRC's restart lists for the 49 year-plus outages that followed Palisades. This is clearly a case in which an ounce of prevention would have been worth a pound of cure. Had the nuclear power industry and its regulatory agency heeded the lesson of the Palisades outage and given more than mere lip service to quality assurance, many if not all of the ensuing extended outages would likely have been avoided. It's not too late to get serious about effective quality assurance (or, under its current moniker, problem identification and resolution).

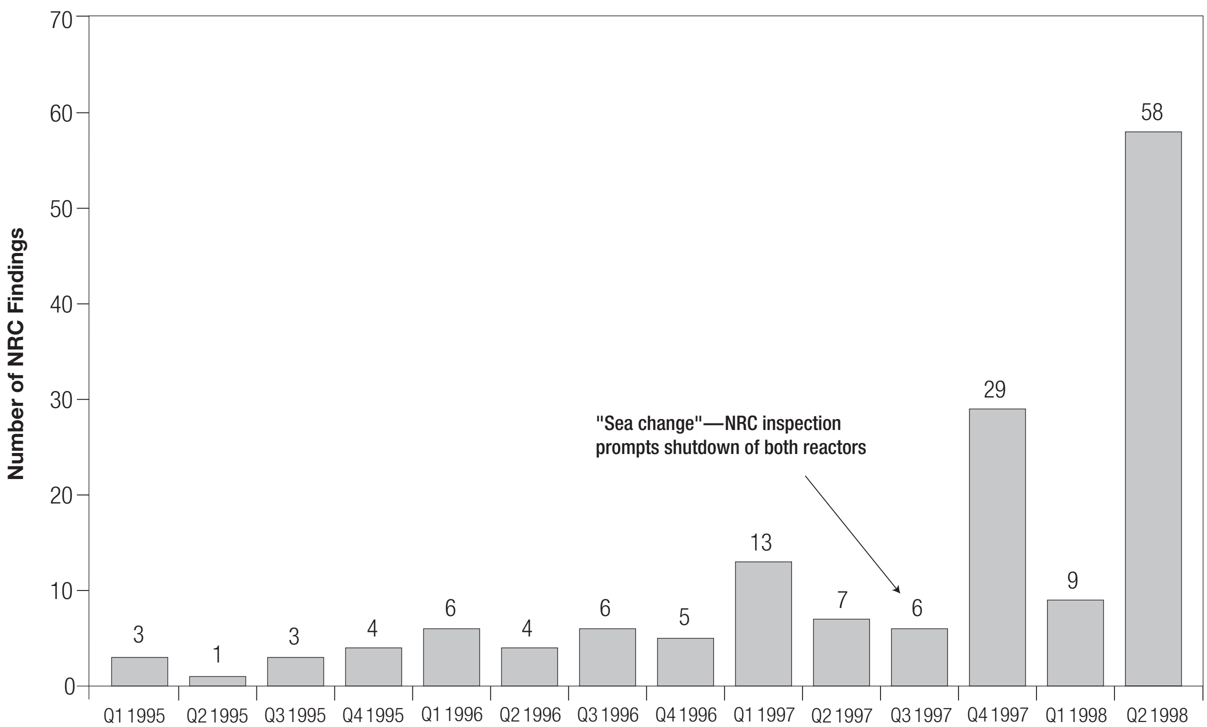
Lesson 6: Perceptions (Not Reality) Guide Safety Decisions

As previously stated, more than 70 percent of year-plus outages were caused by broad, programmatic breakdowns. In most of these cases, the NRC's assessments of a plant's safety performance prior to the beginning of the outage were positive. It was only after an extended outage began that the assessments underwent a sea change and began documenting poor safety performance at that plant.

Michigan's Donald C. Cook facility typifies this bizarre pattern of assessments (Figure 14, p. 24). For three years prior to the beginning of the plant's year-plus outage in the third quarter of 1997 (and the NRC's apparent sea change), the agency recorded less than one violation every two weeks. In the first few months of the outage, the NRC began to identify violations—most of which had existed for years—at a rate of nearly one every other day.

By the first quarter of 1998, when Indiana Michigan Power Company was preparing to restart the plant, the number of violations the NRC identified dropped to pre-outage levels. But questions remained about plant safety, and as public pressure forced the NRC to go back

Figure 14. Safety Violations Found by the NRC at Donald C. Cook (Bridgman, MI)



and look at specific problems, the number of violations it identified skyrocketed during the second quarter of 1998.

The conditions at Donald C. Cook did not change overnight; the NRC's perception of the conditions did. In other words, how could NRC inspectors not find problems at a "bad" plant? The process was essentially working backward from the way it should.

To be fair, plant owners have been equally guided by perception rather than reality. Florida's Crystal River 3 facility offers a prime example of this tendency. When the NRC placed Crystal River 3 on its Watch List on January 29, 1997 (nearly 20 years after the reactor began operating), plant workers suddenly found the following safety problems:

- February 1—The temperature inside the rooms housing the emergency diesel generators could exceed the 120 degrees Fahrenheit design limit when ambient temperatures in that part of Florida reached 95 degrees Fahrenheit.
- February 7—Thermal relief valves on the cooling water system would not function under the environmental conditions experienced during accidents.
- February 13—Temperatures in various plant buildings exceeded the limits established for safety-related electrical equipment.
- February 14—Both of the emergency feedwater pumps would not function as needed in response to accidents.
- March 7—During certain accidents, radiologically contaminated water would have been transferred from the reactor building to the auxiliary building, resulting in excessive radiation exposure for workers and members of the public.
- March 15—Containment isolation valves for the emergency feedwater system would not close as required during accidents.

- March 19—Leakage from the lubricating oil system for the reactor coolant pumps violated fire protection requirements.
- March 27—Heating, ventilation, and air conditioning systems had been improperly excluded from an analysis of equipment needing manual adjustments in response to a fire.

This abridged list omits dozens of other problems identified by workers after the NRC placed Crystal River 3 on its Watch List. Most of the problems had existed since the plant's startup 20 years earlier but were missed during countless subsequent tests and inspections. Did the plant's owner bring in busloads of smarter workers after the NRC put the reactor on notice? No, capable workers missed these problems for the same reason that capable NRC inspectors found few problems at Donald C. Cook prior to its year-plus outage: when Crystal River 3 was perceived to be a good plant, tests and inspections "confirmed" this perception. When Crystal River 3 was perceived to be a troubled plant, the same tests and inspections "confirmed" this perception, too.

The Crystal River experience reflects that of many other year-plus outages. Plant owners do not continue operating reactors that they know suffer from extensive degradation. Instead, widening gaps between perception and reality and a steadfast belief in overly optimistic perceptions leaves the plant owners as "surprised" as the NRC when the depths of the problems are finally revealed.

Despite numerous attempts over the past four decades to prevent safety test and inspection results from being influenced by perceptions, this problem has yet to be addressed effectively. The public health risks and financial stakes of a "surprise" nuclear disaster are too high to allow false perceptions to continue guiding nuclear safety decisions.

Lesson 7: Owners Are Not Made Aware of Non-Hardware Problems

The NRC issues generic communications to its licensees in the form of bulletins, circulars, generic letters, information notices, and regulatory issue summaries that describe new and revised regulations and lessons learned from operational events. Thousands of such communications have been issued by the NRC since 1975, and plant owners incorporate the content into their procedures, practices, and training.

Our case studies reveal that the NRC has issued numerous generic communications about equipment problems it identified prior to and during year-plus outages, but hardly any regarding non-hardware problems—despite the fact that it knew such issues were associated with extended outages. For example, the NRC informed Congress about programmatic failures at TVA that caused the extended outages at Browns Ferry in Alabama and Sequoyah in Tennessee. But it did not issue generic communications to plant owners about these failures nor (for the most part) about similar programmatic failures it knew had occurred at nearly two dozen other reactors experiencing year-plus outages.

Consequently, plant owners have not had the same opportunities to update flawed procedures, practices, or training that they have had to fix equipment problems. The NRC must stop keeping "secrets" about programmatic breakdowns that can cause significant erosion of safety margins at nuclear power reactors.

Lesson 8: Programmatic Breakdowns Are Not Confined to One Plant

At nuclear power plants with multiple reactors, programmatic breakdowns (the cause of most year-plus outages) typically resulted in all of the reactors being shut down until the problems were corrected. This makes sense considering that programmatic breakdowns are unlikely to be confined to only one of the reactors at a given site.

And yet, companies operating multiple nuclear power plants seldom shut down all of their reactors when one plant experiences a programmatic breakdown. This makes little sense considering that programmatic breakdowns are unlikely to be confined to only one facility owned by a poorly managed company. The NRC must determine whether programmatic breakdowns identified at one site also affect reactors operated by the same company at other sites. The agency must also ensure that a plant owner's focus on restarting a troubled reactor does not cause or contribute to declining performance at other reactors owned by that company.

Lesson 9: Better Communication Is Needed inside the NRC

The NRC quite properly does not accept excuses from a plant owner such as, "The maintenance department knew about an unresolved equipment problem but failed to inform the operations department." As documented in our case studies, however, the NRC repeatedly suffers from internal communication barriers of its own.

For example, NRC Region III staff knew about containment problems identified by its inspectors at Donald C. Cook, but was unaware of related problems that the staff at NRC headquarters knew existed at other plants. This pattern recurred five years later when UCS had to inform Region III staff about problems known to NRC headquarters that were applicable to the regional team's work at Davis-Besse. The NRC must develop more effective internal communications so that knowledge possessed by one region or office is shared by all.

Lesson 10: Not All Poor Performers Have Had a Year-plus Outage

Though it was not an explicit objective of this analysis, we came across five reactors that were not on the year-plus outage list even though their documented performance levels were as bad as, or worse, than many reactors on the list. Dresden Units 2 and 3 in Morris, IL, for example, were on the NRC's Watch List for 7.5 years—longer than any U.S. reactor other than Browns Ferry—but never experienced a year-plus outage. Seventy-five percent of the reactors on the Watch List for a year or longer experienced a year-plus outage, and all of the reactors on the Watch List for three years or longer—except for Dresden—experienced a year-plus outage. Apparently, the NRC believed Dresden had the same performance problems as the other reactors but, for some reason, did not need the same remedy.

New Jersey's Salem Units 1 and 2 experienced a year-plus outage in the mid-1990s, but they, along with the Hope Creek reactor literally next-door, did not meet a similar fate in 2003 despite ample evidence from several independent assessments that safety levels were at least as bad as they were at the time of the mid-1990s outage. Salem had clearly suffered a relapse, but the NRC inexplicably opted for a different treatment regimen the second time around.

Lessons Must Translate into Action

The bad news about the many lessons to be learned from the 51 year-plus outages is that much work needs to be done by the NRC to more effectively oversee safety levels at nuclear power reactors. The good news is that the NRC, when working effectively, can produce successful outcomes. The challenge and imperative is thus to move this needed work from the road ahead to the rearview mirror.

Chapter 4

NRC Oversight of Safety Programs

The 104 currently licensed U.S. nuclear power reactors received their operating licenses after the NRC made two determinations: (1) that the reactor's design and construction conformed with all applicable regulations, and (2) that reasonable assurance existed that the reactor would be operated and maintained in conformance with the license and all applicable regulations. For example, the NRC's predecessor, the AEC, issued a full-power operating license for Vermont Yankee on October 12, 1972, based on the provisions highlighted in Figure 15.

This licensing process recognizes the fact that nuclear power reactors are complex industrial facilities subject to periodic equipment breakdowns. The operating license issued for each reactor includes technical specifications that define the minimum complement of safety equipment needed for operation and how quickly the reactor must be shut down when one or more pieces of safety equipment become unavailable.

Figure 15. NRC Operating License for Vermont Yankee (Vernon, VT)

Vermont Yankee Nuclear Power Corporation

(Vermont Yankee Nuclear Power Station)

Docket No. 50-271

Facility Operating License

License No. DPR-28
Amendment No. 3
[TEMPORARY OPERATING LICENSE]

The Atomic Energy Commission (the Commission) having found that:

a. Construction of the Vermont Yankee Nuclear Power Station (the facility) has been substantially completed in conformity with the application, as amended, the Provisional Construction Permit No. CPPR-36, the provisions of the Atomic Energy Act of 1954, as amended (the Act), and the rules and regulations of the Commission as set forth in Title 10, Chapter 1, CFR; and

b. The facility will operate in conformity with the application, as amended, the provisions of the Act, and the rules and regulations of the Commission; and

In addition, the NRC (under Appendix B to 10 CFR Part 50) requires plant owners to implement quality assurance (QA) programs (now commonly referred to as corrective action programs but constituting the same measures). Quality assurance is defined as "all those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service,"[9] and Appendix B also defines 18 criteria needed to measure quality assurance. Criterion XVI, for example, describes the proper approach to "corrective action:"

> *Measures shall be established to assure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, defective material and equipment, and nonconformances are promptly identified and corrected. In the case of significant conditions adverse to quality, the measures shall assure that the cause of the condition is determined and corrective action taken to preclude repetition. The identification of the significant condition adverse to quality, the cause of the condition, and the corrective action taken shall be documented and reported to appropriate levels of management.*[10]

In other words, QA programs ensure that plant owners have effective methods in place for promptly finding and fixing problems, and that nuclear power reactors are operated and maintained within the configuration reviewed and approved by the NRC.

Multilayered Defense or Feedback Loop?

Just as the "defense-in-depth" approach to nuclear power plant design (see Chapter 3) employs features such as redundant pumps to ensure that a single equipment failure will not result in disaster, QA programs incorporate multiple levels of quality control (Figure 16).

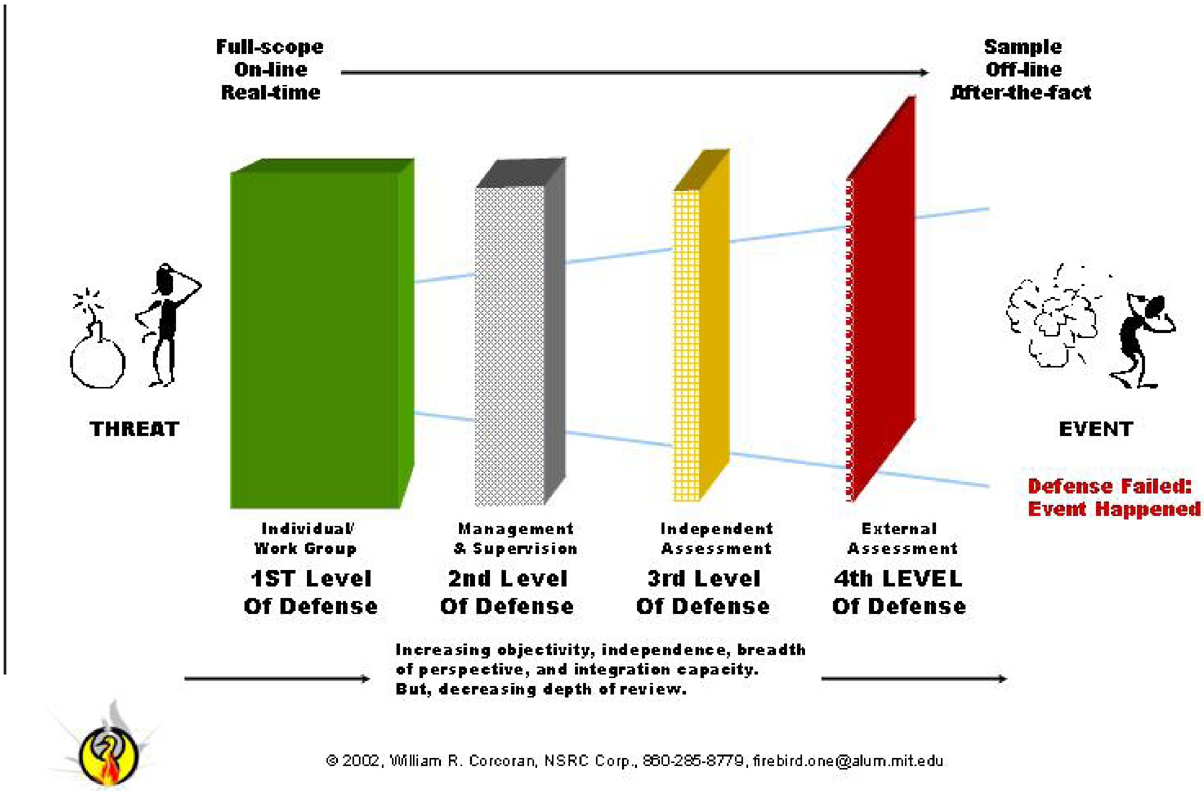
Plant workers provide the first level of QA defense; these individuals must be qualified for their work assignments and trained to complete specific tasks, and they must follow pre-approved procedures. Supervisors provide the second level of QA defense by ensuring that the right individuals are doing the right tasks the right way, and verifying the outcomes by monitoring work in progress and checking the results. The third level of QA defense is provided by other workers inside the plant who independently verify the outcomes of specific tasks. The shared objective of these three levels is to find and fix problems as required for both safe reactor operation and conformance with Appendix B to 10 CFR Part 50.

NRC inspectors provide the fourth level of QA defense. **For an NRC inspector to find a problem, all three other levels had to have failed.** That point cannot be over-emphasized. If the individual worker had been successful, or the worker's supervisor had been successful, or the internal oversight had been successful, the NRC inspector would not have identified a problem. Thus, every NRC finding of a safety problem has two components: the broken equipment and the concurrent failure of all three internal levels of QA protection.

This context is important because while the NRC has periodically revised how it oversees safety levels at nuclear power plants, it has never made substantive progress in how it assesses the health of QA programs. When an NRC inspector finds broken equipment today, the owner must do the same thing that was done when an AEC inspector found a similar problem in 1966: fix the broken equipment. But that's only part of the problem that should be addressed.

As explained above, the fact that an NRC inspector has found broken equipment means that all three levels of the plant's QA program failed. Yet findings by NRC inspectors are treated

Figure 16. Levels of Defense within Quality Assurance Programs



no differently than findings by individual workers, their supervisors, and internal auditors. The NRC inspector's finding is entered into the very QA program that has just proven faulty, raising concerns that the finding will not be used effectively to improve the situation.

NRC inspectors must not merely be another source of input to a plant's QA program. Their proper role is to independently evaluate how effectively individual workers, supervisors, and internal auditors are finding and fixing problems. NRC inspection findings are unique in that they and they alone demonstrate that all three other levels of quality assurance failed. Therefore, NRC inspection findings must trigger needed repairs to the three defective levels of the plant's QA program in order to prevent continued safety margin erosion.

The Tip of the Iceberg

The NRC's misguided approach to regulating QA programs is the primary reason for the 51 year-plus reactor outages. Since the agency's inspectors only audit about five percent of the activities conducted at nuclear power plants, it is reasonable to assume there are roughly 95 problems that go undiscovered for every five that are. By only requiring these five problems to be corrected and not patching the associated holes in the QA program that produced the problems, more and more problems will go uncorrected as time passes. Eventually, something acts as a catalyst to cause these myriad problems to finally get fixed, but by that time the list of overlooked problems is so long that it takes a year or more to address them all.

It is imperative that the NRC do a better job of gauging the health of QA programs at nuclear power plants—not just to reduce or eliminate year-plus reactor outages that reduce electricity reliability and hurt consumers and stockholders financially, but to provide a stronger defense against even worse outcomes. Though the NRC grants operating licenses after determining that reactors conform with all applicable regulations, conformance does not guarantee zero risk. Conformance only reduces the risk to a level deemed acceptable.

The volume of non-conformance associated with year-plus reactor outages suggests that the risk represented by these reactors was unacceptably higher than necessary. The more often reactors walk a nuclear tightrope with large holes in the safety nets below, the more likely it becomes that one will eventually plunge into disaster.

Chapter 5

NRC Performance during Year-plus Outages

In this chapter, we review the effectiveness of NRC oversight in terms of six specific year-plus outages. Three of these outages reflect a performance level far below what should be minimally acceptable for a federal safety regulator, but the other three reflect quite favorably upon the NRC's capabilities.

Like any person or organization, the NRC has good days and bad days. We point out examples of the agency's bad days in the hope that similar problems will be avoided, leading to more good days—examples of which show that the agency is not fundamentally flawed and has the capacity to learn from its mistakes.

Poor Performance

The NRC's oversight of the 51 year-plus reactor outages was worst in the following three cases:

San Onofre Unit 1 (San Clemente, CA, February 1982 to November 1984)

In May 1976, the NRC began its Systematic Evaluation Program to assess the safety of older reactors according to current regulations. This effort led the NRC to conclude that San Onofre Unit 1 did not comply with the current regulations for protection against earthquakes—even though it was operating in proximity to active geologic faults. For these reasons, consumer advocate Ralph Nader petitioned the NRC to shut down the reactor in July 1981, but the NRC denied Nader's petition that November.

In February 1982, Southern California Edison (SCE) shut down Unit 1 for a scheduled refueling outage and, two months later, submitted information to the NRC indicating that some vital equipment on the reactor would not survive an earthquake of the magnitude specified in the current regulations. When the NRC asked whether that equipment would survive the smaller earthquake specified in the older regulations, SCE—rather than answering that question explicitly—agreed to voluntarily upgrade the vital equipment to meet the current standard. That voluntary gesture became a requirement in August of that year when the NRC ordered SCE to upgrade Unit 1 to satisfy the current earthquake regulations before it could restart the reactor.

In 1984, the California Public Utilities Commission ruled that Unit 1 would be removed from the rate base if it was not returned to service by the end of the year. SCE responded by lobbying the NRC to allow Unit 1 to be restarted even though the agency's August 1982 order had not been met. In a truly deplorable decision, the NRC granted SCE its wish, using a questionable legal maneuver that its own general counsel suggested would probably not be upheld by the courts if appealed. The public was poorly served by an agency that ignored federal regulations and allowed a reactor with a known safety deficiency to restart for purely financial reasons.

Indian Point Unit 3 (Buchanan, NY, February 1993 to July 1995)

The New York Power Authority shut down Indian Point Unit 3 in February 1993 to fix problems identified in a backup safety system. Less than six weeks later, the NRC invoked its right to oversee the restart of a troubled plant following an extended outage. This seemingly prompt regulatory response, however, needs to be seen in the proper context.

The New York Power Authority also owned and operated the FitzPatrick reactor in Scriba, NY. FitzPatrick had been shut down from November 1991 until January 1993 to resolve a litany of programmatic problems—the same litany spelled out on the NRC's April 1993 restart list for Indian Point Unit 3. The NRC considered these problems serious enough at FitzPatrick that it did not allow that reactor to be restarted until all of the problems were fixed; yet the agency knowingly allowed Indian Point Unit 3 to operate with the same problems until FitzPatrick had been restarted.

The NRC clearly put the New York Power Authority's generating capacity ahead of safety at Indian Point. To properly protect public health, the NRC must require plant owners to correct safety problems when they are identified, not when it becomes more convenient and less unprofitable to do so.

Millstone Units 2 and 3 (Waterford, CT, February 1996 to May 1999 and March 1996 to July 1998)

Millstone and Ohio's Davis-Besse competed for the third worst NRC regulatory performance in connection with year-plus outages. It was a tough call—the NRC knew about many longstanding safety problems at Millstone but did nothing about them, and was clueless about the equal number of longstanding safety problems at Davis-Besse.

We decided the NRC's oversight of Millstone was worse because the agency knew that performance levels were low and heading lower, but did very little about this disturbing trend until plant engineer George Galatis and the nonprofit organization We The People brought public attention to the plant's unsafe practices. The NRC's inspector general ultimately validated Galatis's concerns, and *Time* magazine depicted the agency as an impotent regulator. The NRC had begun seeing warning signs at Millstone as early as the 1980s, but tolerated—and possibly enabled—its sustained inadequate performance until 1996.

Strong Performance

Fortunately, the regulatory miscues described above do not tell the whole story. The following year-plus outages demonstrated admirable regulatory prowess by the NRC:

Nine Mile Point Unit 1 (Lycoming, NY, March 1982 to July 1983)

The NRC's performance prior to and during this outage was nothing less than outstanding. As Nine Mile Point was preparing to restart its Unit 1 reactor following a brief maintenance outage, it was an NRC inspector rather than a plant worker who discovered water leaking from a small crack in a pipe connected to the reactor vessel. Had the reactor been restarted before this problem was found, the crack could have triggered a serious accident.

The NRC's response to the discovery was equally commendable: the agency promptly required other plant owners to look for similar cracks. As inspection results came in from these plants, the NRC adjusted its requirements—more stringent in some areas, less burdensome in others—as appropriate. The agency thus ensured this problem was corrected not only at Nine Mile Point but also at all other reactors.

Sequoyah Units 1 and 2 (Soddy-Daisy, TN, August 1985 to November 1988 and May 1988)

NRC regulation 10 CFR Part 50.49, which went into effect on March 31, 1985, attempts to ensure that safety equipment exposed to harsh environments during an accident will continue to function under such conditions. When the NRC notified TVA that its Sequoyah plant was going to receive one of the first audits the agency was planning to conduct under these new requirements, TVA hired an independent company to pre-audit Sequoyah.

The pre-audit results were so bad that TVA voluntarily shut down both Sequoyah reactors to correct the problems. The NRC then resisted concerted efforts by the company to confine its corrective measures to equipment qualification problems, and also forced TVA to address programmatic problems at Sequoyah that had plagued the company's reactors at Browns Ferry in Alabama and Watts Bar in Tennessee as well.

TVA then tried to get away with the ethical equivalent of turning in a test with grades the company had already assigned to itself. The NRC balked, asking TVA to bring in another independent company to determine whether TVA's restoration efforts had been thorough and effective. When the company refused, the NRC sent its own team of inspectors, which documented more than five dozen problems in just a single system. TVA had to go back and do much more work.

Turkey Point Unit 3 (Florida City, FL, February 1981 to April 1982)

For nearly four years prior to this outage, the NRC maintained a dynamic yet effective balance between protecting public health from an unexpected hazard and allowing another reactor to operate in a time of uncertainty. The unexpected hazard was the steam generator tube leak that occurred at Virginia's Surry nuclear power plant in September 1976. Though the NRC had anticipated such leaks when licensing reactors like Surry and Turkey Point, it had not anticipated the rapid rate of corrosion that caused the Surry tube to leak.

To avoid unfairly burdening Turkey Point's owner for the problem that had occurred at Surry (while also protecting the public by studying this problem's true dimensions), the NRC allowed Turkey Point to operate for up to six months between the shutdowns needed to inspect the plant's steam generator tubes. The agency also adjusted the operating period between inspections as more data became available from Turkey Point and other plants. By the time Florida Power & Light shut down Turkey Point Unit 3 in February 1981 to replace the steam generators entirely, the NRC had accumulated sufficient information about the corrosion problem to know that the replacement equipment would be more resistant to corrosion—justifying longer intervals between inspections.

Finishing a close fourth was the agency's performance during the outage at Surry Unit 2 from September 1988 to September 1989. The NRC reacted to an emerging problem (pipe wall thinning) in a thorough and timely manner both at Surry and at other affected reactors around the country.

The agency also deserves honorable mention for its performance during the outages at Michigan's Donald C. Cook Units 1 and 2 that began in September 1997. The NRC design inspection team found serious, but subtle, design problems that had gone unnoticed by previous inspectors for up to 20 years.

Signs of Slippage?

It was disconcerting to realize that all three of the NRC's best performances occurred nearly two decades ago, while two of the "Terrible Three" occurred more recently (and the fourth, Davis-Besse, was very recent). It would have been vastly more comforting had the data suggested that the agency's performance was improving and its worst days were receding into the past. Instead, the strongest NRC oversight occurred shortly after the Three Mile Island accident in 1979, when the nuclear power industry and its federal regulator could ill afford to appear complacent. We hope the agency is not succumbing to complacency today.

Chapter 6

Conclusions and Recommendations

Fifty-one year-plus outages at 41 reactors in the space of 40 years represent unacceptable regulatory performance by any measure.

Recommendation #1: The NRC must significantly improve its assessment of corrective action programs at nuclear power plants.

More than 70 percent of the 51 year-plus outages were caused by broad, programmatic breakdowns that gradually reduced safety to a level so low that reactor operation could not continue. The NRC essentially tolerated performance declines until they became too serious to ignore—at which point the problems required great expense and longer than a year to correct. This overly passive regulatory posture thus allowed safety levels to fall far lower than necessary and caused plant owners' costs to rise far higher than necessary. Either result would be sufficient grounds to induce reforms at the NRC; the fact that both results occurred signals an urgent need for overdue reforms.

The reform most needed at the NRC is the way the agency evaluates the health of CAPs at nuclear power plants. Federal regulations require plant owners to manage a CAP that finds and fixes problems in a timely and effective manner, thereby helping to ensure that safety margins are maintained during reactor operation. The most common theme among the 51 year-plus outages was an inadequate CAP; the second most common was the NRC's mistaken perception that these CAPs were just fine.

As detailed in Chapter 4, the NRC must view the findings of its inspectors differently in order to narrow the gap between perception and reality. In theory, NRC inspectors auditing safety levels should not be able to find a problem. If an inspector does identify a problem, the plant owner should be required to fix not only any broken equipment but also the weaknesses in its CAP that allowed the equipment to remain broken until the NRC discovered it.

Recommendation #2: The NRC must expand the scope of its generic communications program to alert plant owners about non-hardware problems that have reduced safety levels.

The NRC currently uses its generic communications program to alert plant owners about hardware problems identified at a specific plant. This information, along with input from other sources such as the Institute for Nuclear Power Operations, is brought to the attention of a plant owner's operational experience program, which evaluates the input for potential applicability and incorporates the applicable lessons into procedures and training. Missing from this extensive infrastructure are generic communications about non-hardware problems.

During our review of the 51 year-plus outages, we did not find a single instance in which the NRC had alerted plant owners about programmatic breakdowns that led to broken equipment and, ultimately, extended outages. The agency's generic communications have been too narrowly focused on hardware problems; the lessons of non-hardware problems must also be communicated so that they can be incorporated into procedures and training at all nuclear power plants.

Recommendation #3: The NRC must expand the scope of its oversight efforts when programmatic breakdowns at a plant are identified (i.e., when Manual Chapter 0350 is invoked). Specifically, the NRC must ensure that other plants operated by the same company do not suffer from similar problems or experience declining performance while the company focuses on restarting the troubled plant.

The programmatic breakdowns that caused most of the 51 year-plus outages typically led owners of plants with multiple reactors to shut down all the reactors at the affected site until the many problems were corrected. But such breakdowns seldom inspired the NRC to look at reactors operated by the same owner at other sites.

A programmatic breakdown at one plant does not necessarily mean the same breakdown exists at a poorly managed company's other plants, but it certainly represents a possibility that the NRC must investigate. Furthermore, even when a programmatic breakdown is confined to just one of a company's plants, the significant attention and resources devoted by management to restarting that facility could contribute to declining performance at other sites. Thus, when programmatic breakdowns are identified at a plant, the NRC must take tangible steps to (1) determine whether other plants operated by the same company have the same problems, and (2) ensure that performance does not deteriorate at those plants while the company focuses on restarting the troubled facility.

Recommendation #4: When longstanding problems are identified at a plant, the NRC must require the owner to (1) determine why its testing and inspection programs failed to find the problems earlier and (2) address those failures.

A review of the 51 year-plus reactor outages reveals the bizarre fact that numerous safety problems that were invisible to plant workers and NRC inspectors during years of tests and inspections magically became visible after an extended outage caused a sea change in how that plant was perceived. The workers and inspectors all suffered from a bias that steered test results away from finding problems.

The author of this report, prior to joining UCS, experienced an effective way of properly focusing inspections as a member of a team of consultants hired to inspect four systems at the Salem nuclear power plant in New Jersey. The team leader's directive was to assume that the systems were broken and uncover the evidence. My initial reaction to these instructions was, "I've been doing this for 17 years; I know how to evaluate systems," but I soon came to the realization that all of the safety assessments I had conducted in those 17 years were biased toward documenting the number of links in the plant's safety chain. The Salem inspection, on the other hand, was biased toward finding the weakest link in the chain and testing its soundness.

However the task is accomplished, the NRC must break the longstanding pattern of NRC inspectors and plant workers repeatedly overlooking safety problems until operations grind to a halt.

Recommendation #5: The NRC must develop a central repository for all current information about plant safety levels, potential safety problems, and generic safety issues so that all agency employees have access to the same data when making regulatory decisions.

Most of the post-mortems on year-plus outages conducted by the NRC, the NRC's inspector general, and the GAO show that the NRC had known about many of the problems but had not "connected the dots" to see the picture of a plant headed for trouble. Why? Because the dots resided in numerous places within the agency: some with regional staff, some with headquarters staff, and some with a different program office. There is no excuse today for not making all of the dots readily available to all NRC staff.

Until the NRC completes these five steps, it is quite likely that safety levels at nuclear power reactors will drop even while their safety assessments reflect good, sustained performance. This divergence between reality and perception has already caused too many year-plus reactor outages, and too much is at stake for the NRC not to take these steps now.

Recommendation #6: The scope of the NRC's monthly report to Congress should be expanded to include the agency's efforts in addressing the five recommended improvements detailed above.

Just as the NRC ensures that its licensees are following federal safety guidelines at their plants, Congress ensures that the NRC is doing everything possible to provide effective industry oversight and protect public safety. In the early 1980s, for example, Congress responded to a number of problems at nuclear power plants under construction (e.g., Zimmer in Ohio, Midland in Michigan, Diablo Canyon in California) by passing legislation that forced the NRC to examine quality control during plant construction. The agency reported back to Congress:

> *The staff concluded that the root cause for the major quality-related problems in design and construction was the failure or inability of some utility management to effectively implement a management system that ensured adequate control over all aspects of the project.*[11]

As a result, the NRC revamped its regulatory process to expand the depth and breadth of its inspection efforts at plants under construction.

Congress revisited the subject of quality assurance 10 years later, this time directing the GAO to investigate how the NRC evaluates quality control during plant operation. The GAO's report sounded eerily similar to what the NRC had earlier told Congress about plant owners' failings:

> *The fact that several NRC determinations that major utility management improvements were needed at operating plants came only after the occurrence of safety-related incidents or several years of marginal utility performance illustrates that NRC will need to develop better and more disciplined assessment tools if it is to successfully detect and correct utility performance problems before the problems lead to plant incidents.*[12]

Senators Joseph Lieberman (D-CT) and Joseph Biden (D-DE) subsequently asked the GAO to investigate how the NRC handled three specific troubled plants: Cooper in Nebraska, Millstone in Connecticut, and Salem in New Jersey. In the case of the Salem reactors, which the NRC kept shut down until it was satisfied that 43 different technical problems had been corrected, the GAO determined that the NRC had known about 38 of the problems prior to the outage—in two cases for nearly seven years prior—but had allowed Salem to continue operating.[13] This finding led the NRC to revamp its regulatory process for operating reactors and incorporate (for the first time) specific responses to specific performance problems.

More recently, the Senate's Subcommittee on Clean Air, Climate Change and Nuclear Safety examined what the NRC said it had learned from the near-disaster at Ohio's Davis-Besse reactor. Subcommittee Chairman George Voinovich (R-OH) clearly communicated his impression that the NRC had failed to fully address safety culture problems (which played a major role at Davis-Besse) and urged the agency to do more. The NRC got the message and made substantial improvements in its safety culture oversight.

These examples demonstrate that congressional oversight is essential in pushing the NRC to be the most effective regulator of nuclear power plant safety it can be. And the fact that there have been 51 year-plus outages in the past 40 years strongly suggests that Congress must compel the NRC to undertake reforms that will stop the prolonged, excessive erosion of safety margins that triggers unnecessarily costly extended outages.

The NRC today is akin to the National Aeronautics and Space Administration before the Columbia tragedy or the Federal Emergency Management Agency before the Katrina disaster. These agencies had dedicated, talented staffs with strong commitments to safety, and faced the challenge of protecting against low-probability events with deadly consequences. Congress must not wait for a nuclear Columbia or Katrina before beefing up its oversight of the NRC—it should adopt a proactive approach to its oversight function and help the NRC refocus its efforts.

Congress could easily enhance its oversight capabilities if the monthly report it currently receives from the NRC (describing the agency's progress in granting license renewal applications and certifying new reactor designs) were expanded to include updates on the specific reforms we have outlined in this chapter.

Public Safety Should Be Paramount

We hope it is apparent from our report that UCS is not suggesting that the NRC and its licensees be prohibited from shutting down reactors for a year or more if that is what is required to restore safety margins to an acceptable level. What concerns us is the extensive erosion of safety margins that occur prior to year-plus outages, and the fact that reactors have continued to operate throughout that erosion.

In the weeks and months leading up to the start of a year-plus outage, the people living nearby face an unnecessarily high—and often unpublicized—risk of an accident that could release deadly amounts of radiation. Such undue hazards simply must be eliminated.

Endnotes

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*Mr. Collins' response was a formal letter on NRC letterhead to the author. A copy was placed in the NRC's formal document repository and is an official agency record.

WALKING A

NUCLEAR TIGHTROPE

Unlearned Lessons of Year-plus Reactor Outages

The Nuclear Regulatory Commission (NRC) seems to be following the script of the movie *Groundhog Day*, reliving the same bad event again and again. This event—an outage at a nuclear power plant that lasts more than a year—has happened 51 times at 29 different plants around the United States and shows no signs of stopping.

Each such occurrence results from a violation of federal regulations that require plant owners to find and fix safety problems in a timely, effective manner, coupled with the NRC's inability to detect these problems (which multiply and worsen as a result). The accident at Three Mile Island might have been prevented had the NRC broken this cycle.

Since the nuclear power industry is unable to script Hollywood-style happy endings once events have begun to spin out of control, Congress must compel the NRC to be a more aggressive enforcer of federal safety regulations. Otherwise, declining safety performance could result in a nuclear disaster rather than a year-plus outage.

In *Walking a Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages*, the Union of Concerned Scientists identifies common themes among extended outages and steps the NRC should take to end these undue threats to public health and the U.S. economy.

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