A Graceful Exit?

Decommissioning Nuclear Power Reactors

by Darryl Farber and Jennifer Weeks

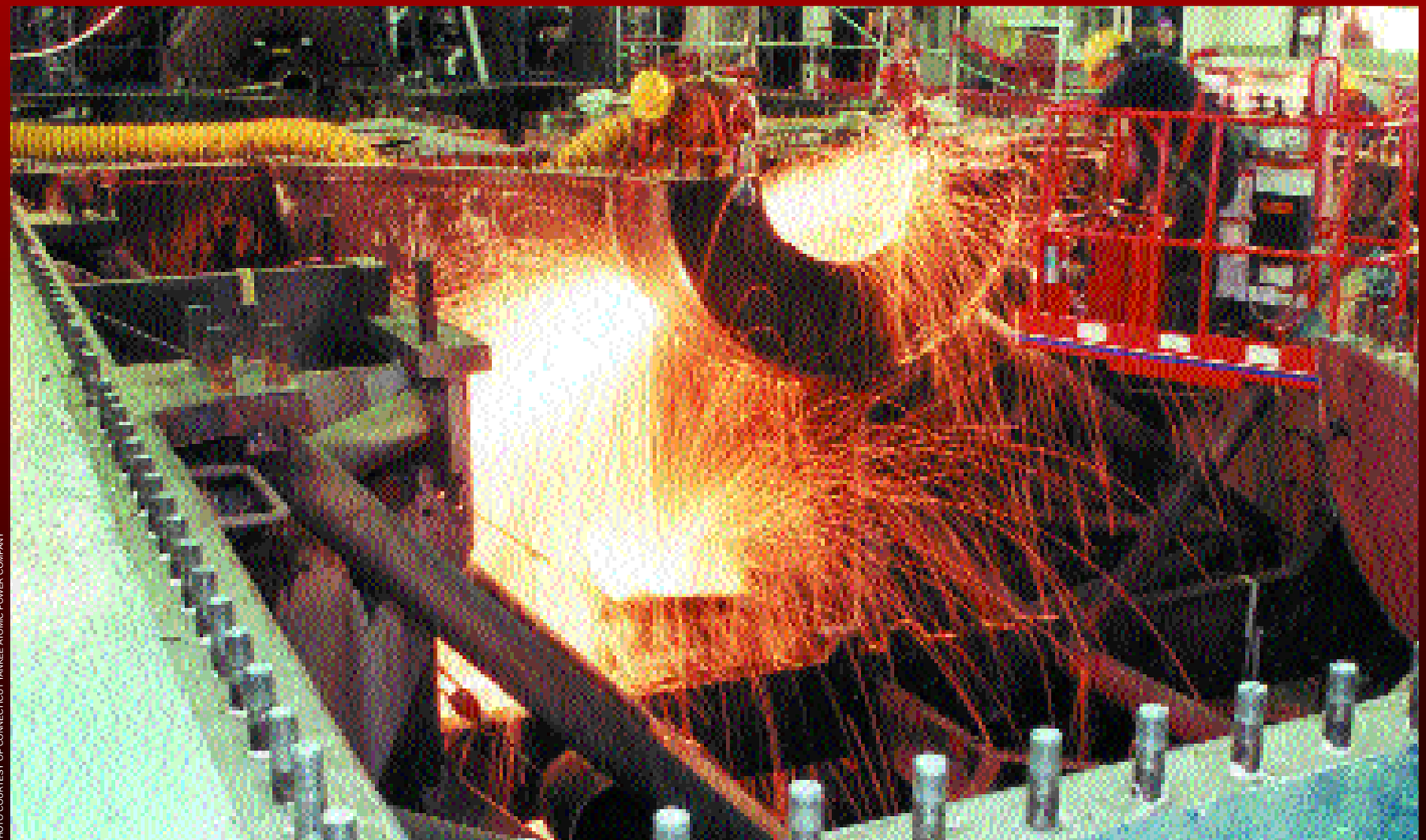

PHOTO COURTESY OF CONNECTICUT YANKEE ATOMIC POWER COMPANY

The reactor at the Palo Verde Nuclear Power Plant in Arizona (upper right), is one of 103 licensed nuclear reactors in the United States. Each plant owner eventually needs to decide either to decommission their reactor(s) or apply for license extensions. Decommissioning reactors is a long, costly process requiring the removal of spent fuel and contaminated material and the dismantling of large components, like this turbine at the Connecticut Yankee Nuclear Power Plant (above).

Nuclear power reactors built in the 1960s and 1970s are coming of age around the world, and dozens are scheduled to end operations in the next several decades. Decommissioning—removing reactors from service and cleaning up the sites so that they can be released for other uses—is providing an increasing stream of business to the nuclear industry.[1] Most countries that use nuclear power have decommissioned at least some small facilities, but the task is growing as

larger reactors approach the end of their operating lives. As a result, policy issues associated with decommissioning are commanding increased attention.

Decommissioning involves removing spent fuel from reactors, dismantling components that have become activated (contain radioactive materials), decontaminating or removing components with surfaces that have become radioactive, disposing of wastes, and ensuring that the site has been cleaned up to required standards. Certain aspects of the process are highly controversial. For example, some stakeholders—particularly local activist and watchdog groups—do not believe that the nuclear industry or federal regulators are sufficiently committed to protecting the environment and public safety. The business environment for utilities that own nuclear reactors has changed with the ongoing transition in many states to competitive electricity markets, further complicating the decommissioning process.

This article outlines major policy issues involved in decommissioning and recommends ways to improve the process, focusing primarily on the country with the largest nuclear power industry—the United States. (The box on this page offers information on decommissioning in other countries.) Like other environmental cleanup issues, decommissioning requires citizens to judge risks that are often expressed in highly technical terms and over which even experts disagree. Therefore, the roles of risk communication and public participation in the decommissioning process warrant special attention.

Reactor Decommissioning Worldwide

Dozens of nuclear reactors have been shut down or are expected to close soon in Europe, Canada, the former Soviet republics, and Japan. The great majority of near-term decommissioning work will take place in Europe: France, Germany, and Britain each are currently decommissioning 20 or more reactors, while nations using less nuclear power, such as Italy, Belgium, Spain, and Sweden, are decommissioning one or more reactors.

The European Commission (EC) is working to harmonize national decommissioning policies, which vary widely on key questions such as how long sites will be put in safe storage to allow radiation to decay (from a maximum of 30 years in Finland to 135 years in Britain). Waste management poses a serious challenge: The EC estimates that by 2060, decommissioning will produce more than 2 million metric tons of metallic waste and concrete, but many member states currently have limited storage and disposal options at best.[1]

The ongoing international effort to close unsafe Soviet-designed reactors in central and eastern Europe has important decommissioning implications. The European Community has made closure of these reactors a condition for membership and has pledged financial support for decommissioning eight reactors in Lithuania, Bulgaria, and Slovakia that are expected to be closed by 2008. The European Bank for Reconstruction and Development is collecting international contributions for these projects and supports pre-decommissioning work at Ukraine's Chernobyl plant.

Four nuclear power plants have shut down in Russia, and another ten units may close in the coming decade, although Russian officials are considering life-extensions. Russia does not have adequate funding, a regulatory framework, or defined waste management and disposal plans for reactor decommissioning.[2]

Because most Asian reactors are not as far into their licensed operating lives, decommissioning there is a less urgent issue—although it will become a concern as reactors age in Japan, South Korea, and Taiwan, all of which derive major shares of their electricity from nuclear power. However, none of these countries currently has a viable plan for long-term management of radioactive waste, so decommissioning may loom larger in coming decades. In September 2000, Taiwanese Economics Minister Lin Hsin-Yi sparked controversy by arguing that Taiwan should scrap their partially constructed fourth nuclear power plant and phase out nuclear power by 2025 because it lacked a way to safely dispose of nuclear waste.

1. P. Vankerckhoven, "European Regulatory and Policy Strategy Aspects on Nuclear Decommissioning," European Commission DGXI/C3, accessed via http://www.sckcen.be.eccdecmmissioning on 7 December 2000.

2. *Review of Existing and Future Requirements for Decommissioning Nuclear Facilities in the CIS*, prepared for the European Commission, Directorate General XI (January 1999), accessed via http://europa.eu.int/comm/environment/nuclear/reports.htm on 21 December 2000.

Decommissioning in the United States

About 20 percent of U.S. electricity is generated by nuclear power. By the year 2033, all 103 reactors currently operating in the United States will have reached the end of their original 40-year license periods, and owners must either apply to the Nuclear Regulatory Commission (NRC) for 20-year license extensions or decommission the reactors (see Table 1 on pages 12–13 for a listing of license expiration dates for U.S. reactors).[2] Their choices will be affected by questions such as whether plants need expensive upgrades to continue operating and whether they can provide power at competitive rates in a restructured energy market.[3]

A number of reactors have already shut down, some well before the end of their licensed operating lives. By and large, the plants that shut down in the 1990s before their licenses had ended did so because they needed expensive capital upgrades (typically, new steam generators), and the owners judged that they would not recover the costs of these upgrades over the plants' remaining lives. As of May 2000, 3 NRC-licensed reactors had been fully decommissioned and 18 others were in various stages of decommissioning (see Table 2 on page 14). Major decommissioning work cannot be carried out until the spent fuel has cooled in on-site ponds for 5 to 7 years, but reactors must be fully decommissioned within 60 years after ceasing operations. Owners have three basic options:[4]

DECON or decontamination is an approach that seeks to return the site to alternate uses as quickly as possible. Equipment, structures, and portions of the facility that contain radioactive contaminants are removed and dismantled. NRC estimates that DECON activities will take about nine years at large light-water reactors.[5] The amount of time involved is affected by factors such as the length of the reactor's operation. Reactors that have operated for decades require extensive planning and analysis before decontamination can begin.

SAFSTOR or safe storage is an approach that takes advantage of the fact that most hazardous radioactive byproducts from reactor operation decay relatively quickly. (Cobalt-60, a major short-term radioactive byproduct from reactor operation, has a half-life of just over five years.) Spent fuel is removed from the reactor vessel and radioactive liquids, such as water from the cooling system, are drained. After a wait-period that could be as long as several decades, facilities are decontaminated and dismantled.

ENTOMB or entombment involves partial dismantling of the reactor, encasing the remaining radioactive structures in a long-lived material such as concrete, and monitoring the site until the radioactivity decays to levels that permit license termination. Most large power reactor sites would probably still produce too much radiation to permit unrestricted use even after 100 years and thus are not well suited for entombment, but NRC is re-examining this option, which is less expensive than dismantlement and disposal.[6]

Some owners are combining DECON and SAFSTOR by performing limited dismantlement and then putting the facility in storage for several years before completing dismantlement. In the case of some multi-reactor sites where one unit is shut down, owners have chosen SAFSTOR for the closed unit with the intention of simultaneously decommissioning the entire site when all of the reactors go out of service.

Decommissioning produces several types of radioactive wastes and emissions. NRC estimates that decommissioning a typical power reactor will produce minor releases of airborne radioactive dusts and particles, which are largely caught by filters in containment buildings. The process also produces radioactive liquid effluents, most of which are decontaminated through filtration and ion exchange methods used during reactor operations. The solids filtered out of liquid radioactive wastes are disposed of at low-level waste sites, as long as they meet federal low-level waste criteria. The main exception is water contaminated with tritium, which is normally discharged at controlled rates to surface water bodies.[7] Decommissioning also produces three categories of solid radioactive waste.

© 2001 CORBIS

Removing spent fuel from the reactor is a crucial step in the decommissioning process.

- Low-level waste (LLW) includes contaminated clothing, sludges, equipment, piping, and concrete. LLW constitutes 99 percent by volume, but less than 0.1 percent by radioactivity, of all commercial nuclear waste.[8]

- Mixed low-level waste (MLLW) comprises blends of radioactive and hazardous substances, such as metallic lead shielding. It accounts for only a few percent of LLW.

- High-level waste (HLW) consists of irradiated spent nuclear fuel. Because it is highly radioactive and poses serious public and worker health risks, spent fuel must be shielded to contain its radioactivity and so that the heat generated by radioactive decay can be dispersed slowly in a controlled manner.

NRC estimates that decommissioning a large power reactor will generate more than 18,000 cubic meters of LLW.[9] Most LLW is buried in shallow trenches at licensed sites in Washington, Utah, and South Carolina. MLLW is generally stored on site. (Commercial reactors typically generate only about two 55-gallon drums per year.) There is a shortage of capacity for some types of MLLW, although firms in Utah, Tennessee, Florida, and Texas accept and treat various types of MLLW.[10] The Department of Energy (DOE) signed contracts in the 1980s to accept commercial spent fuel for disposition in a geologic repository in Yucca Mountain, Nevada, starting in January 1998 but is far behind schedule and currently expects to start accepting fuel no sooner than 2010.

Risks in Decommissioning

Nuclear power regulation in the United States is shifting away from a philosophy that one recent analysis characterizes as "conservative . . . deterministic and prescriptive," to a risk-based approach that seeks to make the regulatory process more efficient while still protecting public safety.[11] NRC is moving to a risk-informed, performance-based regulatory strategy, oriented by a "risk triplet" of three basic questions:

- What can go wrong?
- How likely is it to occur?
- What are the consequences?[12]

These questions are systematically analyzed through probabilistic risk assessment methods, such as event tree and fault tree analysis.[13] The basic idea is to identify events that may cause engi-

neering systems to fail and to characterize how radioactive material may be released into the environment, potentially harming workers or the public through inhalation, ingestion, or external exposure. Releases of radioactive material from decommissioning activities are monitored to ensure they meet NRC criteria. Current decommissioning regulations do not require licensees to use probabilistic risk assessment if activities are within the scope of the reactor's license. However, if licensees seek changes that require license amendments and go beyond technical reviews that NRC has performed, then a licensee may be asked to submit a probabilistic risk assessment for review.[14] NRC has used probabilistic risk assessment to identify risks from decommissioning, particularly hazards associated with spent fuel pool accidents as described below.

In general, decommissioning a power reactor poses substantially less health risk to the general public and to plant workers than an operating reactor. However, a release of radiation from an accident in the reactor's spent fuel pool system could present a serious threat to public safety.[15] The most dangerous scenario would arise if the spent fuel pool cooling system malfunctions or coolant leaks out and the zirconium in the fuel rods is exposed to air. Were this chain of events to occur, the rods could spontaneously catch fire and release radioactive material into the atmosphere. Currently, at most defueled reactors, portable, skid-mounted pumps and heat exchangers cool the pools. At operating reactors, additional safety measures, such as physical separation, barrier protection, and emergency on-site power sources provide further protection against cooling system malfunction.[16] Analytical modeling has shown that if the cooling system fails at reactors that have ceased operations, a minimum of 100 hours would have to pass before the older, decayed, spent fuel would generate sufficient heat to boil off enough coolant to uncover the fuel rods and start a zirconium fire.[17] For this reason, safety measures are relaxed at such sites. Because many measures, such as refilling the pool, may be taken in the time between system failure and rod exposure, the redundant safety measures required for operating reactors may not be necessary during decommissioning.

Plant workers may be accidentally exposed to radiation while performing decommissioning tasks. For example, at the Maine Yankee reactor, previously used shipping containers were moved on 29 September 2000 from the nuclear side of the plant to the non-nuclear side, where workers received a dose of 1 millirem (mrem), (NRC's annual dose limit for the general public is 25 mrem.) which is considered to be a very low radiation dose.[18] Additionally, the general public may receive a very small dose simply by standing next to a transport vehicle when low-level radioactive waste (LLW) is moved for off-site disposal. NRC estimates that a person standing six feet from a transport vehicle for one hour would receive a dose of 10 mrem.[19] There is greater risk if a transport vehicle is involved in a major accident. To reduce this risk, LLW is shipped in specially designed casks and is transported in solid form so that contamination from a transportation accident would be unlikely to spread beyond a small area.[20]

Decommissioning has smaller potential health and safety impacts than extending the license of an operating plant. This does not imply, however, that decommissioning is automatically preferable to life extension. In fact, NRC has made a generic finding that the environmental impacts of renewing a license and the concomitant risks are not expected to exceed its health and safety regulations.[21] License extension decisions involve many factors, such as the replacement cost and the environmental impact of the substitute power, such as sulfur, nitrogen, and carbon emissions from fossil fuel plants, as well as the economic impact to the local community through job losses and decreased tax revenues after plant closure.[22]

Current Issues

As reactors age and the U.S. electric industry moves from regulated monop-

Table 1. License expiration dates for U.S. nuclear power plants

Year	Reactor	State	Capacity (MW)	Start of commercial operation	License renewal?
2006	Dresden 2	IL	791	1969	
2007	Palisades	NY	730	1971	
2009	Nine Mile Point 1	NY	565	1969	
	Ginna	NJ	480	1970	
	Oyster Creek 1	NJ	637	1969	
2010	Robinson 2	SC	683	1971	Applying in 2002
	Monticello	MN	578	1971	
	Point Beach 1	WI	485	1970	Applying in 2002
2011	Dresden 3	IL	791	1971	
2012	Vermont Yankee	VT	510	1972	
	Surry 1	VA	801	1972	Applying in 2001
	Pilgrim 1	MA	670	1972	Applying in 2004
	Turkey Point 3	FL	693	1972	Applied in 2000
	Quad Cities 1	IL	769	1973	
	Quad Cities 2	IL	769	1973	
2013	Surry 2	VA	801	1973	Applying in 2001
	Point Beach 2	WI	485	1972	Applying in 2002
	Turkey Point 4	FL	693	1973	Applied in 2000
	Peach Bottom 2	PA	1,093	1974	Applying in 2001
	Fort Calhoun 1	NE	478	1973	Applying in 2002
	Prairie Island 1	MN	522	1973	
	Indian Point 2	NY	951	1974	
	San Onofre 2	CA	1,070	1983	
	San Onofre 3	CA	1,080	1984	
	Kewaunee	WI	511	1974	
2014	Cooper	NE	764	1974	Applying in 2003
	Duane Arnold	IA	520	1975	
	Three Mile Island 1	PA	786	1974	
	Arkansas Nuclear One 1	AR	836	1974	Applied in 2000
	Browns Ferry 2	AL	1,118	1975	Applying in 2003
	Peach Bottom 3	PA	1,093	1974	Applying in 2001
	Hatch 1	GA	787	1975	Applied in 2000
	FitzPatrick	NY	813	1975	
	DC Cook 1	MI	1,000	1975	
	Prairie Island 2	MN	522	1974	
	Brunswick 2	NC	811	1975	Applying in 2004
2015	Millstone 2	CT	873	1975	
	Indian Point 3	NY	965	1976	
2016	Beaver Valley 1	PA	810	1976	Applying in 2004
	St. Lucie 1	FL	830	1976	Applying in 2002
	Browns Ferry 3	AL	1,118	1977	Applying in 2003
	Salem 1	NJ	1,106	1977	
	Brunswick 1	NC	820	1977	Applying in 2004
	Crystal River 3	FL	818	1977	
2017	Davis-Besse	OH	873	1978	
	Farley 1	AL	847	1977	Applying in 2003
	DC Cook 2	MI	1,060	1978	
2018	North Anna 1	VA	893	1978	Applying in 2001
	Hatch 2	GA	855	1979	Applied in 2000
	Arkansas Nuclear One 2	AR	858	1980	Applying in 2003
2020	Salem 2	NJ	1,106	1981	
	North Anna 2	VA	897	1980	Applying in 2001
	Sequoyah 1	TN	1,123	1981	

(continued on facing page)

Table 1. continued

Year	Reactor	State	Capacity (MW)	Start of commercial operation	License renewal?
2021	Farley 2	AL	852	1981	Applying in 2003
	McGuire 1	NC	1,129	1981	Applying in 2001
	Sequoyah 2	TN	1,118	1982	
	Diablo Canyon 1	CA	1,073	1985	
2022	Lasalle 1	IL	1,078	1984	
	Grand Gulf 1	MS	1,204	1985	
	Susquehannah 1	PA	1,090	1983	
	Summer 1	SC	948	1984	Applying in 2002
2023	McGuire 2	NC	1,129	1984	Applying in 2001
	St. Lucie 2	FL	830	1983	Applying in 2002
	Lasalle 2	IL	1,078	1984	
	Washington Nuclear 2	WA	1,107	1984	
2024	Susquehanna 2	PA	1,094	1985	
	Callaway 1	MO	1,125	1984	
	Limerick 1	PA	1,134	1986	
	Byron 1	IL	1,105	1985	
	Catawba 1	SC	1,129	1985	Applying in 2001
	Waterford 3	LA	1,075	1985	
	Palo Verde 1	AZ	1,243	1986	
2025	Wolf Creek	KS	1,163	1985	
	Fermi 2	MI	1,080	1988	
	Diablo Canyon 2	CA	1,087	1986	
	River Bend 1	LA	936	1986	
	Millstone 3	CT	1,140	1986	
	Palo Verde 2	AZ	1,243	1986	
2026	Catawba 2	SC	1,129	1986	Applying in 2001
	Perry 1	OH	1,160	1987	
	Hope Creek 1	NJ	1,031	1986	
	Clinton	IL	930	1987	
	Braidwood 1	IL	1,120	1988	
	Seabrook	NH	1,158	1990	
	Harris 1	NC	860	1987	
	Nine Mile Point 2	NY	1,123	1988	
	Byron 2	IL	1,105	1987	
2027	Vogtle 1	GA	1,151	1987	
	Palo Verde 3	AZ	1,247	1988	
	Beaver Valley 2	PA	820	1987	Applying in 2004
	S. Texas Project 1	TX	1,251	1988	
	Braidwood 2	IL	1,120	1988	
2028	S. Texas Project 2	TX	1,251	1989	
2029	Vogtle 2	GA	1,154	1989	
	Limerick 2	PA	1,115	1990	
2030	Comanche Peak 1	TX	1,150	1990	
2033	Comanche Peak 2	TX	1,160	1993	
	Oconee 1	SC	846	1973	Approved (2000)*
	Oconee 2	SC	846	1974	Approved (2000)*
2034	Oconee 3	SC	846	1974	Approved (2000)*
	Calvert Cliffs 1	MD	835	1975	Approved (2000)*
2035	Watts Bar 1	TN	1,158	1996	
2036	Calvert Cliffs 2	MD	840	1977	Approved (2000)*

*License expiration dates here reflect license extensions.
MW=megawatts

SOURCE: Nuclear Regulatory Commission, Nuclear Energy Institute. License application extensions current as of February 2001. It is likely that more reactor owners will apply for extensions.

Table 2. U.S. commercial nuclear power reactor decommissioning

Reactor (State)	Type	Capacity (MW)	Operation	Method	Status
Big Rock Point (MI)	BWR	67	1963–1997	DECON	Spent fuel will be loaded into dry storage in 2001 or 2002; target end date for decommissioning is 2004.
Dresden 1 (IL)	BWR	197	1960–1978	SAFSTOR	SAFSTOR until Dresden 2 and 3 end operation (licensed through 2006 and 2011; owner may apply for license extensions).
Fermi 1 (MI)	FBR	65	1966–1972	SAFSTOR	Owner announced plans to decommission in October 2000; target end date is 2005–2007.
Fort St.Vrain (CO)	HTGR	330	1979–1989	DECON	Decommissioning complete; converted to gas-fired power plant.
Vallecitos (CA)	BWR	30	1957–1963	SAFSTOR	No current plans for decommissioning.
Haddam Neck (CT)	PWR	560	1968–1996	DECON	About 30% of physical decommissioning work has been carried out; target end date is 2004.
Humboldt Bay 3 (CA)	BWR	63	1963–1976	SAFSTOR	Owner expects to move spent fuel to dry storage by 2005 and to dismantle plant by 2015.
Indian Point 1 (NY)	PWR	257	1962–1974	SAFSTOR	SAFSTOR until Indian Point 2 and 3 end operation (licensed through 2013 and 2015).
Lacrosse (WI)	BWR	48	1969–1987	SAFSTOR	Target date for complete decommissioning is 2019.
Maine Yankee (ME)	PWR	860	1972–1997	DECON	Dismantlement in process; expected to be completed by 2004.
Millstone 1 (CT)	BWR	641	1971–1998	SAFSTOR	No target date for dismantling plant; Millstone 2 licensed through 2015.
Pathfinder (SD)	BWR	59	1966–1967	SAFSTOR	Decommissioning completed.
Peach Bottom 1 (PA)	HTGR	40	1967–1974	SAFSTOR	SAFSTOR until Peach Bottom 2 and 3 end operation (licensed through 2013; owner plans to apply for license extensions).
Rancho Seco 1 (CA)	PWR	873	1975–1989	SAFSTOR	Dismantlement in process; target completion date for decommissioning 2012.
San Onofre 1 (CA)	PWR	436	1968–1992	SAFSTOR	Dismantlement in process; target completion date 2008.
Shoreham (NY)	BWR	820	1989	DECON	Decommissioning completed; site released for unrestricted use.
Three Mile Island 2 (PA)	PWR	880	1978–1979	SAFSTOR	Unit placed in long-term safe storage after cleanup of 1979 accident; TMI 1 license expires in 2014.
Trojan (OR)	PWR	1,095	1976–1992	DECON	Reactor vessel and large components removed; final site survey plan under state and NRC review; target end date 2003.
Yankee Rowe (MA)	PWR	167	1961–1991	DECON	Radioactive components removed from site; spent fuel to be moved to dry cask storage in 2001, followed by building dismantlement. Licensee withdrew license termination plan from consideration in 1999 for revisions.
Zion 1 (IL)	PWR	1,040	1973–1998	SAFSTOR	Funding for decommissioning will not permit the start of dismantlement phase until 2015 or later.
Zion 2 (IL)	PWR	1,040	1974–1998	SAFSTOR	Same as Zion 1.

MW = megawatts; BWR = boiling-water reactor; FBR = fast breeder reactor; HTGR = high-temperature gas-cooled reactor; PWR = pressurized-water reactor.

SOURCE: Data compiled from International Atomic Energy Agency and Nuclear Regulatory Commission reports, licensee materials, and telephone interviews with licensees.

oly to competition, nuclear power watchers are raising questions about decommissioning. Key questions include: Who should pay for decommissioning? How should the resulting waste be managed? And does the regulatory process adequately mitigate risks and give meaningful roles to stakeholders (e.g., local communities, state and local governments, workers at the reactor, the utilities that own the reactors, and contractors who perform much of the decommissioning work)?

Who Pays?

Decommissioning costs vary from site to site but average roughly $300 million to $500 million for large commercial power reactors (mainly for labor, energy, and radioactive waste management). NRC requires licensees to set aside or provide surety for decommissioning costs, which are estimated according to an annually adjusted formula.[23] Currently, the minimum amount required to assure decommissioning is $290 million for pressurized-water reactors (PWRs) and $370 million for boiling-water reactors (BWRs) (in 1999 dollars).[24] These figures do not include non-radioactive cleanup or storing spent fuel on site, even though both issues represent significant additional costs for licensees.[25]

Nearly all operating utilities earmark a portion of their revenues for decommissioning and deposit the money in dedicated trust funds. In 1999, the General Accounting Office (GAO) reported that under likely assumptions, nearly half of U.S. nuclear power reactor owners (36 out of 76 licensees) had not accumulated sufficient decommissioning funds through the end of 1997, although all but 15 had since increased their savings rate to make up these shortfalls.[26] GAO implied that these shortfalls were due to major uncertainties in the decommissioning process, which are described below. Because licensees typically build up funds for decommissioning by investing a share of their profits over the life of reactors, restructuring the electric utility industry in many states—which has required utilities that once earned guaranteed rates of return to compete in the marketplace—raises additional concerns about paying for decommissioning. To date, most states that have restructured their electric utility industries have allowed nuclear plant owners to recover decommissioning costs through a "non-bypassable wires charge," a mandatory fee paid by all consumers regardless of whether their source of electricity is nuclear power.[27]

© WERNHER KRUTEIN—PHOTOVAULT

By seeking public comment on controversial issues during the decommissioning of Oregon's Trojan reactor (scheduled for completion in 2003), state regulators avoided the public relations problems that have delayed the process in other cases.

Reactors that shut down well before the end of their licensed operating lives may not accumulate all of the funds needed for decommissioning. In such cases, if utilities seek to keep collecting decommissioning funds from ratepayers, they must gain approval from the Federal Energy Regulatory Commission and/or state public utility commissions, which may resist burdening consumers with the entire cost. For example, public utility companies in Maine and Connecticut required the owners of the Connecticut Yankee and Maine Yankee reactors, which closed in 1996 and 1997, respectively, to reach settlements in which ratepayers and shareholders would share decommissioning costs.[28]

Dealing with Radioactive Waste

Nuclear waste disposition raises major uncertainties for reactor decommissioning. Because no geologic repository for high-level waste is available, licensees are storing spent fuel at reactors in pools or dry casks.[29] This may hinder release of decommissioned sites because storage facilities must be kept secure until DOE accepts the spent fuel (although other portions of the sites may be released).[30] DOE is expected to start accepting fuel at Yucca Mountain no sooner (and probably later) than 2010. The opening of the Yucca Mountain facility has been delayed by many factors, notably the complex geology at the site. As of mid-2000, 15 nuclear plants had built on-site dry cask storage facilities for spent fuel.[31]

Disposing of low-level waste (LLW) could pose a problem in coming decades. LLW disposal became the responsibility of the states after the passage of the Low-level Radioactive Waste Policy Act in 1980 (amended in 1985), which was designed to increase LLW capacity and to distribute the burden equitably among the states. Although states have spent nearly $600 million since 1980 on efforts to develop LLW disposal facilities, none have been licensed, due mainly to public and political resistance. Depending on how many reactors cease operation in the next sev-

eral decades and how many licensees opt for rapid decommissioning, a shortage of LLW disposal space could occur. Possible remedies to this shortfall include opening the disposal market to private competition or requiring DOE to accept LLW at federal sites, but both of these options would have to overcome the unwillingness of states to host disposal sites.[32]

Low-Level Radiation Risks

Controversy over the health effects of low-level radiation has spurred debate over "how clean is clean" in decommissioning. NRC requires licensees to clean up sites so that the maximum total effective dose equivalent will not exceed 25 mrem per year from all pathways and to reduce doses to as low as reasonably achievable below that threshold.[33] The U.S. Environmental Protection Agency (EPA), which is authorized under the Atomic Energy Act to set general standards for protecting the public from radiation hazards but not to implement or enforce them, supports an all-pathway limit of 15 mrem per year, plus an additional limit of 4 mrem per year for ground water. EPA has indicated that it may view NRC's standards as inadequate and may seek to enforce tighter limits through its authority to regulate cleanups at Superfund sites.[34]

The nuclear industry supports the less stringent standard, arguing that some owners of nuclear plants may be subject to both NRC and EPA standards and that this potential dual regulation is redundant and inefficient. Conversely, many environmentalists argue that the primary goal in an area of scientific uncertainty should be protecting human health rather than minimizing cleanup costs.[35] Even so, the cost of requiring licensees to comply with the higher standards could be substantial: NRC estimates that cleaning up ground water at a generic nuclear site from a baseline of 25 mrem per year to 3 mrem per year could cost up to $7 million.[36] Nonetheless, in response to stakeholder concerns, several licensees have pledged to meet more stringent standards than those required by NRC.[37]

The risks associated with recycling slightly radioactive materials (including metals, concrete, and soils) from decommissioned facilities into other uses have sparked a debate. NRC has struggled for more than a decade to define a threshold level of radioactivity in waste streams below which materials need not be regulated and in the interim has approved release requests on a case-by-case basis.[38] The controversy intensified in the mid-1990s when DOE awarded cleanup contracts at nuclear weapons facilities that included plans to recycle large quantities of slightly radioactive metal.[39] Labor and environmental groups objected that NRC and EPA had not been able to agree on national recycling standards and argued that there is no safe level of exposure to ionizing radiation.[40]

In mid-2000, then Energy Secretary Bill Richardson suspended radioactive recycling at DOE facilities, and NRC requested guidance from the National Academy of Sciences on how to regulate recycling of radioactive materials. No formal NRC action on the issue is expected until mid-2001, at the earliest. The issue is also contested in Europe: The European Union issued a radiation protection directive in 1996 that allows members to adopt their own standards for releasing slightly radioactive materials, but there is little agreement among member states on what levels and procedures should be considered safe.[41] U.S. and European metal industries that could receive recycled materials from nuclear facilities have opposed the general concept of radioactive metal recycling for fear of public resistance.

Reducing the Impact of Decommissioning

Environmental impacts of decommissioning may be reduced through techniques including:

- decontamination procedures that minimize generation of radioactive residues (for example, scraping or sand-blasting may produce less residue than using a liquid wash);
- segregation of radioactive waste and decontamination residues from nonradioactive waste;
- minimization of potential releases during transportation of radioactive waste (for example, by avoiding urban areas);
- use of controls and procedures during demolition to minimize contamination of tools and equipment, during spills and potential introduction of pollutants to ground water, and during generation of particulates and dust emissions; and
- limited access to radiation control areas.[1]

1. U.S. Environmental Protection Agency, Office of Federal Activities, "Pollution Prevention/Environmental Impact Reduction Checklist for Nuclear Decommissioning" (January 1995).

NRC Oversight of Decommissioning

Current U.S. decommissioning rules divide the process into three stages: initial activities, major decommissioning activities/preparation for storage or dismantlement, and activities to terminate the license.[42] Specific fractions of decommissioning funds may be expended at each stage.

After deciding to end operations, a licensee must certify in writing to NRC within 30 days that the reactor is permanently shut down. Within two years of permanent shutdown, the licensee must submit a post-shutdown decommissioning activities report (PSDAR) to NRC and appropriate state officials. The PSDAR describes decommissioning activities and provides schedule milestones and a general cost estimate. It also evaluates site-specific environmental impacts and determines whether these impacts were reviewed in NRC's 1988 generic environmental impact statement on decommissioning or in the site-specific environmental impact statement issued when the reactor was originally licensed.[43] The PSDAR demonstrates that the expected environmental impacts from decommissioning, such as radioactive releases to air or water, fall within the ranges projected in these documents; if not, the licensee must request a license amendment for the proposed activities and address these impacts.[44]

As part of the first stage, licensees must also update the final safety analysis report (FSAR), which describes the reactor, its design basis, and its safety systems.[45] An updated FSAR explains how structures, systems, and components will be affected during decommissioning and provides the basis for the licensee to perform activities that do not require a license amendment.[46] The PSDAR is a relatively sketchy outline of decommissioning activities, but the FSAR for decommissioning is a detailed description of the plant and its operations and the structures, systems, and components that affect safety—all in reference to the plant's initial design. The FSAR for decommissioning may be several hundred pages and may include updates as decommissioning progresses.[47]

The second stage of decommissioning involves either removing and dismantling components (DECON) or preparing the reactor for safe storage (SAFSTOR). Licensees may perform major decommissioning activities 90 days after the PSDAR is submitted and 30 days after NRC holds a public meeting in the vicinity of the reactor. Major activities include permanently removing major radioactive components, such as the reactor vessel and steam generators, and altering the structure of the containment vessel (cutting it into pieces). Decommissioning techniques include cutting metals and concrete, using abrasive blasting to remove surface contamination, dismantling highly radioactive components (sometimes using remote equipment), and ultimately, demolishing the buildings.[48] These activities can affect soil conditions, ground water, plant and wildlife habitats, and wetlands at the site (see the box on page 16).

The third stage begins two years before the licensee is ready to terminate the license. At this point the licensee submits a license termination plan, which must include:

- a site characterization,
- a list of remaining dismantlement activities,
- plans for site remediation,
- detailed plans for the final radiation survey,
- a description of the end-use of the site, if restricted,
- an updated site-specific cost estimate,[49] and
- a supplement to the environmental report describing any new information or significant environmental change associated with the licensee's termination activities.

If the licensee proposes restricted use of the site, it must show that it has discussed this decision with the local community.[50] This final stage is a licensing action, so the public is entitled to petition NRC for a formal adjudicatory hearing.

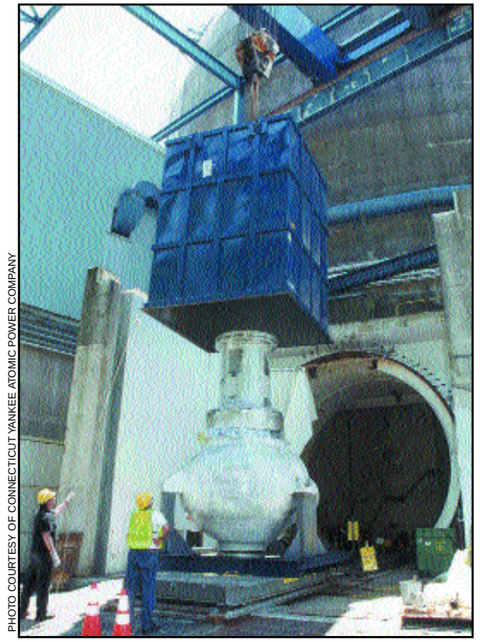

PHOTO COURTESY OF CONNECTICUT YANKEE ATOMIC POWER COMPANY

Decommissioning involves the removal of large contaminated components from the reactor and the transfer of these components to appropriate waste storage facilities.

Stakeholder Concerns

In general, decommissioning thus far has generated less public controversy than siting reactors or managing nuclear waste. There are many possible explanations for this relative lack of concern: The decommissioning mission is relatively new, and therefore many projects are in their early stages. Furthermore, decommissioning is about the removal of nuclear technology, rather than its introduction. As nuclear safety engineer David Lochbaum of the Union of Concerned Scientists observes, "Even those with safety concerns about the pathway see that outcome as lowering their risk."[51]

In some cases, however, choices about how to decommission have drawn significant local criticism. One central question is whether stakeholders are able to evaluate the environmental and public health impacts of proposed decommissioning actions critically and independently. Critics contend that the regulatory process does not provide early opportunities to understand precisely how decommissioning activities will proceed and that it does not allow citizens ample time to intervene if they believe the plan poses a threat to public health or the environment.

Citizens, environmental groups, and state regulators have raised specific questions about issues such as emergency planning (especially for spent fuel pool accidents), the roles of federal and state regulatory agencies, and the adequacy of licensees' radiation site survey methods.[52] Some licensees have created citizen advisory panels to improve public participation in decommissioning, but these bodies are not mandated by NRC regulations and are convened at the discretion of the licensee. At a hearing on

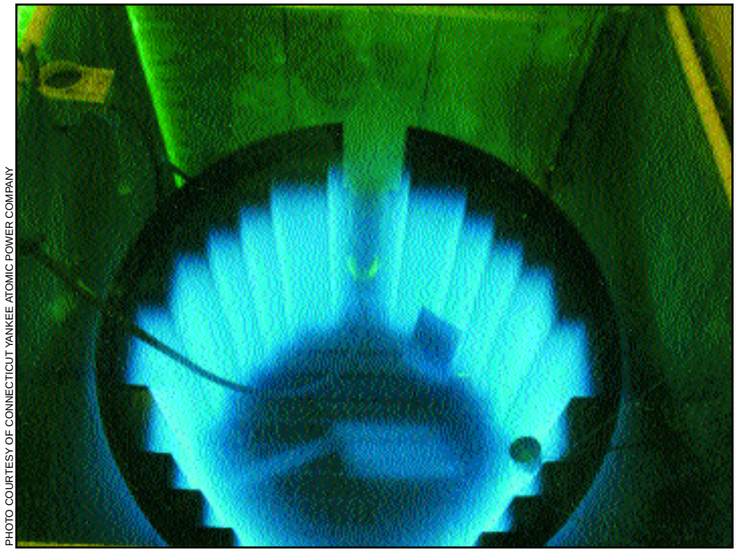

PHOTO COURTESY OF CONNECTICUT YANKEE ATOMIC POWER COMPANY

After fuel has been removed from a reactor, the internal surface remains radioactive. Under the SAFSTOR option, reactors are left on site for as long as several decades to allow the radioactivity to decay before being dismantled.

the Maine Yankee plant, one citizen remarked that the process "relies on a reporting system, basically a system of trust."[53]

In contrast, prior to 1996, licensees were required to submit a decommissioning plan and were not permitted to carry out any major decommissioning activities until NRC reviewed the plan, assessed site-specific environmental impacts, and amended the reactor license. This process also offered an opportunity for state review.[54] Currently, the post-shutdown decommissioning activities report (PSDAR) effectively substitutes for a decommissioning plan in reactor decommissioning, and because the process does not involve a license amendment, the public cannot request a formal hearing with the right to conduct discovery and cross-examine witnesses. Citizens living nearby closed reactors complain that PSDARs contain few details about environmental impacts of decommissioning and assert that site-specific analyses should be required.[55]

The first major controversy over NRC oversight of decommissioning occurred in 1993 under the system requiring decommissioning plans, when NRC allowed Yankee Atomic Energy Co. to conduct an "early component removal project," which involved removing and dismantling major components accounting for 90 percent of the nonfuel residual radioactivity on site, *before* submitting a decommissioning plan for its Yankee Rowe plant in Massachusetts.[56] Citizens Awareness Network (CAN), a local watchdog group, went to court after requesting hearings on the component removal plan. In *CAN v. NRC*, the First Circuit ruled that NRC's action was arbitrary and capricious because it had not explained the shift in policy. The court argued that allowing Yankee Atomic to complete 90 percent of decommissioning prior to assessing environmental impacts amounted to a skirting of the National Environmental Policy Act.[57]

In 1996, NRC published its current decommissioning rule, establishing the PSDAR requirement in lieu of a decommissioning plan. NRC reasoned that major decommissioning activities were not sufficiently different from activities conducted during normal reactor operations to require a license amendment, as long as those activities did not prevent the site from being released from its license for some future use, result in significant environmental impacts that had not been previously documented in relevant environmental reviews, or threaten the availability of adequate decommissioning funds.[58] By providing the reasoning underlying this new policy and offering opportunities for public review and comment on the new rule, NRC held that it had addressed the issues raised in *CAN v. NRC*.[59] Critics assert, however, that the current regulatory process does not provide stakeholders enough information to conclude whether the planned decommissioning is indeed safe. For example, in 1997, Maine Yankee Atomic Power Company submitted a PSDAR for its Maine Yankee plant. The 12-page report contained a mere four paragraphs on radiation doses to workers and the public, low-level waste burial volumes, and radioactive effluent controls.[60] Several years of debate followed as the power company sought approval for a controversial concept called "rubblization," which would have allowed it to bury concrete contaminated with low levels of radiation in the basement of the plant under a soil and clay cap. Opponents, including EPA, argued that this process amounted to creating an unlicensed low-level waste site. Maine Yankee Atomic Power Company also sought to prevent Maine state regulators from performing their own radiation soil surveys at the site. To the power company's credit, it recognized the importance of listening to stakeholders and is revising its license termination plan: The company has abandoned the "rubblization" option and will clean up the site to radiation levels below federal requirements.[61] It is not surprising that at a press conference in September 2000 company president Mike Meisner said, "The hard part [of decommissioning] is dealing with a range of stakeholders."[62]

Observations and Recommendations

Although U.S. nuclear regulators are seeking to streamline the current system and make it less cumbersome, there is room for greater transparency and better communication about decommissioning activities—especially given its connections to other complex policy debates such as nuclear waste management and electric utility deregulation. European regulations are stronger on this point: The European Commission passed a directive in 1997 instructing member states to require site-specific environmental impact assessments for nuclear decommissioning projects and is putting specific emphasis on public information as part of its effort to develop a code of conduct for European decommissioning.[63]

Closing "knowledge gaps" that may undermine public confidence would be a key step in this direction. For example, after NRC holds a public meeting on a licensee's post-shutdown decommissioning activities report, it releases a meeting transcript but does not issue any formal institutional response to concerns raised at the meeting. This shortcoming allows stakeholders no means to determine whether and how their concerns will be addressed during decommissioning. NRC should follow the example of other agencies by preparing a summary of the issues raised and an explanation of its regulatory response and by making these items available on-line. DOE has done this for several controversial issues, including environmental impact statements associated with nuclear weapons production facilities and several reports on management and disposition of excess plutonium from dismantled nuclear weapons.

Another trust gap could be closed by verifying the accuracy of the information in the updated final safety analysis report (FSAR) for decommissioning. Under current regulations, licensees must follow NRC guidance in updating FSARs, but NRC does not systematically and critically review updated FSARs.[64] NRC should perform some type of risk-informed, documented safety review of the updated FSAR, focusing on how decommissioning activities may affect the likelihood of accidents. NRC should make its analysis publicly available so that stakeholders can see for themselves how the updated FSAR addresses unresolved issues raised in connection with the post-shutdown decommissioning activities report, as well as issues affecting the risk of accidents.

As decommissioning progresses nationwide, NRC should provide more comprehensive reports on the mission—including lessons learned from completed projects—through an annual report or an Internet home page with space for public comments. Several states have created useful web pages to inform the public about local decommissioning projects, but only NRC is in a position to draw this information together and summarize what has been accomplished and what remains to be done.[65]

The Yankee Rowe and Maine Yankee examples have several common factors that may have contributed to tensions over decommissioning. Both reactors shut down before the end of their licensed operating lives after controversies about whether they were operating safely, leading some stakeholders to question the owners' competence to manage nuclear risks.[66] After closure, as discussed above, both sites pursued controversial approaches to decommissioning (early component removal at Yankee Rowe and rubblization at Maine Yankee) that intensified local safety fears and perceptions that the companies were seeking to decommission in the most expedient, rather than the safest, way. These issues may not arise at other sites, but they suggest that reactor owners with similar trust handicaps should pay particular attention to stakeholder concerns.

PHOTO COURTESY OF THE U.S. DEPARTMENT OF ENERGY

The U.S. Department of Energy (DOE) signed contracts in the 1980s to accept spent fuel for geological disposition at Yucca Mountain in 1998. But, due to complexities in the geology of the site, DOE is far behind schedule and currently expects to start accepting spent fuel no sooner than 2010.

Conversely, experiences at other sites, such as Oregon's Trojan reactor, suggest that decommissioning can proceed smoothly under the right circumstances. One factor that contributed to success at Trojan was thorough involvement of state regulators, who sought public comment independently of NRC on several controversial issues, such as the transport of large radioactive components by barge up the Columbia River for disposal in Washington State.[67]

As other analysts have observed, decommissioning received little attention during nuclear power's worldwide expansion in the 1970s and 1980s. This is evidenced not only by the relative lack of emphasis on design for decommissioning in currently operating reactors but also by patchy and incomplete regulatory structures in key nuclear countries.[68] Nuclear advocates contend that nuclear power is an appropriate response to climate change, but if decommissioning is not executed systematically and competently over the next several decades, it will likely erode public support for additional investments in nuclear power. Permanently contaminated sites will provide a visible counterweight to optimistic projections about the future performance of new advanced reactors, and failure of regulators to seriously address concerns over issues such as the health impact of low-level radiation will increase public mistrust of nuclear technologies. In sum, the administrative challenges posed by decommissioning civilian nuclear reactors are at least as hard as the technical mission. Though the nuclear industry has obvious incentives to push for a more efficient decommissioning process, the future of nuclear energy may depend on how much care is exercised during this end-stage for nuclear reactors.

Darryl Farber received his Ph.D. from Penn State University and is a post-doctoral fellow in the Science, Technology, and Public Policy Program at Harvard University's John F. Kennedy School of Government. His current research focuses on the role of the public in civilian nuclear decision making, principally in the United States. Jennifer Weeks directs the Kennedy School's Managing the Atom Project. She worked as a congressional defense staffer and as a lobbyist for the Union of Concerned Scientists from 1991–97. The authors can be contacted at darryl_farber@harvard.edu and jennifer_weeks@harvard.edu.

NOTES:

1. N. Fell, "Decommissioning: A Rapidly Maturing Market," *Nuclear Engineering International*, 30 November 1999, 18.

2. NRC approved its first license extensions in 2000 for two plants in Maryland and South Carolina. Another five reactors located in Arkansas, Georgia, and Florida have filed for extensions, with up to 28 more expected to follow suit by 2004. (Nuclear Energy Institute, "License Renewal," accessed via http://www.nei.org on 27 October 2000.)

3. The nuclear industry is in the midst of a major consolidation phase (driven by restructuring of the electric utility industry) in which many companies that owned one or a few reactors are selling them, but several large utilities that view nuclear power as a profitable business are investing heavily and merging. One of the largest owners is Exelon Nuclear, which was recently formed with the merger of PECO Energy, Commonwealth Edison, and AmerGen's nuclear fleets; the company operates 17 reactors in the midwest and mid-Atlantic regions. Overall, the nuclear industry is performing better now than it was five or ten years ago: Plants are operating at higher capacity factors (i.e., are running more of the time) and a number of the worst run plants have closed down.

4. For a discussion on the benefits and costs of each alternative, see NRC, *Staff Responses to Frequently Asked Questions Concerning Decommissioning of Nuclear Power Reactors*, NUREG-1628 (Washington, D.C., June 2000), sections 2-6 to 2-13.

5. NRC, *Generic Environmental Impact Statement for License Renewal of Nuclear Power Plants*, NUREG-1437, Volume I (Washington, D.C., 1996), section 7.2.2.1. Smaller reactors at Shippingport, Pennsylvania (72 megawatts), and Fort St. Vrain, Colorado, (330 megawatts) were decommissioned in less than four years, but neither reactor was heavily contaminated, and the Shippingport reactor pressure vessel was small enough to remove in one piece. The Shoreham, New York, plant (849 megawatts) was decommissioned in less than two years, but the plant was not heavily contaminated because it had operated only for the equivalent of two full-power days before it was closed in response to political opposition. Light-water reactors use ordinary water to moderate and cool the fission process; they are the dominant reactor design worldwide.

6. "The NRC Staff Hopes to Send a Rulemaking Plan on the Entombment of Shutdown Nuclear Power Plants," *Inside NRC*, 23 October 2000, 4.

7. NRC, *Generic EIS for License Renewal* (Washington, D.C., 1996), sections 7.2.5.1–2; and NRC, note 4 above, pages 45–7.

8. Class A LLW, the least dangerous level, represents about 97 percent of commercial LLW and is hazardous for about 100 years. Of the balance, classes B and C are hazardous for about 300–500 years, and greater-than-class-C (GTCC) LLW is harmful for up to several thousand years. GTCC waste must be disposed of by the federal government in a geologic repository. (U.S. Congress, Office of Technology Assessment (OTA), *Aging Nuclear Power Plants: Managing Plant Life and Decommissioning*, OTA-E-575 (Washington, D.C.: U.S. Government Printing Office, 1993), 108–13.)

9. NRC's estimates are 18,340 cubic meters of LLW for pressurized-water reactors (PWRs) and 18,975 cubic meters for boiled-water reactors (BWRs). (NRC, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities*, NUREG-0586 (Washington, D.C., August 1988), Tables 4.4-1 and 5.4-1, 4–16, 5–16). In its 1996 *Generic EIS for License Renewal*, NRC used lower estimates of up to 6,992 cubic meters for a PWR and up to 14,282 cubic meters for a BWR, reflecting advances in compaction techniques. However, because the 1988 *Generic EIS for Decommissioning* is the controlling regulatory document for decommissioning, licensee use of the higher numbers is consistent with NRC decommissioning regulations.

10. G. Lobsenz, "EPA Mixed Wasted Reprieve Good News for Nuclear Utilities," *Energy Daily*, 1 May 1996.

11. The Center for Strategic and International Studies, *The Regulatory Process for Nuclear Power Reactors: A Review* (Washington, D.C., August 1999), 1. See also U.S. General Accounting Office, *Nuclear Regulatory Commission: Strategy Needed to Develop a Risk-Informed Safety Approach*, T-RCED-99-71 (Washington, D.C.: Government Press Office, 4 February 1999).

12. See the NRC white paper on risk at http://www.nrc.gov/NRC/COMMISSION/POLICY/whiteppr.html, accessed on 8 March 2001. The risk triplet is consistent with the risk assessment process advocated by the National Academy of Sciences. For more information, see National Research Council, *Understanding Risk: Informing Decisions in a Democratic Society* (Washington, D.C.: National Academy Press, 1996).

13. NRC, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis*, Regulatory Guide 1.1174 (Washington, D.C., July 1998).

14. Ibid.

15. NRC, *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants* (Washington, D.C., October 2000).

16. Ibid, page 3-2.

17. See NRC, note 15 above, page 2-1. The time it takes to heat up and boil off coolant depends upon many factors, including building air flow paths, fuel storage configuration, and decay heat rate. Boil-off in 100 hours assumes the spent fuel from a PWR has been cooling in the pool for 60 days. For a BWR, fuel cooling for 60 days would take 145 days to boil off. The longer the fuel has been decaying in the pool, the longer it would take to generate sufficient heat for boil-off.

18. C. Boynton, "Maine Yankee To Return to Work Next Week," *Boothbay Register*, 12 October 2000.

19. NRC, note 4 above, section 9.2.2.

20. Ibid, section 9.2.10.

21. For a comparison of the respective environmental impacts of license renewal and decommissioning, see NRC, note 5 above, sections 7 and 8.4.

22. For an example of the environmental and economic impacts resulting from closure of one nuclear reactor, see R. E. Löfstedt, "Playing Politics with Energy Policy: The Phase-out of Nuclear Power in Sweden," *Environment*, May 2001, 20–33.

23. 10 CFR 50.75(c).

24. NRC, note 4 above, section 10.1. BWRs generate more contamination than PWRs because they rely on a single loop that circulates water both to cool the reactor and to power steam turbines, spreading radioactivity further throughout the plant.

25. NRC excludes these costs from its formula for calculating decommissioning costs because it regulates on-site dry spent fuel storage separately from decommissioning and does not regulate nonradioactive site cleanup. 10 CFR 50.54(bb) ensures the adequacy of funds for on-site spent fuel storage and maintenance.

26. GAO, *Nuclear Regulation: Better Oversight Needed to Ensure Accumulation of Funds to Decommission Nuclear Power Plants*, RCED-99-75 (Washington, D.C., May 1999). GAO noted that although NRC had begun requiring more detailed reports from licensees on decommissioning funds, it had not defined acceptable levels of financial assurance or specified how it would respond if licensees failed to provide such assurance.

27. Many environmental organizations oppose this and other forms of "stranded cost recovery" for nuclear plants. In response, the nuclear industry contends that decommissioning is a key public safety mission and that it is therefore essential to collect adequate decommissioning funds. For opposing perspectives, see *A Federal Agenda for Electric Industry Restructuring* (Washington, D.C.: Natural Resources Defense Council and other organizations, February 1997), available at http://www.nrdc.org/air/energy/utagen/utaginx.asp; and Nuclear Energy Institute, "Decommissioning of Nuclear Power Plants" (Washington, D.C., September 1999), available at http://www.nei.org.

28. Maine Public Utilities Commission, 22 December 1998; and Connecticut Department of Public Utility Control, 18 August 1997.

29. NRC has made a generic determination that spent fuel can be safely stored on site in either pools or dry casks for up to 30 years after the end of reactors' licensed operating lives (10 CFR 51.23). Licensees typically build dry storage facilities when they have used up the maximum allowable amount of storage space in their spent fuel pools.

30. Licensees that own multiple reactors may be able to move spent fuel from closed plants to operating reactors that have on-site storage space available. Additionally, two private interim storage facilities are under development in Utah and Wyoming, although both are politically controversial and face strong local resistance. Some state officials contend that it will be hard to promote alternative uses for decommissioned sites if parts of those sites are still restricted for spent fuel storage.

31. Nuclear Energy Institute, "Used Fuel Storage," fact sheet, accessed via http://www.nei.org on 29 November 2000.

32. GAO, *Low-Level Radioactive Wastes: States Are Not Developing Disposal Facilities*, RCED-99-238 (Washington, D.C., September 1999).

33. NRC has also set cleanup standards for restricted use at heavily contaminated sites that permit higher residual radioactivity and require institutional controls (such as fences and deed restrictions) to prevent activities that would lead to radiation exposures above the authorized levels. These levels are expected to be more applicable to nuclear processing facilities than to power reactors, which are relatively less contaminated. See NRC, note 4 above, section 8.13. Normal background radiation in the United States averages about 300 millirem (mrem) per year.

34. While NRC regulates radiological aspects of decommissioning, EPA has authority over selected areas such as liquid effluent discharges to bodies of water, which in many cases it delegates to states. EPA withdrew draft standards reflecting its proposed cleanup levels in 1996 but later issued them in nonbinding Superfund guidance. NRC promulgated its standards as a final rule in 1997. See "Radiological Criteria for License Termination," 62 *Federal Register* (FR) 39058, 21 July 1997.

35. For example, see A. Makhjijani, "Decommissioned but Dangerous?" *The Washington Post*, 24 January 2000, A21.

36. GAO, *Radiation Standards: Scientific Basis Inconclusive, and EPA and NRC Disagreement Continues*, GAO/RCED-00-152 (Washington, D.C., 2000), 41, 44.

37. Maine Yankee Atomic Power Co. has pledged to meet the state of Maine's 10 millirem all-pathway and 4 mrem ground water standards at its Maine Yankee plant. Similarly, Yankee Atomic has pledged to meet the state of Massachusetts's 10 mrem all-pathway standard at its Yankee Rowe plant. (105 *Code of Massachusetts Regulations* 120.291; and Yankee Rowe Community Advisory Panel, Meeting Minutes, 11 May 2000.)

38. In 1990, NRC proposed "below regulatory concern" (BRC) standards of 1–10 mrem per year for individual doses and a collective annual dose of 1,000 person-rem, which it subsequently withdrew in the face of sharp public and political criticism. See OTA, note 8 above, pages 104–5.

39. G. Lobsenz, "DOE Hopes Radioactive Recycling Will Reduce Cleanup Costs," *Energy Daily*, 21 February 1996.

40. See, for example, Nuclear Information and Resource Service, "Warning: Radioactive Waste and Materials Are Being Used to Make Everyday Household Items," (Washington, D.C., October 1999); and Public Citizen, "Tainted NRC Process on Radioactive Waste Recycling Continues," (Washington, D.C., 9 May 2000).

41. A. MacLachlan, "Radiation Experts Don't Agree on How to Release Materials," *Nucleonics Week*, 30 March 2000; and A. MacLachlan, "Dicus Leaning Against Recycling of Radioactive Materials," *Inside NRC*, 22 May 2000

42. 61 FR 39279–80, 29 July 1996.

43. Excerpts of the Generic Environmental Impact Statement (GEIS) relating to power reactors may be accessed at http://www.nrc.gov/NRC/REACTOR/DECOMMISSIONING/GEIS/index.html.

44. In early 2000, NRC announced plans to update the 1988 GEIS, a process that is likely to change some of the parameters for environmental impacts. Notably, improvements in compaction techniques have reduced the volumes of LLW generated from decommissioning below earlier projections. It is unclear how licensees that are developing their decommissioning plans are to show that their environmental impacts are within the limits of the GEIS when these numbers will probably change in the draft supplement, scheduled for release in 2001.

45. 10 CFR 50.34(b).

46. 61 FR 39281, 29 July 1996; and 10 CFR 50.59.

47. FSARs in principle are public documents but are not widely distributed, although they may be accessed at NRC public document rooms.

48. For descriptions of major decontamination and decommissioning technologies, see OTA, note 8 above, pages 127–34.

49. 10 CFR 50.82(a)(9).

50. 10 CFR 20.1404(a)(4).

51. David Lochbaum, Union of Concerned Scientists, personal communication with authors on 28 February 2001.

52. See NRC, Transcript—Maine Yankee Decommissioning Meeting, 7 October 1997; NRC, Transcript—Maine Yankee Post-Shutdown Decommissioning Activities Report (PSDAR) Public Meeting, 6 November 1997; and NRC, Transcript—Public Meeting to Discuss Maine Yankee Atomic Power Station License Termination Plan, 15 May 2000, at www.nrc.gov/OPA/reports.htm. (All of the sources above are available at this web page.)

53. A. D. Burt, quoted in NRC, Transcript—Maine Yankee Decommissioning Meeting, 7 October 1997, available at http://www.nrc.gov/OPA/reports/my100797.htm

54. See the Oregon Department of Energy report on its year-long analysis of the decommissioning plan for the Trojan nuclear plant, available at http://www.energy.state.or.us/siting/decom.htm.

55. See public comments at scoping meetings in the spring and summer of 2000 on NRC's proposed revision of the GEIS on decommissioning, available at http://www.nrc.gov/NRC/REACTOR/DECOMMISSIONING/GEIS/index.html.

56. The licensee sought permission for early component removal to take advantage of an opportunity to send radioactive waste to the Barnwell, South Carolina, site.

57. *Citizens Awareness Network v. Nuclear Regulatory Commission*, 59 *Federal Reporter* 3d 284 (1995), U.S. First Circuit Court of Appeals. Local intervenors continued to contest Yankee Atomic's decommissioning plans, arguing that the company was not providing enough detail about how it would address issues such as radioactive waste buried on site and criticizing its calculations of residual radiation at the decommissioned site. EPA's New England office seconded these concerns when Yankee Rowe released its License Termination Plan (LTP) in 1997. In 1999, after Citizens Awareness Network was granted intervenor status in hearings on the LTP, the company withdrew the plan to implement a new radiological survey program. (M. Cohen, "Critics Wonder If Yankee Atomic's Plan Will Clean Up Site," *Boston Globe*, 14 March 1999, B6. See also Yankee Rowe's web page at http://www.yankee.com for updates on decommissioning activities.)

58. 10 CFR 50.59; and 61 FR 39279–80, 29 July 1996.

59. See Issue 8—Court Decision in Decommissioning of Nuclear Power Reactors, Final Rule, 61 FR 39286–7, 29 July 1996. Arguably, NRC's explanation addresses the court's procedural concerns, but not its substantive concern that "[b]y allowing licensees to conduct most, if not all, of the permanent removal and shipment of the major structures and radioactive components before the submittal of a decommissioning plan, it appears that the commission is rendering the entire decommissioning plan approval process nugatory." (*CAN vs. NRC*, note 57 above.) Currently, licensees do not have to submit detailed license termination plans until decommissioning is for all practical purposes completed—a process that appears to render much of the preceding NRC oversight and public comments moot.

60. The company claimed that conditions for significant environmental impacts would not occur because indices of radioactive risk, such as estimated radioactive waste volume and radiation protection controls, would be kept within the acceptable parameters outlined in the 1988 GEIS but provided no analysis or evidence to support this position.

61. Maine Yankee is expected to submit a revised license termination plan no sooner than 1 June 2001.

62. J. Weil, "Plan for Decommissioning Now or Pay More Later, Meisner Says," *Nucleonics Week*, 28 September 2000.

63. In the words of the Union's Environment Directorate, "Decommissioning operations and the related strategy decisions should be undertaken in a spirit of transparency and openness, with the involvement of the public and an understanding of their concerns." (Council of the European Union, *Council Directive 97/11/EC of 3 March 1997*, available at http://europa.eu.int/comm/environment/ nuclear/decomm1.htm.)

64. NRC staff contact and reactor project manager, interview with author (Farber), 5 December 2000.

65. See the state web pages on Trojan, at http://www.energy.state.or.us/ siting/trojan.htm, and Maine Yankee, at http://www.janus.state.me.us/dep/rwm/myankee/homepage.htm.

66. In each case, safety investigations raised the need for expensive repairs, leading owners to close the plants rather than making major upgrades at reactors that had already run for much of their licensed operating lives. (M. L. Wald, "A-Plant Shut Down, Ending Industry's Test Case," *The New York Times*, 27 February 1992, 12; and P. J. Howe, "Talks To Sell Maine Plant Break Down," *Boston Globe*, 2 August 1997, A1.)

67. Adam Bless, resident Trojan inspector, Oregon Office of Energy, personal communication with the authors, 2 January 2001.

68. See, for example, S. Owens and D. Cope, "The Wider Perspective of Decommissioning," in M. J. Pasqualetti, ed., *Nuclear Decommissioning and Society* (New York: Routledge, 1990); M. G. Morgan, "What Would It Take To Revitalize Nuclear Power in the United States?" *Environment*, March 1993; NRC, "Improving Decommissioning Regulations for Nuclear Power Plants," SECY-99-168 (Washington, D.C., 30 June 1999); and European Commission, "Decommissioning Policies in the EU," accessed via http://europe.eu.int/comm/environment/nuclear/decomm1.htm on 19 December 2000.