

POSITION PAPER: COMMERCIAL NUCLEAR POWER

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ABOUT NRDC

NRDC (Natural Resources Defense Council) is a national, nonprofit organization of scientists, lawyers and environmental specialists dedicated to protecting public health and the environment. Founded in 1970, NRDC has more than 1 million members and e-activists nationwide, served from offices in New York, Washington, Los Angeles and San Francisco. For more information, visit www.nrdc.org.

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EXECUTIVE SUMMARY

Because of the sheer magnitude and urgency of the global climate challenge, the United States must consider all forms of energy—as long as they do not otherwise undermine international and environmental security. Unfortunately, the nuclear power industry in its present state suffers from too many security, safety, and environmental exposure problems and excessive costs to qualify as a leading means to combat global warming pollution.

Large-scale nuclear plants remain uneconomic to build. And while the nuclear fuel cycle emits little global warming pollution, nuclear power still poses globally significant risks that need to be further reduced, including:

- Diversion of “peaceful” nuclear facilities and materials to secret nuclear weapons programs;
- Theft and terrorist use of nuclear materials;
- Accidental releases of radioactivity, ranging from locally harmful to potentially catastrophic;
- The vulnerability of some spent nuclear fuel storage pools to terrorist attack;
- Occupational and public health risks associated with uranium mining and milling; and
- Long-term leakage from underground repositories intended to isolate high-level radioactive waste and spent fuel from the human and natural environment for tens to hundreds of thousands of years.

If and when the nuclear industry establishes—and includes within its future cost structure—a nuclear fuel production, utilization, and long-term waste disposal regime that fully protects international security, public health, the environment, and future generations, NRDC would not seek to exclude new nuclear generation from competing on a level playing field with other reduced-carbon energy sources. Specifically, this means that nuclear power, without further government subsidy, could compete in the market for reduced-carbon energy alternatives developed in response to a national cap on carbon emissions, or to a new federal carbon-intensity portfolio standard seeking reductions in carbon emissions from electric power generation.

However, for nuclear power to qualify as a significant global carbon reducer, the international nuclear industry, the respective governments, and the International Atomic Energy Agency must ensure that:

- Nuclear fuel cycles do not afford access, or the technical capabilities for access, to nuclear explosive materials, principally separated plutonium and highly enriched uranium;
- The Nuclear Nonproliferation Treaty regulating nuclear power’s peaceful use is reinterpreted to prohibit the spread of latent as well as overt nuclear weapons capabilities, by barring national ownership and control of uranium enrichment plants in non-weapon states;
- The occupational and public health risks associated with uranium mining, milling, and the nuclear fuel cycle are remedied; and
- Existing and planned discharges of spent nuclear fuel and high-level radioactive waste will be safely sequestered in geologic repositories.

Until such time as the nuclear industry is able to meet these requirements, NRDC favors more practical, economical, and environmentally sustainable approaches to reducing both U.S. and global carbon emissions, including clean, flexible, renewable energy and efficiency technologies.

INTRODUCTION

Global warming, caused by human-made heat-trapping pollution, is the most dangerous environmental problem caused by human activity. The single most important heat-trapping gas is carbon dioxide, which comes mainly from burning fossil fuels. Coal-fired power plants are the largest source of carbon dioxide in the United States.

While nuclear power plants and their fuel cycle facilities emit little carbon dioxide, they are neither necessary nor sufficient to avoid dangerous global warming. U.S. electricity needs could be met while reducing emissions by 70 percent or more through a combination of increased end-use efficiency, wind power, solar power, integrated gasification combined-cycle coal plants with carbon capture and storage, and high-efficiency natural gas combined-cycle turbines. These technologies are cheaper than new nuclear plants, and they can be built or installed much more quickly, without the serious security, public health, and environmental dangers that accompany nuclear power.

Moreover, unless plug-in hybrid, all-electric, or fuel-cell-powered vehicles, or electric trains are commercialized on a large scale, nuclear power has virtually no role to play in reducing emissions from the transportation sector, which currently depends on petroleum for more than 95 percent of its energy needs.¹ Far more promising, at least for the next several decades, is significantly improving fuel economy through such technologies as gasoline- or diesel-electric hybrid vehicles and biofuels made from energy crops, forest products, and agricultural waste.²

For nuclear power to have any appreciable impact on global warming, nuclear capacity globally—now about 440 plants—would have to be increased severalfold over the next few decades. This would mean adding a dozen or so new uranium enrichment plants worldwide, a similar number of Yucca Mountain-type geologic repositories for spent nuclear fuel, and a significant expansion of uranium mining. Current international arrangements are insufficient to prevent a non-weapon state, such as Iran, from suddenly changing course and using “peaceful” uranium enrichment or spent-fuel reprocessing plants to separate nuclear material for weapons. Finally, there is not one single long-term geologic repository for spent nuclear fuel in operation anywhere in the world.

Global warming and the risks associated with nuclear power are, of course, not the only environmental or security risks posed by energy production. Coal-fired power plants produce many harmful emissions besides carbon dioxide, particularly sulfur dioxide, nitrogen oxides, and mercury, and mountaintop removal of coal is causing devastating damage in Appalachia. Oil dependence creates national security risks because the world’s oil reserves are concentrated in the volatile Middle East. Oil and natural gas exploration and production threaten America’s pristine heritage areas.

The most economically efficient way to address these risks is to internalize their costs in the market price of electricity and fuels. The United States can do this by regulating carbon dioxide emissions, the unique risks of nuclear power, and other associated energy production risks, and then letting the market pick the lowest-cost supply and demand technologies. The nuclear industry rejects this approach. Its lobbyists seek additional massive federal subsidies so they can reap profits on what would otherwise be dubious investments. The likely outcome of this approach, exacerbated in this time of severe budget deficits, would be to displace cleaner, more competitive technologies while failing to reduce global warming pollution significantly.

The fastest, cheapest, and cleanest solutions to global warming will come from providing energy efficiency and renewable energy a chance to compete on equal terms with other energy investments.

NUCLEAR POWER'S ECONOMIC WOES

Not one utility or energy-generation company in the United States has been willing to order and construct a new nuclear plant in more than 30 years. Energy companies and Wall Street have been decidedly uninterested in bankrolling new construction, despite decades of large federal subsidies to the nuclear power industry. This is not because of public opposition over safety or national security concerns. Rather, it is because new commercial nuclear power plants are uneconomical in the United States: They simply cannot compete with other sources of electricity.

But now the nuclear industry and a wide range of advocates are touting nuclear energy as one of the answers to global warming, and are calling for a new round of federal subsidies to build several new plants in the United States.

Subsidizing detailed engineering design, licensing, and construction of a few large nuclear power plants will cost the taxpayers billions of dollars, but will not significantly reduce the high capital cost of subsequent nuclear plants relative to alternative sources. Hence, these subsidies are unlikely to stimulate the widespread deployment of non-carbon-emitting technology needed to make a dent in reducing global warming emissions, and will be counterproductive by siphoning scarce government resources away from more productive investments that have the actual potential to transform energy markets on a global scale. Moreover, the subsidies do nothing to address the enormous security and public health risks that plague the nuclear industry.

A Mature Industry That's Received More than Its Share of Federal Subsidies

The worldwide nuclear power industry is a creature of government subsidies. Indeed, in many if not most countries, it is a government-owned or quasi-governmental enterprise. Originally a by-product of the U.S. nuclear weapons program, the commercial nuclear power industry in the United States has received more than \$77 billion (constant 2005) dollars in federal subsidies—an estimated 60 percent of the total federal energy research and development funding between 1948 and 1998.³ Over the same 50 years, \$26 billion in Research & Development expenditures, or 23 percent, went to oil, coal, and natural gas; \$12 billion, or 11 percent, to renewable energy sources such as wind, hydro, geothermal, and solar power; and \$8 billion, or 7 percent, to energy efficiency technologies.⁴ The nuclear power industry has been further sheltered from market forces by the Price-Anderson Act, which limits nuclear industry liability in the event of a catastrophic accident, and by the federal government assuming the multi-billion dollar responsibility for developing an underground repository for long-term isolation of the industry's highly radioactive waste.

Existing U.S. Nuclear Plants are Generally Reliable and Cost Competitive

In the United States, there are currently 104 licensed commercial nuclear power reactors, of which 103 are currently operable.⁵ With a couple of notable exceptions, they produce electricity reliably.⁶ Existing nuclear plants are also economically competitive with coal- and natural gas-fueled plants. This is because only operation, maintenance, and fuel costs—and not, as in the case of new plants, the high cost of construction—are included in forward cost pricing. In 2002, for example, the average nuclear power production cost of 1.71 cents per kilowatt-

hour (c/kWh) was slightly lower than that of coal plants: 1.85 c/kWh.⁷ With recent natural gas spot prices between \$6 and \$7 per million British Thermal Unit, electricity from existing nuclear plants is considerably cheaper than electricity from natural gas-fueled plants at today's high spot gas prices.⁸

New U.S. Nuclear Plants Are Not Cost Competitive

The cost of constructing new plants remains a major impediment to any expanded use of nuclear power. The main reason that no U.S. energy company has constructed one since 1973 is not public opposition, licensing uncertainties, lack of a licensed geologic repository for spent fuel disposal, or proliferation risks, but rather that new commercial nuclear power plants are uneconomical because of their higher construction costs.

According to *The Future of Nuclear Power*, a 2003 study published by the Massachusetts Institute of Technology (MIT), new nuclear plants are significantly more expensive than coal-fired or natural gas-fueled plants, provided long-term prices for gas do not stay at or exceed today's high price range. As seen from the following table, the MIT study estimated that the "levelized" cost of electricity generated by a new nuclear plant is about 60 percent higher than the cost of electricity from a coal plant or a combined cycle gas turbine plant, assuming moderate gas prices.⁹

As seen in the following table, even with a cap on carbon emissions providing a marketable credit equivalent to tax of \$100 per ton of carbon, the MIT study estimates that new commercial nuclear power plants would not be competitive unless sustained natural gas prices remain high or an unlikely combination of other factors occurs. But a cap on carbon emissions would provide a similar advantage to energy efficiency technologies and renewable energy sources that lack nuclear power's significant harmful externalities—such as the costs of safeguarding weapons-usable materials and disposing of long-lived hazardous waste—and can be flexibly deployed in a far wider range of markets. On a level economic playing field characterized by equal access to the power distribution grid, or in some cases the absence or underdevelopment of an existing grid, these technologies are emerging as formidable competitors to nuclear power.

Costs of Electric Generation Alternatives in Real Levelized Cents/kW-hr

	25-year	40-year
Base Case		
Nuclear	7.0	6.7
Coal	4.4	4.2
Gas (low)	3.8	3.8
Gas (moderate)	4.1	4.1
Gas (high)	5.3	5.6
Gas (high) Advanced	4.9	5.1
Reduce Nuclear Costs Cases		
Reduce construction costs (25%)	5.8	5.5
Reduce construction time by 12 months	5.6	5.3
Reduce cost of capital to be equivalent to coal and gas	4.7	4.4

	\$50/tC	\$100/tC	\$200/tC
Carbon Tax Cases (25/40 year)			
Coal	5.6/5.4	6.8/6.6	9.2/9.0
Gas (low)	4.3/4.3	4.9/4.8	5.9/5.9
Gas (moderate)	4.6/4.7	5.1/5.2	6.2/6.2
Gas (high)	5.8/6.1	6.4/6.7	7.4/7.7
Gas (high) advanced	5.3/5.6	5.8/6.0	6.7/7.0

Source: *The Future of Nuclear Power*, Massachusetts Institute of Technology, 2003.

Sticking U.S. Taxpayers with the Bill

New nuclear plants cost substantially more than new fossil-fueled plants, and the commercial nuclear industry would like U.S. taxpayers to cover the difference. Some of the nation's largest, most profitable energy companies are looking for what they call an investment stimulus at public expense. The nuclear industry is seeking over one-half billion dollars in licensing subsidies through the Department of Energy's (DOE) Nuclear Power 2010 Program budget and several billion dollars in detailed engineering design and construction subsidies through various energy bills in Congress.

The DOE unveiled its Nuclear Power 2010 Program in February 2002, describing it as "a joint government-industry cost-shared effort to identify sites for new nuclear power plants, develop advanced nuclear plant technologies, and demonstrate new regulatory processes leading to a private sector decision by 2005 to order new nuclear power plants for deployment in the United States in the 2010 time frame." The program is projected to provide some \$556 million in subsidies to the nuclear industry from fiscal year 2002 through fiscal year 2011.¹⁰

In the initial phase of this program, nuclear power companies—Exelon Generation, Dominion Energy, and Entergy Nuclear—applied to the Nuclear Regulatory Commission (NRC) for early site permits for three new nuclear plants. These corporations are among the largest and most profitable electricity generation companies in the United States. Nonetheless, the federal government is paying half the cost of obtaining early site permits from the NRC—permits that allow companies to build a plant at these sites without any obligation to do so. The permits will be good for 20 years, can be renewed for an additional 20 years, and can be banked or sold.

Under the second phase of the Nuclear Power 2010 Program, the DOE has awarded two nuclear industry consortia, one called NuStart and the second headed by Dominion Resources, licensing demonstration cost-sharing contracts intended to lead to successful NRC construction and operating licenses. The estimated cost of the two projects is \$1.1 billion, with the DOE's half of the cost estimated to be \$512 million for the period FY 2005 through FY 2011. Here again, the consortia make no commitment to build a reactor. Most of the government funds under these contracts will go to the two reactor vendors participating in the consortia; namely, General Electric, which is advancing its Economic Simplified Boiling Water Reactor, and BNFL–Westinghouse, which is advancing its new AP1000 reactor design.

These licensing subsidies are neither necessary nor warranted. Both General Electric and Westinghouse would have applied to the NRC for construction and operating licenses for these reactors without government support, because both are marketing these designs in Asia. General Electric is now the second largest corporation in the

United States, and perhaps the world, having just been overtaken by Exxon-Mobil. BNFL is a sizable British company, albeit with a large American subsidiary.

And that's just the beginning. The industry's champions have sought—through the Energy Bill, the McCain–Lieberman Climate Stewardship and Innovation Act of 2005, and other legislation—billions in direct subsidies to cover the costs of reactor construction. In the end, if the government subsidizes up to six new nuclear plants, the United States would have up to 110 nuclear plants instead of 104. Subsidizing new plants will not make nuclear power more competitive. Nor will it solve any of our nation's pressing long-term energy needs or provide a solution for global warming.

NUCLEAR POWER'S PROLIFERATION AND SAFETY RISKS

Commercial nuclear reactors do not emit any significant global warming pollution, and during normal operations, their limited radioactive emissions cause far fewer health problems than pollution from coal-fired power plants. Nonetheless, nuclear power has unique problems, including weapons proliferation, reactor safety, mining impacts, and waste disposal. These problems pose global risks of their own. To appreciate these risks it is helpful to have a basic understanding of nuclear reactors and fuel cycles, which is provided in Appendix A.

It is noteworthy that nuclear power is the only energy technology that requires:

- An international safeguards and inspection regime to prevent its use in the development of nuclear weapons;
- National governments to assume responsibility for disposal of the principal waste products because of their extraordinary health hazards and potential proliferation risks; and
- The U.S. federal government to provide insurance against catastrophic accidents.

The proliferation risks associated with nuclear reactors arise from the fact that the highly enriched uranium and plutonium used as reactor fuels are also the principal ingredients of nuclear weapons and other nuclear explosives devices. Reactors and key fuel cycle facilities can also serve both civil and military uses. Under the Treaty on the Nonproliferation of Nuclear Weapons (NPT) and International Atomic Energy Agency (IAEA) monitoring and inspection measures—collectively referred to as “safeguards” for ensuring peaceful use—any declared non-weapon state such as Iran or Japan can lawfully acquire reactors and nuclear fuel cycle facilities and can stockpile large quantities of nuclear weapons-usable material as long as they can point to potential “peaceful uses,” no matter how implausible these may appear from an economic perspective.¹¹

The weapon design and arms control communities agree that it is not the capability to design a nuclear device that determines the pace of a country's acquisition of a first weapon, but, rather, the availability of nuclear weapons materials that can be turned to weapons purposes. For a nation-state, the material for weapons can come from uranium enrichment plants (highly enriched uranium), or reactors and nuclear fuel reprocessing plants (plutonium), or both.

For more than 30 years, there has been no commercial nuclear fuel reprocessing in the United States because of economic and nonproliferation concerns. During that time, U.S. policy has oscillated between promoting reprocessing, tolerating it in a few select countries, and opposing it (see Appendix B). The current administration and Congress are making a strong push to resume reprocessing.

The continued pursuit of fast reactors and inertial confinement fusion in leading industrial countries, and the availability of increasingly capable computers and simulation codes, will likely result in the creation of nuclear

scientific cadres in many nations—not unlike Japan today—with relevant skills for designing advanced nuclear, and possibly thermonuclear, explosives.

It Doesn't Take Much Fissile Material to Make a Bomb

Regardless of its isotopic composition, the minimum amount of plutonium required to make a pure fission nuclear explosive, with a yield equivalent to one to 25 kilotons of chemical high explosives, is quite small, on the order of 1 to 3 kilograms (kg), with the exact amount depending on the level of design expertise and the desired nuclear explosive yield.¹² The minimum amount of highly enriched uranium required is a few times larger—5 to 10 kg.

While far from ideal for military applications, the isotopic composition of the plutonium typically produced in civil power reactors does not pose a serious obstacle to fabricating efficient and powerful weapons, as well as crude terrorist devices.

Current levels of international safeguards are not capable of providing a timely warning of the theft or diversion from bulk handling facilities and other sites that store or process weapons-usable fissile material. Significant quantity (SQ) is the term of art for the quantity the IAEA uses to represent the minimum amount of material required by a non-weapon state to construct a single nuclear explosive device.

Basic considerations of critical mass requirements for nuclear explosive material at various levels of compression strongly suggest that the current IAEA SQ values for plutonium (8 kg) and highly enriched uranium (25 kg) should be reduced eightfold. This is particularly critical if the international system is to rely primarily on safeguards rather than arsenals in the future to deter the use of nuclear energy for weapons purposes.

Uranium Enrichment Plants Can Be Used to Make Highly Enriched Uranium for Weapons

Eleven countries currently operate uranium enrichment plants—nine countries, including three non-weapon states, operate large commercial plants, two operate small plants to produce enriched uranium for weapons, and three additional countries are constructing or planning to construct enrichment plants.¹³ As evidenced by what has occurred in Israel, South Africa, Pakistan, Iraq, and Libya—and is currently occurring in Iran and North Korea—the engineering designs for an enrichment facility can be stolen (Pakistan) the components needed to construct a uranium enrichment facility can be manufactured indigenously (Israel, South Africa, and Iraq) or purchased on the black market or from rogue states (Libya and Iran) and the enrichment programs, pilot- and larger-scale facilities can be readily hidden for decades (Israel and Iran).

In the 1980s, South Africa's apartheid regime declared that its uranium enrichment plant would be used solely to provide uranium for civil reactors, while in fact it was also used to produce the highly enriched uranium for a stockpile of six gun-assembly-type nuclear weapons.

It is now generally appreciated that gas centrifuge plants for producing low-enriched uranium can fairly easily be turned into plants for producing highly enriched uranium. It is less appreciated that the “separative work” required to obtain low-enriched uranium at, say, 4 percent enrichment, is about 70 to 90 percent of that required to produce the

highly enriched uranium used in the bomb that destroyed Hiroshima, or in the six weapons secretly stockpiled by the former white-minority government of South Africa in the 1980s. In short, it takes comparatively little additional separative work to upgrade reactor fuel from low-enriched uranium to highly enriched uranium.¹⁴

Gas centrifuge uranium enrichment plants are bulk handling facilities with numerous gaseous and particulate streams. It is virtually impossible to balance the books against plant inventory measurements. Consequently, it is impossible for the IAEA to ensure that weapon quantities of enriched uranium have not been siphoned off for further enrichment at much smaller clandestine facilities.

Having a gas centrifuge plant producing low-enriched uranium makes it much easier to construct and operate a clandestine one. The presence of the larger plant would mask many of the intelligence and environmental indicators of a clandestine one, making it harder to find.¹⁵

But even in the absence of any commercial enrichment—in the case of a country with one or more stand-alone light water reactors—the presence of light water reactors means that a substantial supply of fresh light water reactor fuel would also be present at times. That such fresh fuel can provide a source of uranium for clandestine enrichment is another possibility that has received essentially no attention in the proliferation literature. Since the fuel is already low-enriched uranium, a much smaller gas centrifuge plant would suffice to raise the enrichment to bomb levels than would be the case if the starting point is natural uranium. By starting with such low-enriched uranium fuel pellets, which are uranium oxide, the enricher would be able to skip the first five processes required to go from uranium ore to uranium hexafluoride gas, the material on which the gas centrifuge operates. To go from the uranium oxide pellets to uranium hexafluoride, the would-be bomb-maker would crush the pellets and react the powder with fluorine gas. Suitably processed, the low-enriched uranium pellets could provide feed for clandestine enrichment.¹⁶

The only effective way to safeguard uranium enrichment plants is to limit them to nuclear weapon states and operate them under strict IAEA safeguards, with safeguards inspectors present on site. Unfortunately, such a regime is not in place and is unlikely to be instituted anytime in the foreseeable future. Even the IAEA agrees that its existing safeguards regime cannot cope with bulk handling facilities. Dr. Mohamed ElBaradei, director general of the IAEA, has called for a five-year moratorium on new nuclear fuel facilities anywhere while the world's nations negotiate new controls. His call has gone unheeded by the majority of nations and is opposed by the Bush administration.

Spent Plutonium Fuel from Reactors is Weapons-Usable After Reprocessing

All U.S. commercial nuclear power reactors and most power reactors in the rest of the world are thermal reactors of the light water reactor type, meaning the fuel is cooled, and the neutrons are moderated, with ordinary water. They are typically fueled with low-enriched uranium, although some (but none currently in the United States) are fueled with a mixture of uranium oxide and plutonium oxide, called MOX. A typical 1000 megawatt-electric (MWe) plant contains approximately 100 metric tons (tonnes) of fuel, and every 18 months or so, the plant is refueled. The spent fuel contains approximately 1 percent plutonium, and on an annual basis the reactors discharge approximately 20 tonnes of spent fuel (containing 200 kg of plutonium) per year per 1000 GWe—the average size of a U.S. nuclear power reactor. The 103 operational U.S. power reactors, therefore, discharge annually approximately 2,000 tonnes of spent fuel containing approximately two tonnes (*i.e.*, 2,000 kilograms) of reactor-grade plutonium.

The reactor-grade plutonium in the spent fuel is weapons-usable, but only if it is first separated from the unused uranium, and the radioactive fission and transuranic products created as a result of fission and neutron absorptions processes, respectively, by reprocessing the spent fuel.¹⁷

The plutonium-fueled fast reactor fuel cycle, which requires reprocessing to recover and recycle the plutonium as fresh fuel, has some 5 tons of plutonium in each commercial-size reactor and three to five times that amount (per reactor) at other fuel facilities—reprocessing plants and fuel fabrication facilities. Moreover, fast reactors provide the technical potential to produce large quantities of separated weapon-grade plutonium, and advanced technologies are under development in several countries that will permit plutonium enrichment, *i.e.*, rapid “cleanup” of reactor-grade plutonium inventories to weapon-grade.

Reprocessing Plants Increased the Risk of Proliferation

The United Kingdom, France, and Japan currently engage in commercial nuclear fuel reprocessing. The United States and Russia have previously engaged in commercial reprocessing, but no commercial reprocessing plants are operational in either country today.

The potential theft and terrorist use of plutonium associated with the Soviet, now Russian, civilian nuclear fuel cycle represents one of the highest U.S. national security risks today. These Russian plutonium stocks are a consequence of a failed effort to commercially recycle plutonium in Russian nuclear reactors. Controlling nuclear weapons proliferation will simply become impossible—further exacerbating the national security risks to the United States—if the nuclear industry continues to pursue nuclear fuel reprocessing for plutonium recycle and wide-scale global deployment of plutonium breeder reactors. As a consequence, the shortest route to acquiring nuclear weapons would be through the civilian nuclear power program, as occurred in India, rather than through the construction of facilities dedicated to weapons production, as occurred in Israel.

Large, commercial-size plants are designed to process 800 tonnes (Rokkasho, Japan) to 1,600 tonnes (La Hague, France) of spent fuel annually.¹⁸ Consequently, when processing light-water-reactor fuel, they are capable of separating and handling 8,000 to 16,000 kg of plutonium annually. These conventional plants use a series of chemical processes to dissolve the spent fuel and separate the plutonium and unused uranium from the highly radioactive waste. The plutonium is typically converted into plutonium oxide, which is a solid powder. Neither national or nor international inventory procedures are capable of confirming that strategic quantities of plutonium have not been diverted from large-scale reprocessing plants. Moreover, plutonium recycling in Japan and Russia has resulted in the buildup of tens of tons of separated plutonium awaiting fabrication in MOX fuel fabrication plants.

MIT's *The Future of Nuclear Power* study concluded that reprocessing and recycling plutonium—which creates weapons-usable material and some of the most radioactive waste in the world—is prohibitively expensive and likely to remain so for decades to come.¹⁹ Separating more weapons-usable material at a tremendous economic loss makes no sense, especially since the world is not running out of low-cost uranium, and reprocessing offers no nuclear waste management benefits.

A reduction in high-level waste management requirements will require deployment of technologies that are even less economical than current reprocessing techniques and are likely to remain uneconomical in the foreseeable future. Similarly, transmutation of selected isotopes is more efficient in fast reactors, but these have proven to be more costly to construct than conventional light water-cooled thermal reactors. Thus, fast reactors can be justified on economic grounds only if the costs of the total fuel cycle are reduced in comparison with the once-through fuel cycle or if they are seen to provide other societal benefits. Moreover, even the advanced separations technologies carry proliferation risks that appear higher, at least in the near term, compared to the open fuel cycle in use today. Even the research programs carry serious proliferation risks since they can encourage other countries to develop means of separating out plutonium. When conducted in non-weapon states, research on transmutation-related technologies that are unlikely to ever be commercialized simply train cadres of experts in actinide chemistry and plutonium metallurgy, a proliferation concern in its own right. The hot cells, used for hands-on research, provide readily available facilities for separation of plutonium and fabrication of plutonium components for weapons.

Concerns About Nuclear Plant Safety

Fortunately, there has not been a complete, or even a partial, core meltdown in a U.S. nuclear reactor since the 1979 Three Mile Island accident. While the risk of a catastrophic accident is widely viewed to be lower today than two decades ago, dangerous precursors continue to occur. For example, in March 2002, a six-inch deep boric acid hole was discovered in the reactor vessel at First Energy's Davis-Besse nuclear generating station in Oak Harbor, Ohio. When plant workers discovered the softball-size hole, only the reactor's outer layer of stainless steel—about one-half inch thick—prevented a loss-of-coolant accident that could have been disastrous. The fact that First Energy and Nuclear Regulatory Commission officials ignored warning signs before the incident raises legitimate questions about the continued safe operation of aging U.S. nuclear plants.

Although the nuclear industry insists its plants do not present a public safety threat, the U.S. government continues to shelter the industry by putting a cap on its liability in the event of a catastrophic accident. The Price-Anderson Act, which Congress reauthorized in 2002, protects nuclear power plant owners from the full cost of accidents and limits the protection offered to the public by the federal government in the event of a large accident. This unique form of federal intervention distorts competition in the wholesale electricity market in favor of nuclear power and underscores the inherent uncertainty about the safety and potential magnitude of accidents at nuclear power plants.

Other safety issues have emerged since the September 11, 2001, terrorist attacks. For example, a recent National Academy of Sciences study warned that if terrorists mounted a successful attack on the spent nuclear fuel pool at some nuclear power reactors, they could drain the water out of the pool, which in turn could result in a zirconium fire—the spent fuel's zirconium cladding would overheat and ignite—resulting in the potential release of a significant amount of radioactivity.²⁰ Some reactors are more vulnerable than others, and therefore the risk is dependent on a number of factors, including the type of reactor and its location, the location and design of the spent fuel pool, and the level of physical security at the reactor. The risk could be reduced by removing the older spent fuel—that which had undergone radioactive decay for three to five years while in the water-filled pools—from the pools and transferring it to safer dry cask storage at the reactor site, or elsewhere, and ultimately sending it off-site to a geologic repository.²¹

NUCLEAR POWER'S ENVIRONMENTAL IMPACTS

Even if the nuclear industry could address its economic, proliferation, and safety concerns, it still has to face the problem of preventing radioactive waste from contaminating the human and natural environment. When considering these impacts, the industry must take into account the entirety of the nuclear fuel cycle, from uranium mining to disposal of the spent nuclear fuel rods generated by commercial reactors that are highly radioactive and pose a potential threat to public health and the environment for hundreds of thousands of years.

Mining, Milling, And Enriching Contaminate Water, Soil

To fuel commercial nuclear reactors or provide material for nuclear weapons, uranium must be mined and separated from its ore or milled. Over the last half century, uranium mining and milling has left large areas of the American West, and similar mining areas around the globe, scarred and polluted. Originally, uranium was mined like other hard rock minerals—by mining out seams of uranium deep underground. Then large, open pit uranium mines were carved out and milled on-site, resulting in huge volumes of radioactive, sand-like residues called mill tailings. More recently in the United States, the industry has tried uranium solution mining, which uses deep wells to inject a base into the ore-bearing portion of an aquifer. After the solution is injected, the uranium and other heavy metals are literally oxidized off the rock and pulled to the surface. The result of uranium solution mining is a profoundly contaminated aquifer, and the uranium mining industry has not restored a single Western aquifer to its original water quality solution after mining was used.²²

After uranium is mined and milled, it then must be enriched to separate naturally occurring isotopes before it can be used in a commercial reactor. Enrichment facilities in Tennessee, Ohio, and Kentucky have generated significant amounts of Polychlorinated biphenyl-contaminated waste and uranium, depleted uranium, and uranium-contaminated scrap metal from facility dismantlement, and have contaminated soil and groundwater with organic solvents, according to the Department of Energy. Newer gas centrifuge enrichment plants should avoid some of these legacy contamination problems, but they must cope with the tens of thousands of tonnes of depleted uranium that is a byproduct of any method of enrichment.²³

The Problem of Waste Disposal is Still Unsolved

During the fission process that powers a commercial nuclear reactor, the reactor produces significant volumes of contaminated wastewater and low-level radioactive materials. In the United States, decommissioning the more than 100 reactors contaminated by neutron activation products in the pressure vessel, fission product and activation product contamination of the piping, and even the turbines of boiling water-type reactors will cost tens of billions of dollars and create a large and varied amount of radioactive waste. But the nuclear waste storage issue of greatest concern is how and where to dispose of the highly radioactive spent nuclear fuel in deep geological repositories. As previously noted, U.S commercial nuclear reactors discharge spent fuel at the rate of about 20 tonnes per year per plant, or about 2,000 tonnes per year for the fleet of just over 100 reactors. To date there is a backlog of about 40,000 tonnes of spent fuel awaiting final disposition.

Given the industry's unique waste problem and the proliferation issues inherent in spent fuel management, the federal government took the responsibility to dispose of high-level radioactive waste in one or more geologic repositories. To date, the government has focused all of its efforts on building a repository at Yucca Mountain in Nevada, but over the years, it has become clear that the site may not have the necessary geology to keep the waste from migrating and eventually contaminating the nearby water table.

Instead of confronting this problem directly, the Environmental Protection Agency (EPA) in 1999 redrew the zone of compliance for environmental laws around the Yucca Mountain site—what is called the controlled area—so that the site could be assured of receiving a license, rather than fully protecting the health of future generations. The controlled area sets the boundary beyond which a radiation dose to individuals living nearby must not exceed acceptable levels when spent fuel canisters corrode away and radioactivity leaks from the repository, tens of thousand of years from now. To ensure licensing, the EPA extended the controlled area 11 miles (18 kilometers) in the direction that radioactivity is projected to leak from the site. The EPA now concedes that the site will leak. Placing an environmental compliance boundary far enough away to allow for licensing would essentially create a radioactive septic field, rather than ensure the geologic isolation required by Congress in the Nuclear Waste Policy Act.²⁴

In July 2001, the state of Nevada, NRDC, and a handful of other environmental groups filed suit against the EPA for issuing inadequate standards for Yucca Mountain. Three years later, in July 2004, a federal appeals court ruled in favor of NRDC and Nevada, finding that the agency's 10,000 year standard was illegal. The EPA should now write stronger standards, and it is unclear whether the site, when filled to capacity, will be able to meet strict, protective public health standards. More recently, e-mails from government scientists have surfaced indicating falsification of technical data regarding water migration. At a minimum, the prospects for building the first U.S. repository at Yucca Mountain are uncertain, raising the question of whether it is sound energy policy to expand our commitment to civilian nuclear power before confidently establishing a pathway for the safe long-term isolation of nuclear waste.

APPENDIX A

A PRIMER ON REACTORS AND NUCLEAR FUEL CYCLES

Nuclear reactors are categorized according to:

- Characteristics of the neutron spectra (fast or thermal, *i.e.*, whether the neutrons are moving fast or slowly when they are reabsorbed in the fuel used to sustain the heat-producing fission reaction);
- The neutron-slowing (“moderator”) material (*e.g.*, light water, heavy water, or graphite); and
- The fuel coolant (*e.g.*, light water, heavy water, gas, or liquid metal).²⁵

All U.S. commercial nuclear power reactors and most commercial power reactors in the rest of the world are light water reactors.

Natural uranium consists of 0.711 weight percent U-235, 0.005 percent U-234, and the remainder U-238. Light water reactors typically operate using uranium-oxide in the form of ceramic fuel pellets in which the uranium has been enriched to between 1.6 to 4.5 percent U-235.²⁶ Uranium enriched to less than 20 percent U-235 is called low-enriched uranium and is not directly weapons-usable. Some light water reactors, as well as other types of reactors, operate using a fuel that is a mixture of plutonium-oxide and uranium-oxide in ceramic form, referred to as mixed oxide or simply plutonium fuel.

CANDU (CANada Deuterium Uranium) reactors, which are used in Canada and marketed abroad, use natural uranium fuel. There is one commercial-size liquid metal fast breeder reactor operating in Russia on highly enriched uranium fuel and a couple of fast breeder demonstration plants in France and Japan that are plutonium fueled.

Nuclear reactors can operate on either an open fuel cycle (see Figure 1) or a closed fuel cycle (see Figure 2). In an open cycle, the spent fuel is intended to be disposed in a geologic repository, or in the absence of a repository, stored indefinitely. In a closed cycle, the spent fuel is reprocessed to recover plutonium and unused uranium, which may be recycled as nuclear fuel, or, in the case of plutonium, used in weapons.

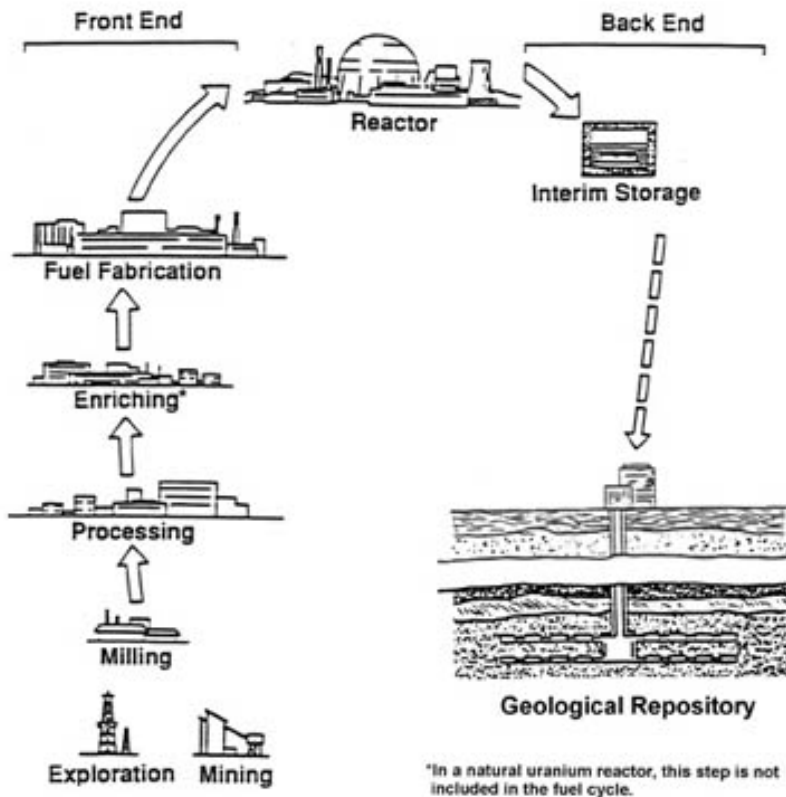
By recycling the plutonium and uranium, more energy is produced per kilogram of natural uranium mined. Historically, the goal of the nuclear industry was to introduce and widely use fast breeder reactors. In theory, a breeder reactor can produce new plutonium—by making the U-238 in the fuel absorb copious fast neutrons, which are in excess of those needed to sustain the nuclear chain reaction—faster than the existing plutonium is consumed. The fast breeder was touted as a way of providing an inexhaustible supply of nuclear fuel and a hedge against high uranium prices as higher-grade uranium resources were exhausted.

This utopia never materialized and, in fact, it is economically unobtainable. Over the past three decades, the cost of reprocessing and fabricating plutonium fuel has increased dramatically, due in large measure to more stringent

physical security, safeguards, and waste management requirements. The most notorious example is Japan’s recently completed (but not operational) Rokkasho reprocessing plant whose construction cost is now pegged at about \$20 billion. Fuel-cycle cost modeling indicates that conventional PUREX (Plutonium and Uranium Recovery by Extraction) reprocessing/MOX (Mixed Oxide) recycle fuel costs are several times greater than the cost of the open fuel cycle used in the United States today.²⁷ As a consequence, nuclear fuel reprocessing and plutonium recycling plutonium as mixed oxide fuel in light water reactors is uneconomical.

Figure 1. Open Fuel Cycle

- Disposal of spent fuel
- Current policy in U.S.



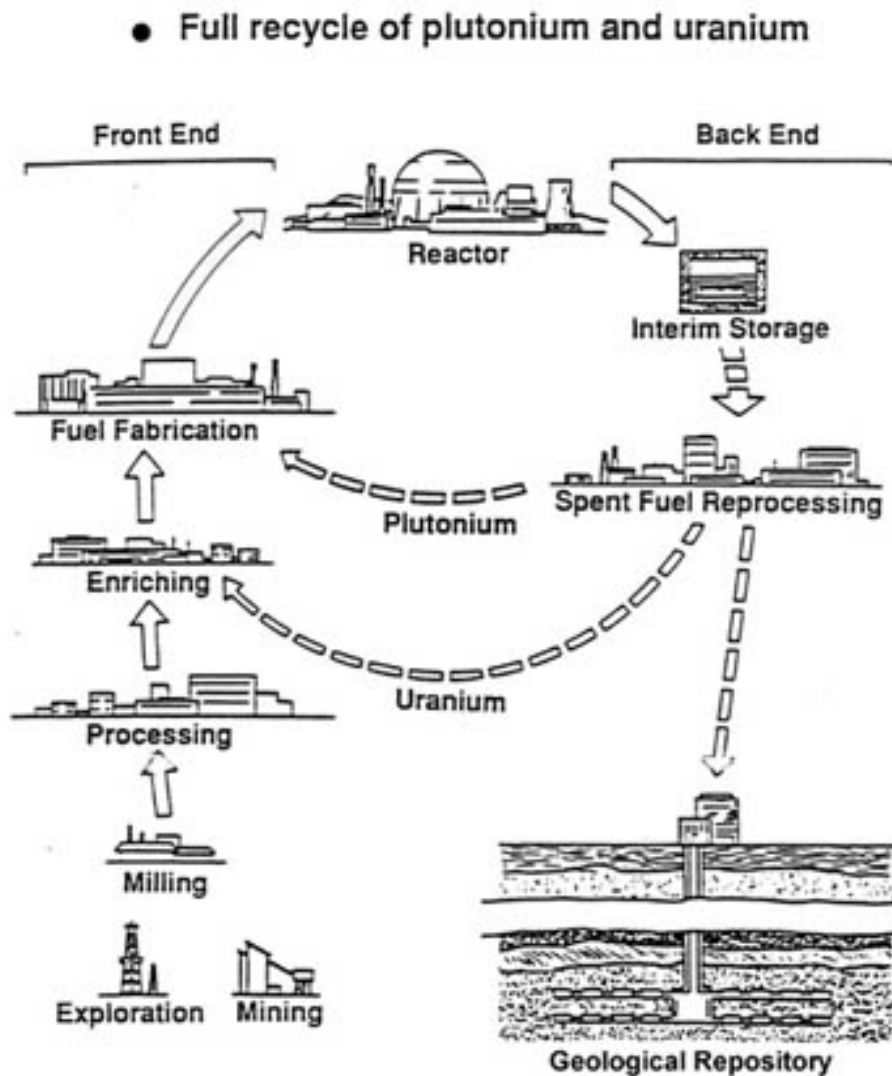
Moreover, the capital cost of reactors also increased, and the capital cost of a liquid-metal fast breeder reactor turned out to be about twice the capital cost of a light water reactor. As a consequence, fast reactors, including fast breeder reactors, are not even close to being competitive with light water reactors, which are themselves uneconomical.

At the same time, the costs of natural uranium and enrichment have decreased in real terms. In the uranium mining business, as with virtually all major mineral resources, improvements in efficiency of extraction outpaces the

depletion of the resource, and over the longterm, the price of minerals decreases in constant dollars. Therefore, plutonium recycle and breeder reactors are unlikely to ever be economical—certainly not in the foreseeable future.

The nuclear business is simply not a free market, and nuclear R&D is largely government-funded throughout the world. Moreover, there are large, powerful, and entrenched nuclear bureaucracies in the United States, France, Russia, Japan, China, India, and elsewhere. Consequently, several countries—most notably France, Russia, and Japan, but now also the United States (see Appendix B)—continue to promote the closed fuel cycle and plutonium recycling as a matter of national policy, despite the fact that it is uneconomical to do so.

Figure 2. Closed Fuel Cycle



Faced with these economic realities, reprocessing proponents are now touting the closed fuel cycle as a way to reduce the uncertainty in long-term risks associated with spent fuel and high-level wastes in geologic repositories, and as a means for reducing the required geologic repository capacity. The justification for pursuing advanced separations technologies is that by separating not only the plutonium and uranium, but also selected actinides and fission product isotopes, these isotopes could be reintroduced into reactors (preferably fast reactors) where they would be transmuted into shorter-lived less harmful isotopes, thereby reducing the high-level waste management burden.²⁸

APPENDIX B

U.S. POLICY REGARDING REPROCESSING AND PLUTONIUM RECYCLE

U.S. policy has oscillated between promoting reprocessing, tolerating it in a few select countries, and opposing it. The United States promoted plutonium recycling until India tested its first nuclear weapon in 1974 using plutonium produced in a civil research reactor and recovered from the spent fuel at a reprocessing plant that was part of the Indian breeder reactor program. The United States had also discovered that Taiwan had been pursuing a secret effort to separate plutonium. In response, President Gerald Ford announced on October 28, 1976, that:

I have concluded that reprocessing and recycling of plutonium should not proceed unless there is sound reason to conclude the world community can effectively overcome the associated risks of proliferation. I believe that avoidance of reprocessing must take precedence over economic interests.... I have decided that the United States should no longer regard reprocessing of used nuclear fuel to produce plutonium as a necessary and inevitable step in the nuclear fuel cycle, and that we should pursue reprocessing and recycling in the future only if they are found to be consistent with our international objectives.²⁹

President Jimmy Carter, in a March 24, 1977, directive, declared, “For its part, the United States will: Indefinitely defer the commercial reprocessing and recycle or plutonium in the U.S.”³⁰ President Carter also suspended the limited work authorization licensing of the Clinch River Breeder Reactor (CRBR), the U.S. plutonium breeder demonstration reactor.

In 1981, President Ronald Reagan opened the door to commercial reprocessing in the United States, and restarted the CRBR licensing process. But by then, there was no longer any commercial interest in reprocessing in the United States, and no commercial firm stepped forward to build a new reprocessing plant in the United States. In 1983, Congress stopped funding, and thereby killed, the CRBR, thus temporarily ending the prospects for commercial reprocessing.

On September 23, 1993, President Bill Clinton issued a nonproliferation policy statement, which said in part: “The United States does not encourage the civil use of plutonium and, accordingly, does not itself engage in plutonium reprocessing for either nuclear power or nuclear explosive purposes. The United States, however, will maintain its existing commitments regarding the use of plutonium in civil nuclear programs in Western Europe and Japan.”³¹

Under President George W. Bush, Vice President Dick Cheney’s National Energy Policy Development Group issued its May 2001 National Energy Policy, calling for a reexamination of U.S. “policies to allow for research,

development and deployment of fuel conditioning methods (such as pyroprocessing) that reduce waste streams and enhance proliferation resistance.”³²

This was followed by President Bush’s 2002 National Security Presidential Directive on National Strategy to Combat Weapons of Mass Destruction:

The United States will continue to discourage the worldwide accumulation of separated plutonium and to minimize the use of highly enriched uranium. As outlined in the National Energy Policy, the United States will work in collaboration with international partners to develop recycle and fuel treatment technologies that are cleaner, more efficient, less waste-intensive, and more proliferation resistant.³³

The Bush administration’s new policy toward reprocessing is being used by the (DOE) Office of Nuclear Energy, Science, and Technology to further its Advance Fuel Cycle Initiative (AFCI). Under this \$70 million per year program, the DOE is conducting research on reprocessing and transmutation technologies.

In May 2005, the House Committee on Appropriations directed the DOE as follows:

As discussed earlier in this report, the Committee believes the Department should embark on a concerted initiative to begin recycling our spent nuclear fuel, starting with the preparation of an integrated spent fuel recycling plan for implementation in fiscal year 2007, including selection of an advanced reprocessing technology and a competitive process to select one or more sites to develop integrated spent fuel recycling facilities (i.e., reprocessing, preparation of mixed oxide fuel, vitrification of high-level waste products, and temporary process storage).

Until such an integrated recycling approach becomes operational, the Committee believes the Department should move aggressively to take title to commercial spent fuel and consolidate such fuel in a smaller number of more secure, above-ground interim storage facilities located at existing DOE facilities.³⁴

Thus, the struggle to halt commercial use of plutonium in the United States and abroad goes on, with no end in sight.

ENDNOTES

¹ The DOE's Generation IV Nuclear Energy Systems Initiative proposes to construct a demonstration very high temperature gas-cooled reactor (VHTGR) at the Idaho National Laboratory to be used to demonstrate hydrogen production. This program has little to offer, since it would require an entirely new infrastructure to store additional energy and to deliver hydrogen and because nuclear production of hydrogen, to power vehicles is a more expensive way to deliver energy to the wheels of the vehicles than supplying electricity directly to plug-in hybrids.

² This is not an endorsement of grain-based ethanol production. See Nathaneal Greene, et al., *Growing Energy*, NRDC, December 2004, available at: www.nrdc.org/air/energy/biofuels/contents.asp.

³ Nuclear power received an estimated \$66 billion (1999 dollars) between 1948 and 1998, according to Defenders of Wildlife, et al., *Running on Empty*, a Green Scissors Report, 2002, available at: www.greenscissors.org/publications/runningonempty.pdf. Adjusting from 1999 to 2005 dollars would increase the 1999 constant dollar amount by about 16 percent. In addition, the DOE Nuclear Energy R&D budget for FY 2000–FY 2005 totaled \$627.5 million (current dollars). William D. Magwood, DOE-NE, NERAC January 11, 2005 Meeting.

⁴ *Ibid.*

⁵ The TVA's Brown's Ferry Unit 1 has been out of service since 1985, but may resume operations in 2007.

⁶ The reliability of existing plants is evidenced by the fact that the median three-year (2002–2004) design electrical rating net capacity factor for the 104 plants was 89.77 percent. E. Michael Blake, "U.S. capacity factors: Does new ownership matter?," *Nuclear News*, May 2005, p. 27. The two notable exceptions are the TVA's Brown's Ferry Unit 1, which is inoperable (see previous footnote) and Davis-Besse, which has a three-year (2002–2004) design electrical rating net capacity factor of only 28.15 percent. *Ibid.*

⁷ Marilyn C. Kray, vice president, project development, Exelon Corporation, "Long-Term Strategy for Nuclear Power," Pew Center/National Commission on Energy Policy, and "The 10-50 Solution: Technologies and Policies for a Low-Carbon Future," workshop, March 26, 2004.

⁸ Department of Energy, Energy Information Agency (EIA), "Natural Gas Weekly Update," May 12, 2005; tonto.eia.doe.gov/oog/info/ngw/ngupdate.asp. The price range can also be expressed as \$6-\$7 per thousand cubic feet (MCF), given 1030 BTU/cubic foot of natural gas.

⁹ *The Future of Nuclear Power: An Interdisciplinary MIT Study*, MIT (2003), Table 1.3. "The levelized cost is the constant real wholesale price of electricity that meets a private investor's financing cost, debt repayment, income tax, and associated cash flow constraints," p. 38.

¹⁰ Of this amount, \$54.1 million has been committed from FY 2002 through FY 2005.

¹¹ In fact, this is what India did in 1974 when it claimed that its first nuclear test in 1974 was for "peaceful purposes." At the time of its second nuclear test in 1998, India admitted that its 1974 explosion was a weapons test. India's claim followed 27 "peaceful" nuclear explosions in the United States conducted between 1961 and 1973, under the Plowshares Program and similar experiments by the Soviet Union. Many of these tests were conducted to investigate the application of nuclear explosions to release of natural gas from tight geologic formations. This "peaceful" nuclear test loophole has been closed by the Comprehensive Test Ban Treaty, which the United States signed in 1996, but the U.S. Senate has thus far refused to ratify.

¹² By way of comparison, the bomb dropped on Nagasaki contained 6 kilograms (kg) of weapon-grade plutonium, and modern U.S. thermonuclear weapons contain an average of about 3 kg.

¹³ Five weapon states—United States, Russia, United Kingdom, France, and China—and three non-weapon states—Germany, Japan, and the Netherlands—operate large uranium enrichment plants. Israel and Pakistan operate small uranium enrichment plants for nuclear weapons materials. Iran, Brazil, and presumably North Korea are

constructing or planning to construct gas centrifuge uranium enrichment plants. There are three operating gaseous diffusion uranium enrichment plants and 11 or so operating gas centrifuge plants. The total capacity of the operating plants is approximately 76 million kg SWU/year, of which about 23 million kg SWU/year is gaseous diffusion and 53 million kg SWU/year gas centrifuge, see www.antenna.nl/wise/uranium/efac.html#ENR.

¹⁴ See Victor Gilinsky, Marvin Miller, and Harmand Hubbard, "A Fresh Examination of the Proliferation Dangers of Light Water Reactors, October 22, 2004, The Nonproliferation Education Center, Washington, D.C., available at: www.npec-web.org/projects/NPECLWRREPORTFINALII10-22-2004.pdf; and C.E. Paine, T.B. Cochran, R.S. Norris, "Technical Realities Confronting Transition to a Nuclear Weapons Free World," Background Papers, Canberra Commission on the Elimination of Nuclear Weapons, August 1996, p.122. The figure is closer to 70 percent if the enrichment plant tails assay is kept low. If adequate low-enriched uranium fuel is available, and a high tails assay is used, the figure is closer to 90 percent.

¹⁵ Ibid.

¹⁶ Ibid.

¹⁷ The U.S. nuclear weapons program used several chemical processes to separate plutonium from spent fuel and target materials, and this step was called "chemical separation." In the civil nuclear power industry, this step is called "reprocessing."

¹⁸ The THORP plant at Sellafield, U.K., has a design capacity of 1,000 tonne/year.

¹⁹ Japan, which has embarked on a hugely expensive program to separate and recycle plutonium as fuel for its civil nuclear reactors, is the current object lesson in the high costs of reprocessing. See discussion at p.7.

²⁰ *Safety and Security of Commercial Spent Nuclear Fuel: Public Report*, Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, Board of Radioactive Waste Management, National Research Council of the National Academies, 2005.

²¹ Sweden, which has 11 nuclear power reactors, has built a central, below-ground, spent fuel storage facility large enough for all of the waste from Swedish reactors.

²² Much of the uranium mining damage in the United States has been done at the expense of a number of Indian nations. In April 2005, the Navajo Nation banned any future mining and processing of uranium on its lands. When he signed the Diné Natural Resources Protection Act of 2005, Navajo President Joseph Shirley said, "As long as there are no answers to cancer, we shouldn't have uranium mining on the Navajo nation. I believe the powers that be committed genocide on Navajo land by allowing uranium mining."

²³ The K-25 gaseous diffusion plant, now deactivated, at Oak Ridge Tennessee has 5,0000 cylinders, some over 50 years old, each containing approximately 14 tonnes of depleted uranium hexafluoride. See U.S. DOE, *Closing the Circle on Splitting the Atom*, January 1995, p. 15.

²⁴ Besides gerrymandering the controlled area boundary, the EPA allowed the Department of Energy to rely on the canisters holding the waste rather than the geology of the site. The EPA did this by setting the dose-limit criteria at 10,000 years from now, even though the projected peak doses would occur long after the canisters can no longer be relied upon.

²⁵ Light water is ordinary water; whereas in heavy water the hydrogen atoms are deuterium atoms. In naturally occurring hydrogen, the nucleus of the atom consists of one proton whereas, in deuterium the nucleus consists of one proton and one neutron.

²⁶ See www.nuc.berkeley.edu/thyd/ne161/klambert/peterson.html.

²⁷ *The Future of Nuclear Power: An Interdisciplinary MIT Study*, 2003, pp. 146-148, gives \$2,040 for the total (ore purchase through disposal) for 1 kgIHM of fresh UOX fuel and \$8,890 for 1 kgIHM of fresh mixed oxide fuel. Although this is a substantial difference in fuel cost, the MIT study estimates that the incremental cost of electricity for use of a mixed oxide/UOX cycle compared to a once through UOX cycle would be 0.28 cents/kWe-hr.

²⁸ The advanced fuel separations technologies that have been the focus of the U.S. DOE's Advanced Fuel Cycle Initiative (AFCI) research and development effort are UREX+ and pyroprocessing. UREX+ is a modification of PUREX, the widely used conventional chemical process. It would leave selected actinides mixed with the plutonium to serve as a radiation barrier to make it difficult to use the plutonium in weapons without further processing. This process has been criticized as not offering the proliferation resistance claimed by its proponents. S. Jungmin Kang and F. von Hippel, "Limited proliferation-resistance benefits from recycling unseparated transuranics and lanthanides from light-water reactor spent fuel," April 10, 2004 (Submitted to *Science and Global Security*). Pyroprocessing is an extraordinarily expensive method of reprocessing based on electro-refining of metals.

²⁹ See www.nce.org.

³⁰ Ibid.

³¹ Ibid.

³² National Energy Policy Group, "National Energy Policy: Reliable, Affordable, and Environmentally Sound Energy for America's Future," May 2001, p. 5-17.

³³ *National Strategy to Combat Weapons of Mass Destruction*, National Security Presidential Directive 17, December 2002. For declassified portions, see www.fas.org/irp/offdocs/nspd/nspd-17.html.

³⁴ House Appropriations Committee, "Energy and Water Development Appropriations Bill, 2006," p. 125.