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ABSTRACT

The processes and associated dilemmas of nuclear power plant decommissioning are reviewed in this publication. Decommissioning involves the clearing up and disposal of a retired nuclear plant and its equipment of such a way as to safeguard the public from the dangers of radioactivity. Related problem areas are identified and include: (1) closure methods (discussing the options of decontamination and dismantlement, storage, and reaction of a permenent tomb); (2) high-level waste management (identifying spent fuel removal and disposal problems); (3) retired reactor disposal (citing examples of waste management systems employed in the United States and in Europe); (4) economics (providing cost estimates for major expense items); (5) savings mechanisms (proposing efforts to offset future decommissioning costs); and (6) long-term strategies (urging the need for safe disposal and decommissioning research and development programs). (ML)

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Unprecedented construction cost overruns for nuclear power plants have halted growth in the nuclear industry in many countries. Even while staggering under these bloated costs, the industry is now faced with the expense of dismantling and disposing of worn out reactors. Decommissioning—the process of cleaning up and burying a retired nuclear plant in order to protect the public from radioactivity—is an essential step in the use of nuclear power.

In most industries, the disposal of retired plant and equipment is a straightforward and relatively low-cost operation. But the high levels of radiation present in shutdown reactors will make the procedure uniquely complex and costly. Decommissioning will require remotely controlled technologies and large work crews to limit the exposure of individuals to radiation Comprehensive strategies for transporting and disposing of radioactive wastes, and large amounts of readily available money will also be needed. The economic competitiveness of electric-generating technologies is traditionally judged by comparing construction and operating costs. But cost estimates for nuclear power will be meaningful only if a third variable, decommissioning costs, is incorporated into the equation.

Nearly four decades and 400 power plants into the nuclear age, the question of how to safely and economically dispose of nuclear reac-

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tors and their wastes is still largely unanswered. Nuclear plants cannot simply be abandoned at the end of their operating lives or demolished with a wrecking ball. Radioactivity builds up each year the plant operates, and all of the contaminated parts and equipment must be securely isolated from people and the environment. Some radioactive elements in plant components will decay quickly, but others will remain hazardous for millennia.

No one knows how much it will cost to decommission the hundreds of units in service and under construction around the world. Estimates range from $50 million to $3 billion per reactor.[1] The reactor construction binge prior to 1980 means that much of the decommissioning bill may fall due shortly after the turn of the century—from 2000 to 2020. Although engineers are attempting to lengthen the life expectancy of reactors, economical operation may not be feasible for longer than 30 years. Numerous technical difficulties, including the constraints radiation buildup places on routine maintenance and the inevitable embrittlement of the reactor pressure vessel, are likely to limit opportunities to extend plant life.

At the turn of the century, demand for new large-scale generating plants of all types is expected to be weak, particularly in the United States.[2] Thus nuclear decommissioning could be the largest expense facing the utility industry, outstripping plant construction. Given current policies, most of this bill will be paid by a generation that neither took part in the decision to build the first round of nuclear plants nor used much of the power generated.

Although nuclear power supplied 13 percent of the world's electricity in 1984, not a single large commercial unit has ever been dismantled.[3] Nuclear engineers have been attracted to the exciting challenge of developing and improving a new technology, not to figuring out how to manage its rubbish. But the problem will demand attention as a growing number of plants approach retirement age. Not one of the 26 countries currently relying on nuclear power is adequately prepared for this undertaking.

"Nuclear plants cannot simply be abandoned at the end of their operating lives or demolished with a wrecking ball."

The oldest commercial nuclear reactors are already nearing the end of their useful lives, and some plants have closed prematurely because of accidents or faulty designs. In the United States, dozens of tiny research and military reactors are no longer used and four small retired commercial units are awaiting decommissioning. The U.S. Nuclear Regulatory Commission (NRC) estimates that another 67 large commercial units will cease operations before the year 2010. Worldwide, more than a dozen power reactors are already shut down, 66 more are likely to retire by the year 2000, and another 162 will reach their thirtieth year of operation in the following decade.[4] (See Table 1.) Countries with advanced nuclear programs will soon start to feel the pressure associated with managing the "back end" of nuclear power production.

The formidable issue of decommissioning is getting less attention than it deserves. Utility companies and ratepayers balk at yet another large expense associated with using nuclear power. And politicians are reluctant to tackle an issue that will not come to the forefront until after their political careers have ended. In many parts of the world, the nuclear power industry is strapped for cash and no longer commands the attention of scientists, business leaders, or policymakers.

Developing new technologies and formulating complicated regulatory guidelines for safely handling, transporting, and disposing of radioactive wastes will be difficult to accomplish in such a milieu. But there can be little argument that public health and safety and the financial solvency of utilities demand accelerated research on and financial planning for decommissioning.

Decontamination and Dismantlement

Following a nuclear plant's closure, the reactor owner must decide which of three courses to follow: decontaminate and dismantle the facility immediately after shutdown, put it in storage for several decades to undergo radioactive decay prior to dismantlement or simply erect a "permanent" tomb. Each option involves removing the spent fuel, draining all liquids, and flushing the pipes.[5]

Table 1: Nuclear Power Reactors in Operation and Under Construction Worldwide, 1956-95, and Year of Expected Retirement

Entered Service	Reactors	Capacity	Planned Retirement After 30 Years of Operation
	(number)	(megawatts)	
1956-60	13	780	1986-1990
1961-65	22	3,920	1991-1995
1966-70	31	10,831	1996-2000
1971-75	84	54,351	2001-2005
1976-80	78	61,476	2006-2010
1981-85	133	117,546	2011-2015
Cumulative in Operation	361	248 904	1986-2015
1986-90*	122	114,061	2016-2020
1991-95*	22	18,099	2021-2025
Total	505	381,064	

*Under construction or on order

Source "World List of Nuclear Power Plants," *Nuclear News*, February 1986

Under the immediate dismantlement scenario, tubing and structural surfaces would be mechanically and chemically cleaned, a process called decontamination, irradiated steel and concrete would be disassembled using advanced scoring and cutting techniques; and all radioactive debris would be shipped to a burial ground. The site would then theoretically be available for unrestricted use.

Plants to be mothballed, on the other hand, would only undergo preliminary cleanup before being placed under surveillance. After 50 years in storage, most of the short-lived radioisotopes would have decayed, further safety gains would be negligible, and the facility would be dismantled Entombment, the third option, entails covering the reactor with reinforced concrete and erecting barriers to keep out intruders. Although once viewed as the cheap and easy way out, entombment is no longer considered a realistic option because of the longevity of several radioisotopes. The protective structure would decay long before the radioactivity within.[6]

A survey of 30 electric utilities in the United States revealed that 22 planned to promptly dismantle and remove their reactors following shutdown. In Japan, utilities are advised to wait no longer than 10 years after closure to dismantle their plants. Utilities in Canada and France, on the other hand, plan to mothball most of their reactors for several decades before dismantling them.[7]

Regardless of the method chosen, decommissioning a large nuclear power plant is a complex task. The high levels of radiation present at recently closed reactors place numerous constraints on the decommissioning crew. Workers must take elaborate precautions, including wearing protective clothing and breathing apparatus, and limiting their time in contaminated environments. Radiation exposure must be carefully monitored, and according to industry standards kept "as low as reasonably achievable." Productivity will unavoidably be low, less than half of what it would be in a nonradioactive environment.[8]

Two sources of radiation will confront decommissioning workers—contaminated and activated materials Contaminated parts include nearly all of the piping and equipment in the reactor containment vessel and the fuel, auxiliary, and control buildings. Many of the concrete surfaces in these buildings also become contaminated. The degree of contamination depends on the number of fuel leaks experienced during operation, the type of material exposed, and its exterior finish. Although high-pressure water jets and chemical decontaminants can wash off some surface contamination, only a fraction of the material becomes clean enough to recycle or dispose of in commercial landfills.[9]

T! volume of solvents used must be carefully regulated because they too become contaminated. Spills during either operation or cleanup can result in contamination of the surrounding soil. Keeping waste volumes to a minimum is an elusive goal: Each piece of machinery and every tool that comes into direct contact with a contaminated surface must be decontaminated or added to the radioactive waste pile

The other source of radiation that will confront decommissioning crews is "activation" products. When nuclear fuel undergoes fission—the splitting of uranium atoms—stray neutrons escape. These neutrons bombard the nuclei of surrounding atoms, and the resulting change in composition causes some trace elements in the steel and concrete that encircle the reactor core to become radioactive. Neutron-activated parts include the reactor pressure vessel, the vessel's internal components and structures, and the surrounding concrete shield. Neutron-activated components are more than 1,000 times as radioactive as contaminated components, and because they are composed of radioisotopes they cannot simply be washed clean.[10]

Estimating the volume and radioactivity of activation products that will be encountered at a retired reactor is difficult. The complex arrangement of the components in and around the reactor core makes it hard to predict the movement of neutrons. Accurate assessments of the quantity of activation products also require a detailed knowledge of the amounts of various elements that are present in the construction materials, sometimes at the parts per million or even parts per billion level. Studies conducted in France showed only a small variation in the composition of concrete used in the European Community's reactors, but studies of reactor construction materials in the United States showed greater variability. Cobalt and niobium concentrations in stainless steel were found to vary more than tenfold.[11]

For the first several decades following plant shutdown, the most problematic elements are those that decay the fastest. Cobalt and cesium are the dominant short-lived radioisotopes, with half-lives (the time it takes radioisotopes to lose half their radioactivity) of five and 30 years respectively. Other elements with longer half-lives are

"Practical decommissioning experience is limited to very small reactors."

present in smaller quantities and will dominate radiation levels in the future. Neutron-activated materials contain significant amounts of long-lived nickel and niobium radioisotopes. Nickel 59, for example, has a half-life of 80,000 years.[12]

Following preliminary decontamination, the structures surrounding the reactor must be cut into smaller pieces for transportation and burial. A steel pressure vessel containing a 1,000-megawatt reactor is typically over 12 meters high and 4 meters in diameter. The concrete vessel surrounding an advanced gas reactor, the type used in the United Kingdom, is several meters thick. Dismantling the vessels is both complicated and hazardous. Each cut causes more airborne contamination, so remote-controlled equipment will probably be used to keep worker exposure to a minimum. Although testing of several dismantling techniques is underway, more research is required to prepare the industry for dismantling today's large reactors. According to Dr. Paul Woollam, a member of the Commission of the European Communities team that in 1984 conducted a comprehensive analysis of decommissioning capabilities, "The design of equipment for dismantling, especially remote equipment, is in its infancy."[13]

Practical decommissioning experience is limited to very small reactors. The tiny 22-megawatt Elk River plant is the largest that has been fully decontaminated and dismantled. The U.S. Department of Energy (DOE) completed this three-year project in 1974 at a cost of $6.15 million. The plant had only been in operation for four years. Plasma arc torches were used to cut apart the reactor, and 3,630 cubic meters of contaminated materials were buried. Many modern reactors can produce 50 times more power and will have operated some seven times as long as Elk River. Since radiation builds up in proportion to plant size and operating life, a 1,000-megawatt reactor used for 30 years would pose considerably more problems.[14]

Twenty-five miles outside of Pittsburgh, Pennsylvania, DOE is currently decommissioning the United States' first commercial reactor The 72-megawatt Shippingport plant began producing electricity in 1957, and after 25 years of operation, it was closed in 1982. In accordance with the original contract, the U S. government is responsible for decommissioning the plant Shippingport will be the largest unit decommissioned to date anywhere in the world and it could be used as a valuable and badly needed prototype.[15]

Instead of seizing this learning opportunity, DOE plans to encase the 10-meter-high steel reactor vessel in concrete, transfer the 770-ton behemoth intact to a 4,000-ton barge, and send it down the Ohio and Mississippi rivers, through the Gulf of Mexico and the Panama Canal, and up the Pacific Coast and Columbia River. It is to be buried in an earthen trench on the government-run Hanford nuclear reservation. Keeping the Shippingport reactor pressure vessel in one piece instead of chopping it up and sending it by truck is estimated to lop at least $7 million, or 7 percent, off the total price tag.[16]

This action is shortsighted. By employing cost-cutting measures now, DOE is depriving the international nuclear industry—the same one it helped foster—of invaluable lessons. Larger reactors may be too big to ship in one piece, and the most difficult task decommissioning crews of the future will face is dismantling the pressure vessel and its contents.[17]

In Europe, efforts to decommission several commercial reactors are just getting underway. The first three projects will be the 100-megawatt Niederaichbach unit in West Germany, the 33-megawatt Windscale advanced gas reactor in the United Kingdom, and the 45-megawatt French G-2 gas reactor at Marcoule. Although the French and U.K. plants are small, each operated for about 20 years—long enough to become well contaminated. The larger, German reactor was in service for only two years before technical difficulties resulted in its closure Each unit has a different design, and dismantling efforts are likely to uncover problems unique to specific technologies.[18]

However, experience gained at the damaged reactor at Three Mile Island will aid future decommissioning work. The industry's knowledge of robotics, chemical decontaminants, and remote cutting techniques has greatly expanded as a result of the cleanup effort.

> **"By employing cost-cutting measures now, DOE is depriving the international nuclear industry—the same one it helped foster—of invaluable lessons."**

International information sharing and on-site observations by foreign experts mean that these lessons may be widely applied.[19]

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The overriding consideration in selecting a decommissioning schedule and the appropriate decontamination and dismantlement methods must be worker and public safety. Although radioactivity declines more than twentyfold during the first 30 years of storage, governments and the public may not be willing to tolerate the presence of these highly radioactive structures, or be willing to face the charge of "passing the buck" to future generations. The Humboldt Bay reactor on the northern California coast has been the center of controversy since its retirement in 1976. The unit lies in a seismically active zone and is not structurally engineered to withstand earthquakes—which is why it was permanently taken out of operation Immediate dismantlement would make the site available for other uses, and would safeguard the public against potential exposure to radiation. Yet efforts to dismantle the plant are not expected until after the year 2000.[20]

High-Level Waste Management

Discussions about decommissioning typically exclude the topic of high-level nuclear waste disposal. But high-level wastes—spent fuel and the byproducts of fuel reprocessing—must be removed from the plant before decommissioning can proceed. At present, not a single country has a permanent disposal facility for high-level wastes and no such facilities are likely to be in operation before the turn of the century

The fuel for most nuclear power plants consists of small pellets of uranium oxide—the size of pencil erasers—that are sealed in 12-foot-long metal tubes and bundled into fuel assemblies. Fission products that result from the splitting of uranium atoms gradually build up to a point that inhibits the chain reaction. One fourth to one third of the fuel in a typical reactor must be replaced each year. The spent fuel is highly radioactive and consequently very warm. Spent fuel remains more radioactive than the original uranium ore for about 3 million years. Remote handling conducted behind heavy shielding is essential.[21]

Until the mid-seventies the international nuclear industry assumed that reprocessing of spent fuel would become a universal practice, providing fuel for the next generation of breeder reactors and a means of quickly removing the spent fuel from utility holding ponds. But along with uranium, fuel reprocessing recovers plutonium, which can be readily made into nuclear bombs. Concerns about nuclear proliferation, coupled with new discoveries of uranium, a slowdown in reactor construction, and the demise of most breeder programs, undercut the rationale for reprocessing in many countries. The U.S. program was abandoned and today only France, the Soviet Union, and the United Kingdom have sizeable reprocessing industries.

Seven European nations and Japan have contracted to send at least a portion of their spent fuel to the British Sellafield reprocessing plant or the French Marcoule and La Hague facilities. The recovered uranium and plutonium, and the high-level wastes that are typically stabilized in glass cylinders, are to be returned to the countries of origin. Therefore, although sending spent fuel abroad for reprocessing temporarily eases the waste management problem, it does not permanently eliminate the need for sound handling and disposal policies. Indeed, reprocessing compounds the handling problem because it increases the number of times the fuel is manipulated and transported. Because reprocessing is more expensive than direct disposal, customers are essentially buying time to decide on a permanent disposal strategy.[22]

In the United States, virtually all of the 12,000 metric tons of spent fuel produced to date is now stored temporarily in water-filled utility holding ponds. The volume of waste is expected to quadruple within 15 years. Utilities do not have adequate space for storing this spent fuel, nor is there anyplace they can send it.[23] For years, the nuclear industry ignored the issue of permanent high-level waste disposal, thinking reprocessing would relieve it of the burden. Today the disposal problem, though managed by national energy agencies, is back

"The toxicity of high-level wastes requires that they be kept out of the biosphere for tens of thousands of years—longer than recorded history."

in their laps It is impossible to fully dismantle a nuclear plant if there is nowhere to put the spent fuel cooling in utility storage ponds.

People exposed to large doses of radiation may become ill or die within several weeks. Exposure to lower doses results in long-term effects, including several types of cancer. And children whose parents were exposed are prone to genetic mutations and birth defects. Some radioisotopes are especially dangerous if they are ingested or inhaled because they mimic essential nutrients, concentrate in vulnerable organs, and then decay inside the body. Radioactive strontium and cesium, for example, behave like calcium and accumulate in bones. And unlike many chemicals, radioactive waste cannot readily be detoxified or destroyed. Health risks can only be avoided by keeping wastes out of the biosphere until they have decayed to harmless levels.[24]

Where to dispose of high-level wastes has become a contentious political issue in each of the 26 countries that produce nuclear power. Few national governments have been in power for more than several decades, and the lifespan of most energy agencies is even shorter. But the toxicity of high-level wastes requires that they be kept out of the biosphere for tens of thousands of years—longer than recorded history

Since reliance on human institutions for such a long period of time is impossible, most countries have decided to bury their wastes in geologic repositories 300 to 1,200 meters below the earth's surface. Searching for stable sites is the current focus of most disposal programs. The characteristics of a good site include unfractured geology so groundwater will not migrate through the area and contaminate water supplies, low seismic activity, and the absence of mineral wealth so future generations will not find the area attractive for drilling.

Political opposition to high-level waste disposal will be at least as difficult an obstacle as finding a geologically appropriate site. Winning public acceptance is likely to be particularly tough where population densities are high, such as in Japan and Europe. Some countries—the Netherlands, for example, where there is strong public opposition to all forms of waste disposal—are hoping that international sites will become available, perhaps operated by reactor suppliers. Yet no nation would likely want to accept large volumes of imported waste. China offered to store a small portion of West Germany's spent fuel, but the contract was linked to China's obtaining a bargain price on two reactor orders. Now that the Chinese have cut back their nuclear program, the offer may no longer be good. The Soviet Union is the only country that takes back the high-level wastes generated by the reactors it sells, most of them to Eastern European nations.[25]

The geologic medium chosen for a permanent repository is likely to be limited by the options available domestically. Sweden plans to dispose of its high-level wastes in granite, West Germany is examining the use of salt mines, and Belgium hopes to place its waste in clay (See Table 2.) Japan is considering several rock types, but the country is so earthquake-prone that none may offer adequate stability. At this time, no single geological formation is considered substantially superior. Problems have been found with each.

Most European nations are just beginning to seriously explore and evaluate permanent disposal sites. West Germany hopes to dispose of its high-level wastes in the Gorleben salt dome and has begun construction of exploratory shafts. The Stripa mine in Sweden has been the focus of international research for almost a decade, but Sweden plans to develop a new granite repository 500 meters below the earth's surface. Construction is not scheduled until the year 2010, when all of the nation's 12 reactors will be taken out of service. The United Kingdom has explicitly deferred the decision to proceed with repository siting and France appears content to rely indefinitely on "temporary" storage at its reprocessing facilities.[26]

Several experimental high-level waste repositories have already been tested in the United States, but none has proved acceptable. In 1982 the U.S Congress passed the Nuclear Waste Policy Act (NWPA), requiring the federal government to develop two permanent mined geologic repositories and have the first ready for business by 1998.

Table 2: Geologic Media Selected for Further Study as High-Level Waste or Spent Fuel Repository in Various Countries

Country	Granite	Clay	Salt	Basalt	Tuff	Shale	Diabase
Belgium		X					
Canada	X						
France	X	X	X				
Japan	X				X	X	X
Spain	X		X				
Sweden	X						
Switzerland	X						
United Kingdom	X						
United States	X		X	X	X		
West Germany			X				

Source: K M Harmon. "Survey of Foreign Terminal Radioactive Waste Storage Programs," in *Proceedings of the 1983 Civilian Radioactive Waste Management Information Meeting*, Washington, D C , December 12-15, 1983 (Springfield, Va National Technical Information Service, 1984)

The Environmental Protection Agency issued standards prohibiting radiation releases from the 300- to 1,200-meter-deep burial sites for 10,000 years The location of the first repository has been tentatively narrowed to one of three sites: Hanford, Washington; Yucca Mountain, Nevada; or Deaf Smith County, Texas.[27]

Final site selection has already become a political hot potato. Potential host states and environmental groups have filed lawsuits challenging the adequacy of the siting guidelines. According to James Martin, a staff attorney with the Environmental Defense Fund: "First, there are concerns that, in its haste to site a repository, [the Department of Energy] has relied on pre-NWPA studies of dubious quality and is delaying analysis of waste transportation risks that cannot be deferred. Second, there is evidence that politics are creeping into and tainting the decision-making process. These factors pose grave threats to the integrity and public acceptance of the siting process."[28]

Each of the proposed sites has drawbacks. There is much concern, for example, that disposal at Hanford could lead to contamination of the nearby Columbia River. And farmers in Texas fear contamination of the aquifer they use to irrigate their crops. Choosing the best site will unquestionably be difficult, but the only way to inspire confidence in the final choice is to conduct extensive testing at each proposed location and make the results available for scientific review.

Several nations are examining intermediate storage of spent fuel at centralized locations away from reactor sites. Sweden has the most advanced program: Its CLAB facility, adjacent to the Oskarshamn power station, will hold spent fuel from all Swedish reactors in artificial underground ponds for several decades prior to geologic disposal. A half-dozen countries are experimenting with dry spent fuel storage as an interim step between utility holding ponds and permanent disposal. Aboveground concrete silos and reinforced concrete vaults are already available in Canada, the United Kingdom, and West Germany.[29]

In the United States, three sites in Tennessee, including the abandoned Clinch River breeder reactor, are being considered as hosts for a retrievable storage program. Though presently blocked by the courts, the storage plan would allow DOE to fulfill its obligation to take possession of commercial spent fuel in 1998 even if a permanent geologic repository is not yet available. Storing the fuel allows further radioactive decay which would result in a cooler—and therefore safer—waste package. But a centralized storage system would also significantly increase the number of times fuel must be handled and transported. Critics fear the strategy is being promoted because DOE will not meet its deadline for establishing permanent repositories.[30]

In 1976, the California legislature was the first to enact a bill forbidding further nuclear power plant construction until "the federal government has approved, and there exists, a demonstrated technology or means for the disposal of high-level nuclear wastes." Without such assurance, it is impossible to fully assess the costs of nuclear power. Controversial at the time, the measure was only one of the

"The present inability to dispose of high-level wastes is causing many developing countries to shy away from building nuclear power plants."

many factors that put an end to reactor orders in the United States. The deteriorating economics of nuclear power, low electricity-demand growth, and tightened regulation after the accident at Three Mile Island are considered the principal reasons that no new reactors have been ordered since 1978.[31]

"Stipulation" laws making continued use or construction of nuclear power facilities contingent upon the development of satisfactory plans for managing the spent fuel and reactor wastes have also been enacted in Belgium, Finland, the Netherlands, Sweden, Switzerland, and West Germany. Though Japan has similar regulations in place, one commentator likens its lack of high-level waste disposal facilities to "living in a house without a toilet." According to the International Atomic Energy Agency in Geneva, the present inability to dispose of high-level wastes is causing many developing countries to shy away from building nuclear power plants.[32]

The Nuclear Energy Agency in Paris projects that nearly 160,000 metric tons of spent fuel will have accumulated in countries belonging to the Organisation of Economic Co-operation and Development (OECD) by the year 2000.[33] Existing utility holding ponds are not large enough to accommodate this increase, nascent away-from-reactor storage techniques are unlikely to be sufficiently developed, and permanent repositories will probably be stalled by political and technical obstacles.

If there is no place to which the spent fuel can be shipped, mothballing will, by default, become the only feasible decommissioning strategy. Choosing the safest and least expensive decommissioning schedule is only possible if high-level waste disposal facilities exist. In countries where fuel is not reprocessed or shipped to central storage facilities (and thus removed from the reactor site), the lack of permanent repositories could severely limit opportunities for timely decommissioning.

Disposal of a Retired Reactor

Removing the spent fuel is only the beginning of the decommissioning process. Few nations have independent commercial disposal facilities for low-level radioactive wastes, a much larger category that encompasses everything from work gloves and used equipment to contaminated water and soil. Although this waste is considerably less toxic than spent fuel and reprocessing wastes, it is produced in far greater volumes. The largest contributor of low-level waste is nuclear power generation, but hospitals, medical laboratories, and a variety of industries also produce substantial quantities. Most low-level wastes decay to safe levels in several decades, but some remain dangerous for hundreds of years.

An average pressurized water reactor, the most commonly used nuclear technology, sends about 400 cubic meters of low-level wastes to burial sites each year. When the reactors are dismantled, they will each produce an estimated 18,000 cubic meters of low-level waste, half again as much as will have been generated throughout the unit's operating life. (See Table 3.) This is enough to bury a football field under four meters of radioactive debris. Decommissioning just one large reactor would yield a volume of contaminated concrete and steel equal to one fourth of the low-level radioactive wastes now shipped to all U.S. commercial dumpsites in a year.[34]

Until 1970, the United States and many other nations discarded low-level wastes by dumping them at sea. Belgium, Japan, the Netherlands, Switzerland, and the United Kingdom were still dumping much of their low-level waste until 1983, when the London Dumping Convention declared a moratorium pending a scientific study of the effect on the marine environment. The reprocessing operation at Sellafield, however, still pumps 1.2 million gallons of slightly radioactive wastewater into the ocean daily.[35]

On-land disposal typically involves packing the debris in barrels and storing them either at the reactor site or in specially designated warehouses. Canada and Japan, each operating large nuclear programs,

Table 3: Estimated Low-Level Radioactive Wastes from Dismantlement of a Typical 1,100-Megawatt Pressurized Water Reactor

Material	Burial Vol (cubic meters)	Truckloads (number)
Activated		216
Metal	484	
Concrete	707	
Contaminated		967
Metal	5,465	
Concrete	10,613	
Radioactive	618	180
Total	17,887	1,363

Source: R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr., *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station* (Washington, D.C.: U.S. Nuclear Regulatory Commission, 1978)

practice this approach. In only some half-dozen countries are the drums transported to commercial low-level waste depositories and buried in earthen, or more recently concrete-lined, trenches.[36]

Experience with traditional shallow land burial has been mixed. Three low-level waste sites in the United States, each opened during the sixties, have subsequently been closed because poor burial practices resulted in surface water infiltration and contamination. Kentucky, Illinois, and New York, the states in which the contaminated trenches are located, each spend millions of dollars annually to clean and monitor the sites. By the late seventies only half of the country's low-level waste sites were still operating—one each in Nevada, South Carolina, and Washington. Objecting to their role as the nation's dumping ground, the three state governments closed or restricted access to their facilities for a short time in 1979.[37]

This prompted the U.S. Congress to pass the Low-Level Radioactive Waste Policy Act in 1980. The law made each state responsible for managing the commercial low-level waste generated within its borders, and encouraged states to form regional agreements to establish and operate disposal facilities cooperatively. The new waste sites were supposed to be operational by New Year's Day 1986. When it became obvious that the deadline would not be met and that half the low-level waste produced in the United States, accounting for nearly three quarters of the radioactivity, would be barred from the nation's waste sites, an eleventh-hour compromise was reached. Slow-acting states were given a seven-year extension and the first seven "regional compacts," involving 38 states were approved.[38]

But the governors of Nevada, South Carolina, and Washington drove a hard bargain. They set limits on the volume of waste their sites will accept each year and developed quotas for individual reactors in various regions. Total volume reduction required per reactor ranges from 18 to 45 percent. In the future all wastes accepted from outside these three regions will be assessed a surcharge rising from $10 per cubic foot in 1986 (a 30 percent increase over present rates) to $40 per cubic foot in 1990. If interim deadlines are met, one quarter of the surcharge fees will be returned to the state of origin to help offset the costs of establishing new waste facilities.[39]

Selecting new burial sites promises to be difficult. Maine, Massachusetts, and South Dakota already require voter approval of either compact or siting decisions. And both Nevada and South Carolina have stipulated that their disposal sites will soon close and other states in their respective regions will have to accept wastes in the future. Political opposition to nuclear waste sites is strong and past operating experience has done little to dispel public concerns.[40]

Because several of the first sites developed leaks, at least five states—Illinois, Kentucky, Massachusetts, Pennsylvania, and Texas—have prohibited the future use of traditional shallow land burial. They may still allow underground waste disposal, but they will require engineered barriers such as concrete-lined trenches, and strict en-

"Political opposition to nuclear waste sites is strong and past operating experience has done little to dispel public concerns."

forcement of packaging regulations. Other disposal techniques seriously being studied include aboveground vaults, earth-mounded concrete bunkers, mined cavities, and augured holes. To date these technologies have been used primarily for waste storage, not disposal, and there is concern about their long-term ability to isolate wastes. Aboveground structures, for example, will be subject to natural catastrophes, possible intrusion, and years of weathering.[41]

Many states are examining new disposal methods, but for the most part they are inexperienced in dealing with low-level wastes and have limited budgets. Congress has made the states responsible for the wastes generated within their borders, but no federal funds have been allocated for assistance, and the two organizations with the most expertise, the NRC and DOE, do not plan to conduct additional research and development activities. Their role will be purely advisory. Despite the desire to build safer disposal sites, most states are ill-equipped to meet the challenge and fear that proposals to use alternative methods will result in regulatory delays.[42]

Since systems with elaborate safeguards are expensive to build and operate, states have been encouraged to join forces to designate regional sites at which high management standards can be enforced. Such regional facilities would certainly be safer than periodically rotating sites among member states, a dangerous alternative that nevertheless is sometimes endorsed for political reasons. New waste sites are only expected to operate for 20 to 30 years before they are closed and a new regional site is required. Disposal responsibility is thus likely to rotate among a regional compact's member states eventually and there is no need to accelerate the process.[43]

In Europe, several different approaches to low-level waste disposal are being examined Sweden plans to dispose of its waste in numerous galleries and chambers sunk into granite rock 50 meters below the Baltic Sea. An abandoned iron mine has been designated as a future disposal site in West Germany, but in the meantime, wastes are temporarily stored in aboveground warehouses. Japanese nuclear plants store low-level wastes on-site. Incinerators and compactors keep waste volumes manageable while research is conducted on both land and sea disposal.[44]

In France, low-level wastes have been disposed of in earth-mounded concrete bunkers at the La Manche center since 1969. The success of the facility has prompted the Westinghouse Electric Corporation to develop a disposal system, called "SAVEPAK," patterned after the French method. Incoming wastes would first be X-rayed to make sure they are liquid-free and to measure their level of radioactivity. Compactors would then squash many of the drums to one-seventh their original size. All the wastes would be placed in concrete monoliths and then buried in huge graves. Several regional compacts in the United States, along with utilities in Japan, Spain, South Korea, and the United Kingdom, have expressed interest in adopting the technology.[45]

All the contaminated and activated components of a reactor require special handling and disposal, but a small percentage of the wastes are considered too radioactive to be classified as low-level. Transuranic wastes, those containing elements heavier than uranium, are all formed as activation products. They have long half-lives and require isolation from the biological environment for many thousands of years. Until recently, transuranics were disposed of the same way as low-level wastes. They are now stored at reactor and reprocessing sites and commonly referred to as "orphan wastes." Their long half-lives make them too dangerous for shallow land burial, but governments have been reluctant to assume responsibility for them as part of national high-level waste programs. Eventually, they will probably be disposed of in geologic repositories.[46]

Plans for developing new low-level waste sites do not address the need to provide adequate capacity for decommissioning wastes. Regulations do not specify a minimum size and it appears that the second generation of disposal sites may only be large enough to accept annual operating wastes. If this occurs, decommissioning activities may be hindered by the lack of both high- and low-level waste disposal facilities.

"Decommissioning policy is held hostage to the lack of disposal sites."

Most nations that have decided to use nuclear power have shirked the responsibility of safely managing radioactive wastes. In 1981, the Atomic Industrial Forum, an industry trade group, observed that "Because of the present waste disposal problem, it may not be possible to conduct a total decommissioning today. Therefore, the options a utility can choose at the present time are mothballing or entombment with onsite storage of all active material."[47] That statement is still true today. Decommissioning policy is held hostage to the lack of disposal sites

Estimating the Costs

The cost of decommissioning nuclear power reactors is highly speculative. Cost estimates have been derived from generic studies, from scaling up the costs of decommissioning smaller research facilities, from calculations based on a fixed percentage of construction costs and more recently from site-specific engineering studies. The detail and sophistication employed in developing these estimates varies greatly and their lack of standardization makes comparisons difficult. Moreover, limited decommissioning experience—none with large reactors—makes it impossible to know if the estimates are on target. In effect, all the figures put forward are guesses based on numerous uncertain assumptions and varying degrees of wishful thinking.

In 1978 the U S. Nuclear Regulatory Commission asked the Battelle Pacific Northwest Laboratory to estimate the cost of decommissioning a generic 1,175-megawatt pressurized water reactor (PWR). A Battelle study conducted two years later estimated the cost of decommissioning a boiling water reactor (BWR). These are the two most commonly used nuclear technologies in the world, accounting for 72 percent of all operating reactors—165 PWRs and 77 BWRs. Battelle concluded that costs would depend primarily on the reactor design and the number of years after shutdown that dismantlement would be deferred In general, more plant components become contaminated in boiling water reactors so they require a larger labor force, produce a greater volume of low-level wastes, and consequently are more expensive to decommission For both designs, immediate dismantlement was considered slightly less expensive than storage, in spite of higher initial costs.[48]

The Battelle figures were widely adopted within the utility industry and used as a proxy by many companies that had not developed their own estimates. But the studies were never intended to be used in this way. They were meant to be used as guidelines, and to give utilities and their regulators a ballpark estimate of the decommissioning costs they were likely to encounter. Differences in plant size and design, operating history, future availability of and distance from waste disposal facilities, regional variations in labor rates, and unique site characteristics such as space limitations were largely ignored. As individual utilities began to conduct their own site-specific cost estimates, and as various component costs such as waste disposal rose much faster than anticipated, it became obvious that the initial estimates were too low.

In 1984, Battelle updated its studies, this time for the Electric Power Research Institute, and costs had indeed risen much faster than inflation over the preceding six years. Waste disposal costs rose the fastest. Assumptions were also modified to reflect current regulations and market conditions. For example, when the original PWR analysis was performed, it was assumed that decommissioning workers could be exposed to four times as much radiation during a one-year period as was subsequently deemed safe.[49]

The projected price tag for immediate dismantlement of a 1,175-megawatt PWR, using outside contractors, rose to $104 million and for a 1,155-megawatt BWR to $133 million. Comparative site-specific, rather than generic, estimates for two 1,100-megawatt reactors produced estimates of $140 million for a PWR (35 percent higher than the updated Battelle estimate) and $134 million for a BWR, excluding the costs of removing nonradioactive structures.[50]

Estimates derived from scaling up costs based on the experience at smaller, less contaminated facilities, and from assuming a fixed percentage of construction expenditures are even higher. California regulators have assumed in some studies that decommissioning expenses would be 10 percent of capital investment. A detailed three-year study of decommissioning costs in Switzerland concluded that retiring a nuclear plant would cost one fifth as much as the facility originally cost to build. After evaluating decommissioning experiences at Elk River and a smaller research reactor, Peter Skinner, a state-hired engineer, advised the New York Public Service Commission that decommissioning could potentially cost 24 percent of original construction costs. This translates to more than $500 million for most recently completed U.S. reactors.[51]

André Crégut of the French Atomic Energy Commission believes that utilities will not begin to decommission their reactors until costs can be brought down to 15 percent of the original investment. He estimates that using currently available techniques, the cost of decommissioning would be at least 40 percent of the cost to build.[52]

All of these projections assume normal reactor operating conditions. Economist Duane Chapman at Cornell University has observed that the Three Mile Island plant is so heavily contaminated that dismantlement may exceed the original cost. Although the level of contamination at Three Mile Island is many times higher than will be encountered at most power reactors, cleanup costs there are projected to pass $1 billion before decommissioning itself is contemplated. Chapman has also predicted that dismantlement might cost as much as reactor construction, in constant dollars, at plants where accidents have not occurred. In the United States, this amounts to an average of about $3 billion for a new 1,000-megawatt unit. Chapman expects that as decommissioning cost estimates rise, utilities will forgo immediate dismantlement and instead favor storage or entombment.[53]

Research done at the Rand Corporation reinforces Chapman's skepticism. Analysts there have concluded that large-scale engineering projects based on newly developed technologies cost on average four times more than initial estimates. Recent U.S. nuclear power plant construction costs total 5 to 10 times original projections, even after accounting for inflation.[54]

Because of gross cost overruns, approximately $20 billion worth of partially constructed nuclear plants have been abandoned in the United States. In the early seventies, reactors were expected to come into service at well under $1 million per megawatt. Costs for just-completed units now average closer to $3 million per megawatt, and at the not-yet-operating Shoreham plant on Long Island, the figure has already surpassed $5 million per megawatt.[55] Decommissioning estimates put forward by the nuclear industry presume that as experience is gained, costs will fall over time. But U.S. nuclear construction experience appears to defy the learning curve—costs rose over the years.

Members of the Atomic Industrial Forum have recently completed "Guidelines for Producing Commercial Nuclear Power Plant Decommissioning Cost Estimates." The guidelines attempt to standardize cost estimates and eliminate past deficiencies so estimates can be readily compared and understood by analysts and members of regulatory commissions. According to the authors, Williams and LaGuardia, "It is of equal importance to identify all assumptions used in the estimate. One of the major problems associated with attempting to compare the costs to decommission units estimated by different parties is to account for the different assumptions made. Unless they are clearly identified, no rational comparison can be made." In the past, some estimates included the expense of removing spent fuel, others the cost of demolishing nonradioactive structures, and still others the cost of long-term surveillance and security at a mothballed plant. Some utilities included costs attributable to complying with stricter regulations governing waste disposal and worker exposure limits while others did not. Rarely were the costs, expense categories, or assumptions comparable from one study to another.[56]

Several site-specific cost estimates that rely on the recently developed guidelines are now complete. For BWRs in the 1,100- to 1,200-megawatt range, these studies estimate the cost to remove and dispose of radioactive structures and waste at between $120 and $170 million.[57]

In Japan, a policy advisory group for the Agency of Natural Resources and Energy studied the costs of and optimal schedule for de-

"Financial compensation may be required to entice communities to accept radioactive waste."

commissioning. It concluded that dismantling a 1,100-megawatt plant after five years of storage will cost $160 million.[58]

The major expenses associated with decommissioning are the packaging, transportation, and burial of wastes; labor; energy; demolition; and equipment. In several site-specific cost estimates, waste disposal accounted for 40 percent of the total. In the last decade, the cost of shallow land burial of a 55-gallon drum of low-level wastes has increased more than tenfold in the United States. And, as discussed in the previous section, new low-level burial grounds will be technologically superior to and more strictly regulated than past sites. The unique problems inherent in establishing new facilities—for both high- and low-level wastes—will further raise disposal costs.[59]

Financial compensation may be required to entice communities to accept radioactive wastes. The United Kingdom is seriously reevaluating its disposal-facility siting policies following vehement local opposition to a plan for using an abandoned salt mine at Billingham in northeast England. Lewis Roberts, director of the Atomic Energy Research Establishment at Harwell, recently acknowledged that the agency may have to adopt the French and Japanese practice of compensating communities for hosting repositories.[60]

Reactor dismantlement is a labor-intensive process. A survey of 21 cost estimates, for both pressurized and boiling water reactors, found that labor expenses were forecast to contribute from between 25 and 50 percent of total costs. Following two years of planning and preparation prior to shutdown, disassembling a large PWR is expected to require more than 300 worker-years. Additional workers will be required to decontaminate and dismantle the cooling systems in boiling water reactors. Permissible radiation exposure levels have become progressively stricter over the years and may continue to tighten in the future because the health effects of long-term exposure to low levels of radiation are still debated by medical professionals. Replacement of steam generators at the Surry reactor in Virginia required more than three times as many worker-hours as anticipated in order to keep down exposure levels.[61]

Decommissioning cost estimates for two of the reactors that will b among the first to be decommissioned amount to more than $1 mi lion per megawatt. (See Table 4.) The Shippingport facility, despite i unique transportation arrangement and federally subsidized wast disposal, is expected to cost $98 million to decommission—$1.36 mi lion per megawatt. This figure excludes the cost of dismantling nor contaminated buildings. Shippingport is also considerably les contaminated than larger reactors will be, not only because it is small

Table 4: Estimated Decommissioning Costs for Nuclear Power Plants No Longer in Operation

Owner/Site	Capacity (megawatts)	Estimated Decommissioning Costs (millions of 1985 dollars)	Cost Per Megawatt	Years Operate
U.S Atomic Energy Commission, Elk River	22	14[1]	0.58	1964-6
U.K. Atomic Energy Authority, Windscale	33	64	1.94	1962-81
Pacific Gas and Electric, Humboldt Bay-Unit 3	65	55	0.85	1963-7
U.S. Department of Energy, Shippingport	72	98	1.36	1957-8
Commonwealth Edison Co., Dresden-1	210	95	0.45	1960-7

[1]Decommissioning of Elk River was completed in 1974

Sources. R Mark Pocta, "Report on the Decommissioning Costs of Pacific, Gas an Electric Company for Humboldt Bay Power Plant Unit No. 3," Californi Public Utilities Commission, June 1985, OECD Nuclear Energy Agency "Compendium on Decommissioning Activities in NEA Member Countries, Paris, January 1985, "DOE Says Decommissioning Costs on Target Despit Shippingport Increase," *Nucleonics Week*, April 25, 1985, Public Citizen Environmental Action, "Dismantling the Myths About Nuclear De commissioning," Washington, D C , April 1985

"Because of the variety of reactor types in operation, decommissioning costs and experience may not be transferable among utilities."

but because it has already been thoroughly decontaminated once during its operating life and has had several reactor cores.[62]

Although members of the nuclear industry expect that economies of scale will make decommissioning larger reactors proportionally cheaper, the amount of radiation that builds up in a plant, especially that contributed by long-lived radioisotopes, depends on the power output of the reactor multiplied by the number of years it operates. The larger the plant, the greater the cleanup and disposal effort it will require.

Because reactor designs have changed so much over the years, very few countries will be able to develop specific decommissioning plans applicable to more than several reactors. Not only have different countries adopted different reactor technologies, but within some nations the nuclear industry has dabbled in most of the systems available. France, Canada, and perhaps the Soviet Union are the only major nuclear countries that have achieved a high degree of uniformity in their construction programs. These nations also commonly build four to eight reactors at each plant, a strategy that should help to hold down decommissioning costs. The United States and Japan typically build only two to three reactors at one site. The 17 shutdown power reactors listed in Table 5 represent eight different designs. Nuclear construction costs steadily rose in the United States in part because each utility built a custom-designed plant. Because of the variety of reactor types in operation, decommissioning costs and experience may not be transferable among utilities.[63]

There are vast uncertainties associated with trying to estimate costs 30 to 100 years in the future. Assumptions must be made about the evolution of technologies and the likely increase in decommissioning costs, inflation, and real interest rates. Estimates must also include provisions for stricter government regulations and other unforeseeable events. The staff most familiar with the plant will have left the company and excellent recordkeeping will be required to inform the future crew of the reactor's intricacies and its operating history. The longer dismantlement is deferred, the greater the margin

Table 5: Nuclear Power Reactors Awaiting or Undergoing Decommissioning, 1985

Reactor	Location	Year Plant Entered Service	Number of Years Plant Operated	Capacity (megawatts)	Reactor Type[1]
Shippingport	Pennsylvania	1957	25	72	PWR
G-2, Marcoule	France	1958	22	45	GCR
G-3, Marcoule	France	1959	24	45	GCR
Dresden-1	Illinois	1960	18	210	BWR
Indian Point-1	New York	1962	12	257	PWR
Windscale	United Kingdom	1962	19	33	AGR
Chinon-A1	France	1963	10	70	GCR
Humboldt Bay	California	1963	13	65	BWR
Garigliano	Italy	1964	14	160	BWR
Karlsruhe	West Germany	1965	19	58	PWR
Gundremmingen	West Germany	1966	11	250	BWR
Peach Bottom	Pennsylvania	1967	7	40	HTGR
Douglas Point	Canada	1968	16	206	CANDU
Lingen	West Germany	1968	9	256	BWR
Gentilly-1	Canada	1970	9	250	HWBWR
NPP-A1	Czechoslovakia	1972	7	110	HWGCR
Niederaichbach	West Germany	1972	2	100	HWGCR

[1]Reactor types listed in order they appear in table Pressurized Water, Gas Cooled; Boiling Water, Advanced Gas, High Temperature Gas Cooled, Graphite Moderated; Heavy Water Moderated PWR (CANDU) Heavy Water Moderated BWR; and Heavy Water Moderated GCR

Sources: OECD Nuclear Energy Agency, "Compendium on Decommissioning Activities in NEA Member Countries," Paris, January 1985, International Atomic Energy Agency, "The Methodology and Technology of Decommissioning Nuclear Facilities" (draft), Annex 2, Vienna, May 1985; "Decommissioning: Survey of Power Reactor Projects," *Nuclear Engineering International*, August 1985

of error and the higher the total costs are likely to be. Only seven of the reactors listed in Table 5 are scheduled to be dismantled prior to 1995.[64]

"Although hundreds of nuclear power reactors have been erected around the world, projecting the cost of decommissioning them is still fraught with uncertainties."

André Crégut of the French Atomic Energy Commission asserts that utilities will not proceed with decommissioning until they are more certain of the costs. He thinks present estimates are still so rough that actual costs could easily be at least 40 percent greater than expected.[65]

New regulatory requirements increased reactor construction costs, and it is logical to assume that actual decommissioning costs will also exceed estimates. As experience is gained in decontamination, dismantlement, waste handling, and disposal, inadequacies in existing regulations will emerge. Rules would then become more stringent. The biggest regulatory gaps at present are the lack of criteria for classifying wastes as either radioactive or nonradioactive, the uncertainties regarding the method of transuranic waste disposal, and the absence of "residual radioactivity" standards. Without these guidelines, utilities do not know exactly how much of their wastes will require special disposal and how clean they will have to leave the plant site. If the final rules are stricter than utilities anticipate, cost estimates could rise substantially.[66]

Although hundreds of nuclear power reactors have been erected around the world, projecting the cost of decommissioning them is still fraught with uncertainties. The bill for all the plants now in service could total several tens or several hundreds of billion dollars. No one can now say with confidence which estimate is correct. Only by using state-of-the-art technology to immediately dismantle some of the reactors being taken out of service will the industry be able to ascertain what future decommissioning costs might be.

Saving for the Burial

To ensure that adequate funds will be available, utilities should start setting aside money early in a reactor's life. If money is not collected from ratepayers during the years the plant produces power, the bill will be charged to future customers or taxpayers who did not use the electricity. In the event that regulators forbid the collection of decommissioning funds from customers who did not use the nuclear power, the expense might bankrupt utilities or result in decommissioning shortcuts that could endanger future generations.

A variety of savings mechanisms have been proposed and, like an insurance policy, the plans providing the greatest assurance tend to be the most expensive. One way to guarantee that funds will be available in the future is to deposit all of the needed money in an interest-bearing savings account before the reactor enters service. Interest income will increase the yearly balance of the account and if the initial cost estimate is correct, or if additional deposits are made when estimates are revised, sufficient funds will be available. This strategy is the most expensive and requires utility customers to pay up front for an expense the company will not incur for several decades.[67]

Making periodic deposits into a decommissioning fund is another way to accrue the money. Customers can be charged a fee, based on the amount of electricity they use, that is collected monthly and credited to a decommissioning account. Utilities prefer to place the account on the books but fold the money into the general revenues used to pay all of the company's expenses, including the construction costs of new nuclear plants. This strategy allows the utility to forgo borrowing and keep debt payments low, but the method has been termed "phantom funding" by some observers because the money will be tied up in assets instead of being readily available to the utility when a reactor is retired.[68]

When the time comes to decontaminate and dismantle the plant, a utility with an unsegregated account will probably need to raise cash by selling "decommissioning bonds." Borrowing capital for decommissioning promises to be expensive because investors will require a high return to cover the perceived risks. If large cost overruns are anticipated or if the utility is small with few income-generating assets, investors may shy away from funding plant dismantlement. The market value of the stocks and bonds of several U.S. utilities with heavy nuclear commitments is already less than 50 percent of book value, reflecting lack of investor confidence.[69]

If even high rates of return are not attractive to potential bond purchasers, the federal government or pools of electric utilities ultimately may have to assume the risk. The $2.25-billion bond default by the Washington Public Power Supply System in 1983 has made investors especially wary of publicly owned nuclear projects. Without government commitments to insure the bonds, municipal and cooperative utilities will be particularly vulnerable because they are wholly financed by tax-exempt bonds: There is no equity cushion provided by private shareholders.[70]

If, on the other hand, money is provided by deposits begun when the plant enters service, if the account is managed by professional investors, and if the fund is allowed to grow until it is needed. the utility's financial situation will not be so precarious at plant retirement. Periodic evaluations of reliable decommissioning cost estimates and corresponding adjustments to customer rates will diminish future risks. Swedish utilities revise their decommissioning surcharges annually.[71]

In a study conducted for the NRC, University of Pennsylvania economist J.J. Siegel concluded that if an outside professionally managed fund were established, " . . . it would be virtually impossible for the utility to divert these assets for other uses and funds would be assured no matter what events, legal or financial, occur.' He ranked internal funding with no segregated account last in terms of assurance.[72]

Even dedicated decommissioning accounts would be inadequate, however, if a plant closes earlier than expected. If this were to occur, particularly as the result of a costly accident, the utility would find itself with insufficient funds. An insurance policy to protect against premature closure is a frequently proposed remedy, and a sound strategy, if there are companies willing to provide such coverage.

Premature closure policies are not yet available, and insurance companies are unlikely to offer them at affordable rates unless the nuclear industry's operational record improves. Of the reactors that are currently retired and awaiting decommissioning, none operated for a full

30 years, the lower bound used in utility calculations. Nuclear plant are more complex than other electric-generating technologies, ar subject to more design regulations, and have up to ten times as man pipes, valves, and pumps.[73] More parts and a harsher operatin environment enhance the potential for breakdowns. Ten of the 1 shutdown reactors listed in Table 5 produced power for less than 1 years.

The least secure funding method postpones collection until de commissioning has begun. Under this strategy, utilities put off unti the last possible moment the acquisition of debt that could tota billions of dollars. There is no assurance that the money will b available. Such last-ditch efforts are also unfair to utility customers i they are charged for decommissioning a reactor from which they di not receive power.

In countries where the electric-genera. system is governmen owned, such as France, the "when-needed" principle of funding ha frequently been adopted. Utility managers assume that the nation or provincial treasury will dole out enough money at the right time t cover the expense of decommissioning. The burden is placed square ly on the shoulders of future taxpayers. The French utility debt is no $30 billion because of the accelerated nuclear construction program and decommissioning costs may significantly increase already larg government budget deficits. Third World governments, many on th edge of insolvency, will be particularly hard-pressed to pay the de commissioning bill for their 23 operating reactors.[74]

Of the four retired commercial reactors in the United States, only on unit had begun to build a decommissioning fund before it shut dow The Pacific Gas and Electric Company, owner of the Humboldt Ba reactor, collected $500,000 during the four years prior to plant shu down In 1984, the Critical Mass Energy Project asserted that at leas 11 reactors had gone through one third of their operating lives with out collecting any funds for decommissioning from ratepayers, an that nationwide only $600 million had been collected. This lack c financial planning prompted nine states to require mandator periodic deposits into external accounts: California, Colorado, Main

"Of the four retired commercial reactors in the United States, only one unit had begun to build a decommissioning fund before it shut down."

Massachusetts, Mississippi, New Hampshire, Pennsylvania, Vermont, and Wisconsin. Only one state, Michigan, does not allow the recovery of decommissioning costs in current rates.[75]

Swedish utilities pay an annual decommissioning fee to the federal government. A separate account has been established for each reactor and utilities may borrow from it when their plants are retired. Less formal funding arrangements exist in West Germany and Switzerland.[76]

Decisions about which decommissioning funding strategy to adopt have been postponed for too long. By the end of 1984, the United States had 84 operable power reactors, more than one quarter of the world total. The Soviet Union with 44 was a distant second. (See Table 6.) Yet despite the large number of plants in operation, most utilities are financially unprepared for decommissioning. A 1985 survey of 30 U.S. nuclear utilities revealed that 12 had not conducted site-specific studies of decommissioning costs, 20 were using the funds they had collected for other purposes, and 8 did not expect their current funding method to adequately cover decommissioning expenses.[77]

If instead of the haphazard funding approach now in place, all of a utility's customers made monthly contributions over a 30-year period, decommissioning might be affordable. The average residential electricity consumer in the United States, if served by an all-nuclear electric utility that assumed decommissioning costs of from $200 million to $1 billion for each 1,000-megawatt reactor, would have paid some 5 to 25 percent more for electricity last year. Customers with inefficient electric-heating and air-conditioning systems would have paid more, but those using electricity efficiently would have paid far less. Actual increases would have been considerably lower because no U S. electric utility relies exclusively on nuclear power.[78]

Commonwealth Edison, an Illinois utility, owns the most nuclear plants in the United States. Its nine operating reactors provide 55 percent of the company's generating capacity, and three more units are under construction. Thus an average residential customer of the

Table 6: Nuclear Power Reactors in Operation, Ten Leading Countries, 1984

Country	Number of Reactors	Total Nuclear Capacity	Share of Total Domestic Capacity	Share of World Nuclear Capacity
		(megawatts)	(percent)	
United States	84	68,536	13	33
Soviet Union[1]	44	22,706	8	11
France	36	28,015	39	14
United Kingdom	32	6,569	10	3
Japan	28	19,025	12	9
West Germany	19	16,127	18	8
Canada	15	8,617	9	4
Sweden	10	7,355	24	4
Spain	7	4,865	12	2
Belgium	6	3,467	28	2
Total	281	185,282		89

[1]Data are for 1983

Sources: Atomic Industrial Forum (AIF), "International Survey," Bethesda, Md., Apri 17, 1985, AIF, "Midyear Report," Bethesda, Md , July 10, 1985, Eric Sorenson International Energy Agency, Paris, private communication, November 8 1985

utility would have paid from $20 to $100 in decommissioning charge in 1985. Again, this assumes a decommissioning cost of from $20 million to $1 billion per 1,000-megawatt reactor. This charge, from 3 to 14 percent of the average annual household electric bill, may be acceptable in affluent societies if fee collection is started when the plant enters service and if the reactor operates for a full 30 years. In practice, actual payments will undoubtedly be higher because few plants now in service will have collected money throughout thei operating lives.[79]

"Regardless of a nation's future energy plans, existing plants must eventually be scrapped."

Although many nations have not set aside money explicitly for decommissioning, funds for high-level waste disposal are collected in a dozen North American and European countries. In all cases, the money is paid to the government agency responsible for establishing geologic waste repositories. The fee typically ranges from $1 to $6 per 1,000 kilowatt-hours of nuclear electricity produced. The average residential electricity customer in the United States uses some 9,000 kilowatt-hours annually, and only a fraction is produced by nuclear plants.[80]

Setting aside funds for decommissioning is essential in every country that uses nuclear power. Regardless of a nation's future energy plans, existing plants must eventually be scrapped. Decommissioning bills will first fall due in the Soviet Union, the United Kingdom, and the United States—those countries that pioneered the development of nuclear power. Neither nations nor utilities are financially prepared to absorb the projected costs, much less overruns, and their skill at managing the expense will be closely watched. Nations with newer reactors may learn sobering lessons, and countries that have not yet built such plants may have misgivings about doing so when they are better able to assess the true lifetime costs of nuclear energy.

A Long-Term Strategy

Just as today's cities would not be habitable without large fleets of garbage trucks and extensive landfills, the international nuclear industry is not viable without a sound decommissioning strategy. More than 30 years after the first nuclear plant started producing electricity, such a strategy has yet to be formulated. Even if reactor ordering ground to a halt tomorrow, more than 500 reactors, including those currently under construction, will have to be decommissioned. Safely retiring these plants will require new technologies and a plan for disposing of the mountains of radioactive waste that are being created. Aggressive, well-funded research and development programs could pave the way.

Unfortunately, decommissioning planning has lagged far behind reactor development. The International Atomic Energy Agency (United Nations watchdog and research arm) did not hold its first meeting on decommissioning until 1973, some 19 years after the first power reactor was built. The initial technical meeting sponsored by the agency was not convened until two years later. Yet by that time hundreds of nuclear power plants were being planned by dozens of governments and utility companies.

Both national and international atomic energy agencies continue to neglect decommissioning. In the past, research and development money was lavished on fuel reprocessing and breeder reactors. The United States has now abandoned these projects and is redirecting the funds to military and space applications. Since 1978, more nuclear reactors have been cancelled worldwide than have been ordered. Industry emphasis is on creating new business, not demolishing old reactors. Research and development for decommissioning is not even included as a category in detailed DOE and NRC budgets.[81]

The Nuclear Energy Agency, a body of the OECD, encourages the exchange of information, materials, and personnel among member countries, but offers no financial assistance. And the much touted decommissioning research program of the European Communities is authorized to spend only $11 million during the five-year period that began in January 1984. In constant dollars, the total five-year budget is less than it cost to build one small demonstration reactor 20 years ago.[82]

The biggest stumbling block for all nations with nuclear plants is the lack of permanent disposal facilities for radioactive wastes. Although many reactor operators agree that plants should be dismantled as quickly as possible after shutdown, that option has been foreclosed until at least the turn of the century. In countries like Japan, where land for any type of power plant is scarce, unproductive use of real estate is expensive.

No country currently has the capability to permanently dispose of the high-level wastes now stored at a single reactor. And the already daunting task of managing low-level operating wastes is only the tip of the iceberg. As reporters Donald Barlett and James Steele have observed, "If the politicians and scientists in charge of nuclear waste had been running the space program, John Glenn [the first U.S. astronaut] would still be orbiting the earth today." And, if nuclear plant construction estimates made in the seventies had come to pass, lack of adequate waste sites might have crippled the industry. In 1970, the OECD projected that its member nations in Western Europe, North America, and Japan would have 563,000 megawatts of nuclear capacity by 1985, more than double the amount now in operation.[80] Slower-than-anticipated ordering and rapidly increasing construction and operating costs thwarted many nations' nuclear programs even before the complicated issues of decommissioning and waste disposal came to the fore.

But in some areas, including France, Japan, and northeastern North America, the use of nuclear power may have already expanded too rapidly. Each area has a relatively dense concentration of nuclear plants, but no detailed plan to decommission them. Given the limitations of current knowledge, those nations still committed to building more reactors—namely France, Japan, and the Soviet Union—might be wise to reconsider their construction programs. The full economic and social costs of using nuclear power will not be known until the many uncertainties associated with decommissioning are eliminated. Multibillion-dollar construction decisions made today will be based on incomplete information.

Without detailed regulations and technical guidelines, and the availability of disposal sites, utilities cannot plan intelligently for the future. Some utilities started reactor construction with designs only 20 percent complete and discovered that because of regulatory changes they were not even that far along. The consequences of inadequate planning for decommissioning would be not only costly but dangerous. If rules defining which wastes require special treatment or what constitutes a clean site are not issued until decommissioning is under way, utilities may find themselves short of funds. Financially troubled utilities might even declare bankruptcy and abandon the plant.

Many orphaned hazardous waste sites were previously owned now defunct companies.

Early knowledge of decommissioning requirements would also all engineers to incorporate design changes that would facilitate la decontamination and dismantlement efforts. A simple concept t was not considered by the manufacturers of the first nuclear pla was the value of putting a protective coating on all surfaces t would be exposed to radiation. Even a thick layer of removable pa reduces the surface contamination of structural components and th the volume of low-level wastes. Limited experience with neutr activated wastes indicates that their quantities can also be diminish by regulating the amount of neutron-absorbing impurities used reactor steel and concrete. Several countries now require utilities submit decommissioning proposals at the design stage. But hindsi will only benefit the trickle of reactor orders yet to come, not hundreds of units in operation.[84]

A look at the decommissioning funding mechanisms in place in v ous countries indicates that we expect our children to pay our elect ity bills. Without savings programs that equitably share decomm sioning costs and assure that funds will be available when need today's electricity customers are getting a free ride. The longer fu collection is deferred, the greater annual payments will have to be order to accumulate enough money. Only by periodically updat site-specific cost estimates, instead of relying on generic studies hypothetical power plants, can utilities hope to build sufficient s ings. Waiving tax liabilities on the money deposited in trust fu and the interest earned on that money could also hasten the grow of decommissioning accounts.[85]

Because many plants operated for years without collecting money decommissioning, electricity customers and taxpayers will suffer "aftershock" of paying for retired reactors. The less money set as while the plant produces power, and the more actual decommissi ing costs diverge from estimates, the greater the aftershock will b experience would shed light on the reasonableness of the theories and assumptions now used for planning purposes. The plant owners could cover half the costs with governments and research institutes from around the world contributing the rest. Logical coordinating bodies would be the International Atomic Energy Agency in Geneva or the Nuclear Energy Agency in Paris. A similar, ad hoc arrangement is in effect at the damaged Three Mile Island unit, with U.S. utilities, the U.S. Department of Energy, and various international participants contributing money in order to learn firsthand about the most advanced decontamination and dismantlement techniques.

Taking full advantage of the learning experience offered by the reactors now coming out of service is sometimes viewed as a needless expense. But saving millions of dollars today could result in spending billions of extra dollars tomorrow.

"Because many plants operated for years without collecting money for decommissioning, electricity customers and taxpayers will suffer the 'aftershock' of paying for retired reactors."

the next three decades, more than 350 power reactors will be out of service. Immediately dismantling some of the largest or most problematic reactors as part of an international test case would yield valuable lessons for future decommissioning projects. Firsthand

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