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Radiation,
reliability,
reprocessing—
and redundancy.

Second of Two Parts

by Karen Charman

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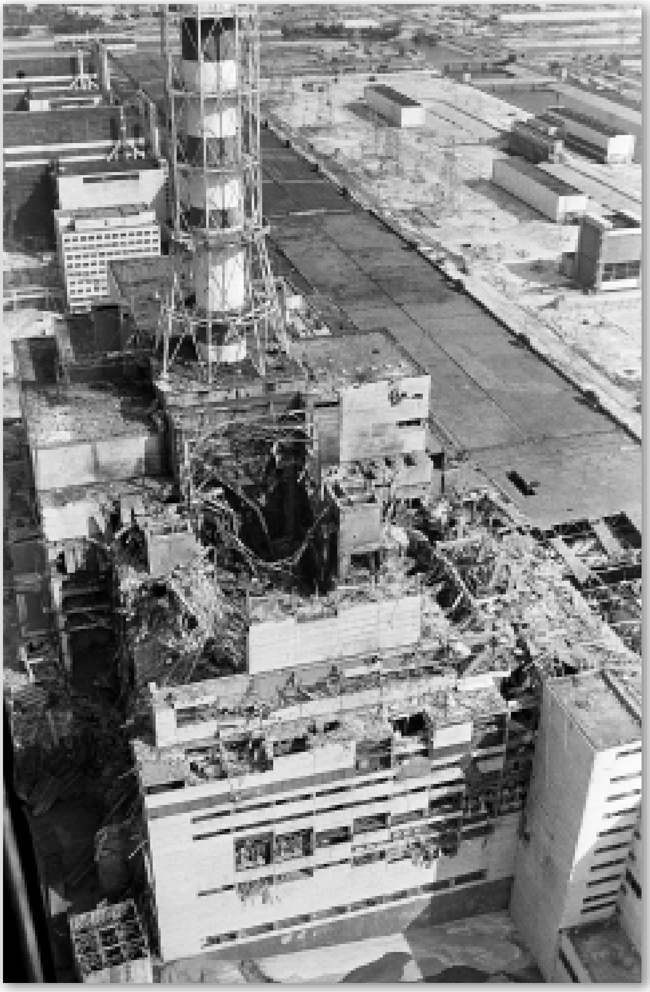
This year marks the 20th anniversary of the world's most notorious nuclear disaster. At 1:23 a.m. on April 26, 1986, the Number Four reactor at the Chornobyl* nuclear plant in northern Ukraine exploded and burned uncontrolled for 10 days, releasing over 100 times more radiation into the atmosphere than the Hiroshima and Nagasaki bombs combined. At least 19 million hectares were heavily contaminated in Belarus, Ukraine, and Russia. Prevailing winds and rain sent radioactive fallout over much of Europe, and it was measured as far away as Alaska. Approximately 7 million people lived in the contaminated zones in the former Soviet Union at the time of the accident (over 5 million still do). More than 350,000 were evacuated, and 2,000 villages were demolished. Radioactive foodstuffs from Belarus and Ukraine continue to show up in the markets of Moscow, and farmers on 375 properties in Wales, Scotland, and England still must grapple with restrictions due to radioactive contamination from Chornobyl.

The operating crew and the 600 men in the plant's fire service who first responded to the disaster received the highest doses of radiation, between 0.7 and 13 Sieverts (Sv). According to chernobyl.info, a United Nations Internet-based information clearinghouse, this is 700 to 13,000 times more radiation in just a few hours than the maximum dose of 1 millisievert that the European Union says people living near a nuclear power plant should be exposed to in one year. Thirty-one of those first on the scene died within three months. A total of 800,000 "liquidators"—mainly military conscripts from all over the former Soviet Union—were involved in the clean-up until 1989, and government agencies in Belarus, Ukraine, and Russia have reported that 25,000 have since died.

By any measure, Chornobyl was a horrific catastrophe and has become the icon of nuclear power's satanic side. Yet controversy has dogged the environmental and health impacts of Chornobyl from the beginning. The Soviet leadership first hoped nobody would notice the accident and then did their best to conceal and minimize the damage. As a result, a full and accurate assessment of the consequences has proved impossible. Historian and Chornobyl expert David Marples wrote that authorities in the former Soviet Union classified all medical information related to the accident while denying that illnesses among cleanup workers resulted from their radiation exposure. Independent researchers have had difficulty locating significant numbers of evacuees and those who worked on the cleanup, and they have had to piece together their conclusions from interviews with medical providers, citizens, officials in the contaminated areas, others involved, and those cleanup workers they could find.

In September 2005, a report on the health impacts of Chornobyl by the UN Chernobyl Forum (seven UN agencies plus the World Bank and officials from Belarus, Ukraine, and Russia) said only 50 deaths could be attributed to Chornobyl and ultimately 4,000 will die as a result of the accident. The Chernobyl Forum report acknowledges that nine children died from thyroid cancer and that 4,000 children contracted the disease, but puts the survival rate at 99 percent. It denies any link with fertility problems and says that the most sig-

* In this article we use the Ukrainian spelling of "Chornobyl." The word may appear as "Chernobyl" in the formal names of organizations.



Vladimir Repik/REUTERS

Aerial view of Chornobyl's Number Four reactor days after it exploded.

nificant health problems are due to poverty, lifestyle (e.g., smoking, poor diet), and emotional problems, especially among evacuees. Marples notes that the overall assessment of the Chernobyl Forum is "a reassuring message."

The reality on the ground offers a different picture. In Gomel, a city of 700,000 in Belarus less than 80 kilometers from the destroyed reactor and one of the most severely contaminated areas, the documentary film *Chernobyl Heart* reports the incidence of thyroid cancer is 10,000 times higher than before the accident and by 1990 had increased 30-fold throughout Belarus, which received most of the radioactive fallout. Chernobyl.info states that congenital birth defects in Gomel have jumped 250 percent since the accident, and infant mortality is 300 percent higher than in the rest of Europe. A doctor interviewed in *Chernobyl Heart* says just 15 to 20 percent of the babies born at the Gomel Maternity Hospital are healthy. Chernobyl Children's Project International executive director Adi Roche says it's impossible to prove that Chornobyl caused the problems: "All we can say is the defects are increasing, the illnesses are increasing, the genetic damage is increasing." Referring to a facility for abandoned children, she adds, "places like this didn't exist before Chornobyl, so it speaks for itself." Marples, who has made numerous trips to the Chornobyl region over the past 20 years, reports the health crisis in Belarus today is so serious that there are open discussions of a "demographic doomsday."

The long-lived nature of the radionuclides and the fact that they are migrating through the contaminated regions' ecosystems into the groundwater and food chain further complicate the task of predicting the full impact of the disaster. But as the global campaign to build new reactors gains momentum, it bears asking whether a Chornobyl could happen elsewhere.

It Can't Happen Here

Nobody wants any more Chornobyls. The question is, can that outcome be ensured without phasing out nuclear power altogether? The Nuclear Energy Institute (NEI), the trade association and lobbying arm of the American nuclear power industry, says a Chornobyl-type accident is highly unlikely in the United States because of "key differences in U.S. reactor design, regulation, and emergency preparedness." Safety is assured, NEI says, by the strategy of "defense in depth," which relies on a combination of multiple, redundant, independently operating safety systems; physical barriers such as the steel reactor vessel and the typically three- to four-foot steel-reinforced concrete containment dome that would stop radiation from escaping; ongoing preventive and corrective maintenance; ongoing training of technical staff; and extensive government oversight. A key argument for nuclear power these days is the claim that nuclear reactors are safe and reliable.

The U.S. nuclear fleet has substantially increased its "capacity factor" (for a given period, the output of a generating unit as a percentage of total possible output if run at full power) since 1980. However, David Lochbaum, director of the Nuclear Safety Project at the Union of Concerned Scientists (UCS), points out that since the Three Mile Island accident in central Pennsylvania in 1979, 45 reactors (out of 104 operating U.S. units) have been shut down longer than one year to restore safety margins. A nuclear engineer by training, Lochbaum left the industry after 17 years when he and a co-worker were unable to get their employer or the Nuclear Regulatory Commission (NRC) to address safety issues at the Susquehanna plant in northeastern Pennsylvania. (The problem at that plant and others across the country was corrected after they testified before Congress.) For the last 10 years Lochbaum has been at UCS monitoring the safety of the nation's nuclear power plants and raising concerns with the NRC. He does not share the industry's confidence in the safety of the current fleet.

Nuclear power plants are incredibly complex systems that perform a relatively simple task: heating water to create steam that spins a turbine and generates electricity. Lochbaum explains that nuclear plant safety problems tend to follow a bathtub curve: the greatest number come at the beginning of a reactor's life, then after a few years when the plant is "broken in" and staff are familiar with its specific needs, problems drop and level off until the plant begins to age.

Most of the current U.S. fleet is either in or entering its twilight years, and since the late 1990s the NRC has allowed reactors to increase the amount of electricity they generate by up to 20 percent, which exceeds what the plants were designed to handle. Such "power uprates" push greater volumes of cooling water through the plant, causing more wear and tear on pipes and other equipment. The agency has also granted 20-year license extensions to 39 reactors, and most of the rest are expected to apply before their initial 40-year licenses expire. At the same time, Lochbaum says, the NRC is cutting back on the amount and frequency of safety tests and inspections. Tests that were carried out quarterly are now performed annually, and once-annual tests are now done when reactors are shut down for refueling, about every two years.

The NRC maintains that it is providing adequate oversight to keep the public safe and prevent serious reactor accidents. Gary Holahan, an official in the NRC's Office of Nuclear Reactor Regulation, explains that extended power uprates, which raise the power output of a reactor between 7 and 20 percent, require modifications to the plant that involve upgrading or replacing equipment like high pressure turbines, pumps, motors, main generators, and transformers. Before a power uprate is granted, he says, the NRC must make a finding that it complies with federal regulations and that there's "a reasonable assurance" that the health and safety of the public will not be endangered.

Lochbaum says the NRC's handling of the large power uprates illustrates the problems with its oversight. In an issue brief entitled "Snap, Crackle, & Pop: The BWR Power Uprate Experiment," he says the Quad Cities Unit 2 reactor in Illinois "literally began shaking itself apart at the higher power level" after operating for nearly 30 years at its originally licensed power level. After the uprate was approved, the steam dryer developed a 2.7 meter crack, and the component was replaced in May 2005. In early April of this year, he says Quad Cities staff found a 1.5 meter crack in the new steam dryer, and they still don't know exactly what is causing the problem. After the problem was first reported, manufacturer General Electric (GE) surveyed 15 of its other boiling water reactors around the world that had been granted 20-percent power uprates and reported problems—all vibration related—in 13.

Despite objections from the Vermont Public Service Board and one of its own commissioners, the NRC recently granted a 20-percent power uprate to the 33-year-old Vermont Yankee reactor. Stuart Richards, deputy director of the NRC's Division of Inspection, says the commission approved the power uprate after a first-time pilot engineering inspection that included an 11,000-manhour technical review failed to find any significant safety issues. "It's not the age of the plant but the physical condition of the components and how well the facility maintains the plant" that is important, he says. In addition, the power is being increased in NRC-monitored stages. But none of this reassures Lochbaum, who points out that this single-unit plant was badly maintained for much of its operating life, making it an especially poor candidate for a practice known to stress reactors. Applications for extended power uprates at six reactors are pending, and the NRC expects nine more through 2011.

The NRC says it is doing a smarter job of regulating the industry today by pinpointing areas likely to need more attention. "The agency and the industry as a whole over the last 10 to 15 years have developed better and better tools to determine what is risk-significant and what is less risk-significant," Richards explains. "So in some cases where in the past we have required more maintenance or surveillance, now those requirements are less stringent, because the components have been demonstrated to be less significant." In other cases, he says, performing too much maintenance can be detrimental, because the components are needed to do their job, and they can be tested "to the point where it causes them to have degradation."

Lochbaum says the flaw in that logic is well illustrated by a near miss at the Davis-Besse plant in Ohio. In 2002 it was discovered that boric acid escaping from the reactor for several years had eaten a 15-centimeter hole in the reactor vessel's steel lid, leaving a thin layer of stainless steel bulging outward from the pressure. Boric acid had been observed on the vessel head in 1996, 1998, and again in 2000, and NRC staff drafted an order in November 2001 to shut Davis-Besse down for a safety inspection. NRC nevertheless allowed the reactor to continue operating until February 2002, when plant workers almost accidentally found the hole. If the reactor head had burst, the reactor would likely have melted down.

Lochbaum and former NRC commissioner Peter Bradford say the Davis-Besse incident and numerous others indicate that the agency seems to be more interested in the short-term economic interest of the nuclear industry than in carrying out its mission to protect public health and safety. Bradford points to an internal NRC survey in 2002 revealing that nearly half of all NRC employees thought they would be retaliated against if they raised safety concerns, and that of those who did report problems, one-third said they suffered harassment as a result. Several critics say the safety culture of the commission changed after Senator Pete Domenici—perhaps the nuclear industry's biggest champion in Congress—told the NRC chairman in 1998 that he would cut the agency's budget by a third if it didn't reverse its "adversarial attitude" toward the industry.

Given the regulatory environment and an aging fleet of reactors, Lochbaum fears that another serious accident is inevitable. He uses the analogy of a slot machine, but instead of oranges, bananas, and cherries, the winning combination is an initiating event, like a broken pipe or a fire; equipment failure; and human error. "As the plants get older, we're starting to see the wheels come up more often, which suggests it's only a matter of time before all three come up at once," he says.

Nuclear proponents claim the new advanced designs are much safer. Unlike current plants with their multiple back-up systems, the new "passive safety" designs, such as Westinghouse's AP1000 pressurized water reactor (PWR) and GE's ABWR (Advanced Boiling Water Reactor) and ESBWR (Eco-

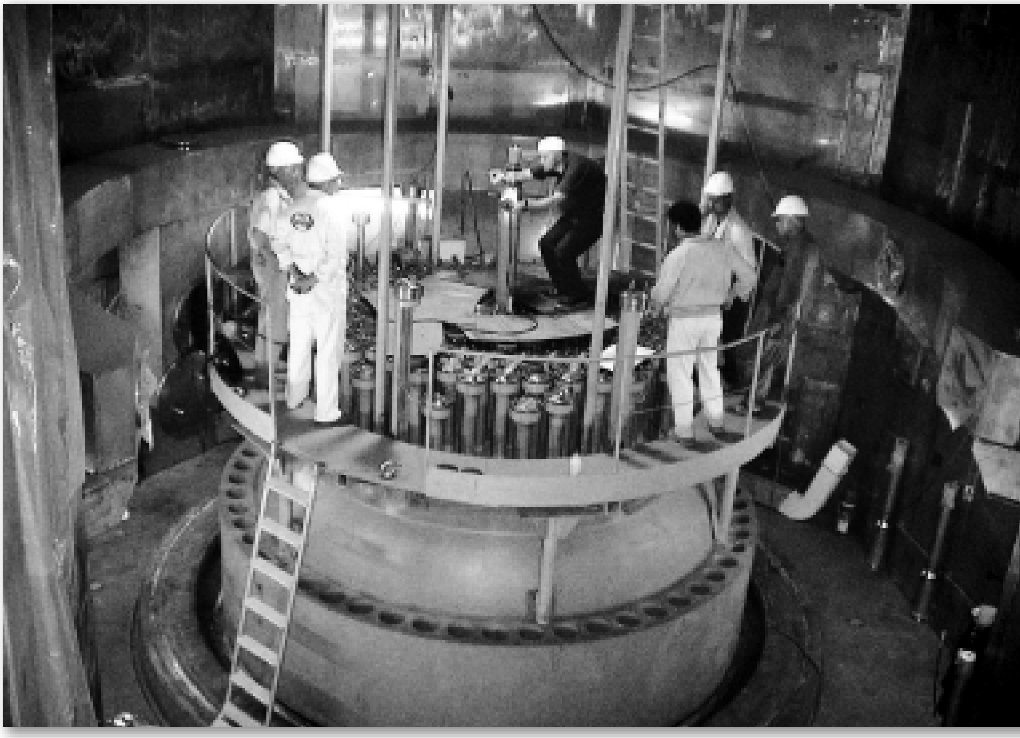


Photo by HO/REUTERS

A 2004 view of Russian workers aiding the construction of the Bushehr nuclear power plant in southern Iran.

nomic Simplified Boiling Water Reactor), rely on gravity rather than an army of pumps to push the water up into the reactor vessel and through the cooling system. Because the systems are smaller, there are fewer components to break.

Physicist Ed Lyman, a colleague of Lochbaum's at UCS who has been studying the new designs, is skeptical of the safety claims of the passive designs. He explains that slashing costs, particularly of piping and the enormously expensive steel-reinforced rebar concrete, motivated the new LWR designs, not safety. It was thought that if the power output of the reactors was lower, a gravity-driven system could dump water into the reactor core without the need for forced circulation and its miles of pipes and accompanying equipment.

Numerous tests of the gravity-driven water system for the AP600, the smaller predecessor to the AP1000, showed the system worked, and NRC certified the design. However, the current trend in reactors is for larger units with higher output. The cost of the AP600 wasn't low enough to offset the loss in generation capacity, so none sold. The AP600 then morphed into the AP1000. GE's new "passive safety" designs followed a similar trajectory beginning with a 600-megawatt design, the SBWR (Simplified Boiling Water Reactor). The company's next design, the ABWR, was 1,350 megawatts, and its ESBWR is 1,560.

The NRC recently certified the AP1000. Lyman is concerned the agency is relying on computer modeling rather than experimental data to demonstrate that gravity-driven cooling will work in these much larger designs. He's also troubled that the containment structures of the new PWRs are less robust than those in the current fleet. NRC's Gary Holahan acknowledges that the agency relied on the tests from the AP600 and computer modeling for the AP1000, but says that after extensive review by the commission's technical staff and the Advisory Committee on Reactor Safeguards, it determined that additional testing was not necessary. Nor does the NRC have any concerns about the thickness of the AP1000's containment dome compared to those of existing PWRs.

Increasing numbers of nuclear proponents and news reports are describing new reactor designs, such as the pebble bed modular reactor, as "accident-proof" or "fail-safe"—so safe, in fact, that the pebble bed doesn't need (or have) a containment structure. Lyman disagrees. The pebble bed is moderated by helium instead of water and uses uranium fuel pellets encased in silicon carbide, ceramic material, and graphite. He says experiments conducted at the AVR demonstration reactor in Germany, the first one ever built, have shown that the models underestimated how hot the pellets could get. The pellets degrade quickly upon reaching the critical temperature, which could lead to a large release of radiation. "So, they just don't have the predictive capacity or the understanding of how these reactors or the fuel technology work to say it's meltdown-proof," he says.

Going to Waste

In the light-water reactors that make up the majority of the world's reactor fleet, uranium fuel is loaded into the reactor, then bombarded by neutrons to trigger the nuclear fission chain reaction. After awhile all of the fissionable material in the uranium fuel is used up, or "spent." But the neutron bombardment makes the fuel two-and-a-half million times more

At the Yucca Mountain Nuclear Waste Site: a worker in a tunnel almost half a mile inside Yucca Mountain, Nevada.

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radioactive, according to Marvin Resnikoff, a nuclear physicist with Radioactive Waste Management Associates in New York. By 2035, American nuclear power plants will have created an estimated 105,000 metric tons of spent fuel that is so deadly it must be completely isolated from the environment for tens or even hundreds of thousands of years. A Nevada state agency report put the toxicity in perspective: even after 10 years out of the reactor, an unshielded spent fuel assembly would emit enough radiation to kill somebody standing a meter away from it in less than three minutes.

No country has yet successfully dealt with its high-level nuclear waste from the first generation of reactors, let alone made plans for the added waste from a vast expansion of nuclear power. Most agree that deep geologic burial is the safest and cheapest disposal method, and countries are in various stages of picking and developing their sites. Steve Frishman of the Nevada Agency for Nuclear Projects thinks the Finns are furthest along, having chosen a permanent repository at a crystalline bedrock site at Olkiluoto that already hosts two operating reactors and one under construction. The site has been tested extensively to ensure it will effectively isolate the waste 420–520 meters down. The repository is expected to open in 2020.

The Swedes also plan to construct their repository in a deep underground granite site, though they have not yet picked the final location. They will encapsulate the spent nuclear fuel in copper canisters surrounded by bentonite clay, which swells up and makes its own watertight seal when exposed to water. Frishman says that's an extra precaution, because while they will probably find some water 500 meters underground where they plan to put the canisters, the water there is not oxygenated and would probably not corrode the canisters even if it did come in contact with them. The Swedish approach is enormously expensive, but they say results, not costs, are guiding their decisions.

These approaches seem reasonably cautious and thus offer some hope that the waste problem—which must be solved no matter what happens to nuclear power—might not be intractable. The U.S. approach, however, is less reassuring. Politics, rather than science-determined suitability, led the U.S. Department of Energy (DOE) to Yucca Mountain, a ridge of volcanic tuff on the edge of the U.S. Nuclear Test Site in the Nevada desert about 145 kilometers northwest of Las Vegas. Nevada was designated by default in an amendment (later tagged as the "Screw Nevada Bill") to the 1982 Nuclear Waste Policy Act that prohibited DOE from considering any sites in granite.

Aside from being located in the third most seismically active region in the country, Yucca Mountain is so porous that after just 50 years isotopes from atmospheric atom bomb tests have already seeped down into the underlying aquifer. But since the mountain was designated as the nation's only repository site, Frishman says DOE has been trying to engineer its way around the problems, and when it can't do that, change the rules. The latest attempt is legislation proposed by the Bush administration that among other things would raise the repository's current legal limit of 70,000 metric tons of high-level waste, remove the nuclear waste fund (money collected over the years from ratepayers by nuclear utilities to build a repository) from federal budgetary oversight, and exempt metals in the underground metal containers from regulation, leaving chromium, molybdenum, and zinc free to contaminate the area's groundwater.

On the basis of the geological instability of the site, Nevada is aggressively fighting the repository. In 2004 a federal court ruled that an Environmental Protection Agency (EPA) health standard that applied for the first 10,000 years was inadequate because the National Academy of Sciences determined that peak doses would likely occur at least 200,000 years after the waste was placed in the site. NRC therefore could not license the site. EPA has since proposed another health standard, which appears to ignore the court ruling by allowing radiation exposure to residents of the nearby Amargossa Valley to jump from a mean of 15 millirems per year for the first 10,000 years to a median value of 350 millirems per year subsequently.

Ultimately, Frishman does not believe Yucca Mountain can meet any real health-based standard. Furthermore, he points out, whatever standard is finally adopted is irrelevant once a licensing decision is made and the waste is placed in the repository: "The site is the standard."

Reprocessing

The nuclear power industry did not expect Nevada's legal challenges to be so successful, and U.S. nuclear proponents have begun to think beyond Yucca Mountain. They maintain that the development of fast breeder reactors, which create nuclear fuel by producing more fissile material than they consume, along with reprocessing the spent fuel (separating out the still-usable plutonium and uranium) will reduce the volume of waste and negate the need for geologic disposal.

Since it was originally assumed that reprocessing would be part of the nuclear fuel cycle, commercial reactors were not designed to house all of the waste they would create during their operational lives. Three commercial reprocessing facilities were built in the United States, though only one, at West Valley in western New York state, ever operated. After six years of troubled operation marked by accidents, mishandling of high-level wastes, and contamination of nearby waterways, it was shut down in 1972. In 1977 the Carter administration banned reprocessing due to concerns about nuclear weapons proliferation after India stunned the world by testing its first atomic bomb, which was made with plutonium from its reprocessing facility. According to UCS, approximately 240 metric tons of separated plutonium—enough for 40,000 nuclear weapons—was in storage worldwide as of the end of 2003. Reprocessing the U.S. spent fuel inventory would add more than 500 metric tons.

France, Britain, Russia, India, and Japan currently reprocess spent fuel, and the Bush administration is pushing to revive reprocessing in the United States. It has allocated $130 million to begin developing an "integrated spent fuel cycle," and recently announced another $250 million, primarily to develop UREX+, a technology said to address proliferation concerns by leaving the separated plutonium too radioactive for potential thieves to handle. In addition, the U.S. Congress has directed the administration to prepare a plan by 2007 to pick a technology to reprocess all of the spent fuel from commercial nuclear reactors and start building an engineering-scale demonstration plant.

UCS's Ed Lyman says it is "a myth" that reprocessing spent nuclear fuel reduces the volume of nuclear waste: "All reprocessing does is take spent fuel that's compact, and it spreads—smears—it out into dozens of different places." Current reprocessing technology uses nitric acid to dissolve the fuel assemblies and separate out plutonium and uranium. But it also leaves behind numerous extremely radioactive fission products as well as high-level liquid waste that is typically solidified in glass. In the process, a lot of radioactive gas is discharged into the environment, and there is additional liquid waste that's too expensive to isolate, he says: "So, that's just dumped into the ocean—that's the practice in France and the U.K."

Matthew Bunn, acting director of Harvard University's Project on Managing the Atom, has laid out a number of additional arguments against reprocessing. First, reprocessing spent fuel doesn't negate the need for or reduce the space required in a permanent repository, because a repository's size is determined by the heat output of the waste, not its volume. Second, reprocessing would substantially increase the cost of managing nuclear waste and wouldn't make sense economically unless uranium topped US$360 per kilogram, a price he says is not likely for several decades, if ever. Third, in this new era of heightened violence and terrorism, the proliferation risks—which would not be addressed by the new reprocessing technologies—take on even greater urgency. Fourth, reprocessing is also a dangerous technology with a track record of terrible accidents, including the world's worst pre-Chornobyl nuclear accident (a 1957 explosion at a reprocessing plant near Khystym in Russia) and other incidents in Russia and Japan as recently as the 1990s. Fifth, the new "advanced" reprocessing technologies, UREX+ and pyroprocessing, are complex, expensive, in their infancy, and unlikely to yield substantial improvements over existing reprocessing methods. Finally, Bunn argues, the Bush administration's rush to embrace reprocessing spent nuclear fuel is premature and unnecessary, since the spent fuel can remain in dry casks at nuclear power plants for decades while better solutions are sought.

Solution in Search of Problem

In the end, the case for nuclear power hinges on an evaluation of its costs and benefits compared with those of the alternatives. Many observers expect a growing ecological, social, and economic crisis unless we figure out how to retard and ultimately reverse climate change by weaning ourselves off increasingly scarce, expensive, and conflict-ridden fossil fuels. Nuclear power, until recently a pariah due to its enormous cost and demonstrated potential for serious accidents, is now touted as an indispensable solution. Nuclear power's dark side—its environmental legacy, high cost, and danger of accidents and the spread of atomic weapons—is currently downplayed. No energy system is without costs, but alternatives that avoid these particularly grave drawbacks do exist.

Space limitations preclude a comprehensive review of the alternatives, but their prospects have never been brighter. For instance, a 2005 report by the New Economics Foundation (NEF) says a broad mix of renewable energy sources that includes micro, small-, medium- and large-scale technologies applied flexibly could "more than meet all our needs." Besides solar and wind power, the mix includes tidal, wave, small-scale hydro, geothermal, biomass, and landfill gas. Rather than relying exclusively on large baseload suppliers of electricity like nuclear plants, or single sources of renewable energy that are not always available, the foundation says the key is setting up an extensive, diverse, and decentralized network of power sources, which would also be much less susceptible to widespread power outages. The total capital cost of setting up such a system has not been calculated and would vary greatly depending on whether it was implemented all at once or incrementally, building on transition technologies. According to the NEF report, a nuclear-generated kilowatthour of electricity—factoring in construction and operating costs but not waste management, insurance against accidents, or preventing nuclear weapons proliferation—costs up to 15.6 U.S. cents, significantly higher than other sources.

Governments and markets are beginning to recognize the potential of renewable energy and its use is growing rapidly. According to Worldwatch Institute's *Renewables 2005*, global investment in renewable energy in 2004 was about US$30 billion. The report points out that renewable sources generated 20 percent of the amount of electricity produced by the world's 443 operating nuclear reactors in 2004. Renewables now account for 20–25 percent of global power sector investment, and the Organisation for Economic Co-operation and Development predicts that over the next 30 years one-third of the investment in new power sources in OECD countries will be for renewable energy.

Alternative energy guru Amory Lovins says the investment in alternatives is currently "an order of magnitude" greater than that now being spent on building new nuclear plants. Lovins has been preaching lower-cost alternatives, including energy conservation, for more than three decades, and the realization of his vision of sustainable, renewable energy is perhaps closer than ever. He argues that the current moves to re-embrace nuclear power are a huge step backwards, and that contrary to claims that we need to consider all options to deal with global warming, nuclear power would actually hinder the effort because of the high cost and the long time it would take to get enough carbon-displacing nuclear plants up and running. "In practice, keeping nuclear power alive means diverting private and public investment from the cheaper market winners—cogeneration, renewables, and efficiency—to the costly market loser. Its higher cost than competitors, per unit of net CO_2 displaced, means that every dollar invested in nuclear expansion will *worsen* climate change," he writes in his 2005 paper "Nuclear Power: Economics and Climate-Protection Potential."


Daniel Joubert/REUTERS © 2006

A container of vitrified nuclear waste being loaded on a cargo ship for shipment from Cherbourg, France, to Japan. Spent fuel from Japanese nuclear power plants is reprocessed in France and then returned to Japan.

As noted in Part One of this series [*World Watch*, May/June 2006], doubling the world's current nuclear energy output would reduce global carbon emissions by just one-seventh of the amount required to avoid the worst impacts of global warming. Researchers at the Massachusetts Institute of Technology point out that achieving even this inadequate result would require siting a permanent repository the size of Yucca Mountain every three to four years to deal with the additional waste—an enormous and expensive challenge. Given nuclear power's drawbacks, and the growth and promise of clean, lower cost, less dangerous alternatives, the case for nuclear power wobbles badly. Stripped of the pretext that nuclear power is the answer to climate change, the case essentially collapses.

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For more information about issues raised in this story, visit **www.worldwatch.org/ww/nuclear**.