VIEWPOINT:

THE PLUTONIUM FALLACY: AN UPDATE

by Paul Leventhal and Steven Dolley

Fissile materials—plutonium and highly enriched uranium (HEU)—are at the heart of the nuclear proliferation problem. With several kilograms of either material, a nation or terrorist group could build a bomb that could destroy a city. Lacking these materials, they cannot. Given their importance as the irreducible element of proliferation, fissile materials should be the central focus of nonproliferation efforts. Paradoxically, they are not.

This has not always been the case. In the United States, the Nuclear Non-Proliferation Act of 1978 (NNPA) established the authority of the United States to give or withhold consent to the recovery of plutonium from the used, US-supplied fuel of foreign nuclear power plants. In the two decades since, however, the US government has proven reluctant to exercise this control, looking to avoid political frictions with important allies, such as France and Great Britain (whose state-owned companies bring in large amounts of foreign exchange by "reprocessing" spent fuel to recover plutonium for overseas clients), and Germany and Japan (whose nuclear utilities contract for these services).

As a result, civilian stockpiles of separated plutonium continue to grow. Plutonium that can be used by the kilogram to build bombs is being separated by the ton for possible future use as nuclear power plant fuel. Shortly after the year 2000, we will reach a turning point, when more atom-bomb material will be circulating in civilian commerce than exists in nuclear weapons.

Despite this growing danger, control of civilian fissile materials remains an orphan issue in the nonproliferation field—regarded as a "non-starter" because of the opposition of the major industrial states that are in the plutonium business. Most non-governmental organizations that work on nonproliferation do not focus on civilian plutonium and HEU. The same is true of international arms control organizations. The United Nations Conference on Disarmament is attempting to negotiate a fissile material production cut-off treaty, but the treaty would only cover materials produced for nuclear-explosive purposes. Civilian production and stockpiling would not be curtailed. A similar neglect of civilian fissile materials characterizes the Non-Proliferation Treaty (NPT) review process. At a recent meeting of the Preparatory Committee for the year 2000 NPT review, only one nation's statement out of dozens (that of the Norwegian delegation) suggested that production of civilian fissile material stocks, as well as military stocks, should be banned.[1]

The resounding silence regarding the plutonium threat is even more unfortunate in light of the unique opportunity to deal with the fissile material problem presented by the plutonium industry's current travails. Nuclear electric utilities, particularly in Germany and Japan, are coming to recognize that reprocessing and recycling of plutonium present them with many liabilities and no benefits, aside from briefly deferring the issue of final waste disposal. As a result, no new reprocessing contracts are being signed, and as we will discuss, the plutonium industry is "on the ropes." Nevertheless, the British and French state-owned plutonium industries resist every attempt to diminish the multibillion-dollar reprocessing business, and now they are attempting to establish reprocessing in the world's largest nuclear power industry, that of the United States. These efforts have benefited from a nonproliferation argument, which we will suggest is misguided, that excess weapons plutonium in Russia must be disposed of through the use of mixed-oxide (MOX) fuel.

In this viewpoint, we recount the proliferation risks and other liabilities of reprocessing and plutonium recycling, suggest explanations for the growing malaise of the plutonium industry, review the lackluster history of US nonproliferation policy on the plutonium issue, rebut the most recent arguments for supporting the plutonium industry, and suggest alternative approaches to minimizing the risks posed by this deadly material.[2] In particular, we argue that financial means exist to make "immobilization" of separated commercial plutonium

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and surplus weapons plutonium more attractive to those countries that most favor the use of MOX fuel.

WHY IS CIVILIAN PLUTONIUM A PROLIFERATION RISK?

Plutonium, a man-made byproduct of nuclear fission, is created in civilian reactors that generate electricity for cities, as well as in military reactors that produce material for bombs. The intended use of these two kinds of reactors is different, but the byproduct is essentially the same. Civilian electrical power reactors are typically much larger than military production reactors and therefore produce many times more plutonium. The plutonium produced in power reactors is so-called "reactor-grade," a different mix of plutonium isotopes than the "weapons-grade" produced in military reactors, but still suitable for use in weapons.[3]

Outside the United States, the nuclear industry is well on its way to introducing this civilian, reactor-grade plutonium on the world market as a commercial fuel. The uranium now used in power reactors is a low grade that cannot be used in its existing form in a nuclear weapon. But the plutonium can be used either for fuel or for bombs.

Plutonium becomes a concentrated nuclear-explosive material once it is separated in "reprocessing plants" from the highly radioactive wastes (so-called "spent fuel") of a reactor. If then mixed with uranium to make a mixed-oxide fuel, the plutonium can be used in power reactors. Plutonium separation, once the exclusive domain of bomb-makers, is now getting underway in earnest in commercial reprocessing plants. Fortunately, it is still confined to a relatively small group of countries—Britain, France, India, Japan, and Russia.

For economic and nonproliferation reasons, the United States does not reprocess spent fuel from power reactors and frowns upon reprocessing overseas. US anti-reprocessing policy was originally promulgated by President Ford in 1975, modified by President Reagan in 1982, and restated by the Clinton administration in 1993. However, the United States has not been prepared to press its anti-reprocessing case on European and Japanese allies or to enforce US nonproliferation laws to restrain their plutonium programs. About three-quarters of the plutonium being extracted today in Europe and Japan is from US-supplied nuclear fuel, and therefore subject to US consent rights. However, the United States has given political interests in avoiding disputes with its allies precedence over the security interest of making sure that US exports of non-weapons-usable nuclear fuel do not end up as weapons-usable plutonium in world commerce. As a result, US-origin plutonium is now beginning to enter world commerce in alarming amounts.

By the turn of the century, nearly 1,400 metric tons of plutonium will have been produced in the spent fuel of nuclear power reactors, and over 280 tons of it will have been separated into weapons-usable form.[4] Less than 18 pounds (eight kilograms) is needed to build a Nagasaki-type bomb. The amounts will continue to grow rapidly. By 2010, there will be over 440 tons of separated plutonium in commerce, more than twice the amount now contained in the world's nuclear arsenals.[5] Assuming that the technology and materials suitable for making nuclear weapons continue to spread as legitimate articles of commerce, nuclear proliferation and the closely connected threat of nuclear terrorism will become ever-increasing dangers.

Plutonium is an essential weapons material, but it is not an essential reactor fuel. Ample reserves of uranium have been discovered to keep power reactors operating. Low-grade uranium fuel for power reactors is several times cheaper than plutonium-uranium MOX fuel. The plutonium industry, originally established to offset an anticipated uranium shortage, is no longer needed. But the factories it has built in the meantime to extract plutonium and fabricate it into fuel continue to operate nonetheless.

A further reason plutonium should not be used as fuel, but rather disposed of as waste, is the difficulty of securing it against diversion or theft for use in weapons. The international inspection regime established by the NPT and the International Atomic Energy Agency (IAEA) to verify that peaceful nuclear programs are not misused for military purposes is inadequate to the task. Iraq and North Korea have both shown how military nuclear programs can be developed under the guise of peaceful ones without detection by international inspectors. Compounding this danger is the inability of the inspectors to detect promptly losses of weapons quantities of plutonium from large commercial facilities that operate "legitimately."[6]

It is well understood in the industry, but not acknowledged publicly, that there are systematic diversion schemes capable of defeating the plutonium measurement and security systems operated by national authorities and monitored by international inspectors. These schemes could be used by the state that operates a large plant, or by individual employees working in collusion with outside states or groups, to divert enough plutonium for several weapons.[7] In addition, prompt conversion of peaceful plutonium (or bomb-grade uranium) stockpiles into nuclear weapons by governments in response to regional or global crises is also possible and may pose the ultimate danger. This is what Iraq undertook in 1990, until the Gulf War interrupted its crash bomb program.

After the reprocessing stage, there are also severe security risks involved in the manufacture and use of mixed-oxide fuel. MOX is made by mixing plutonium oxide with uranium oxide and fabricating the mixture into small ceramic pellets that are loaded into metal rods and formed into fuel assemblies for nuclear power plants. This is a messy process, involving bulk handling of plutonium powder by the ton. Making accurate inventory measurements of weapon-usable plutonium in MOX fuel-fabrication plants—where plutonium dust sticks to surfaces and shavings and scrap must be collected for recycling—has proven impossible.

There is clear evidence of this problem. In May 1994, the Nuclear Control Institute (NCI) disclosed that a major plutonium inventory discrepancy had been building up at Japan's pilot MOX fabrication plant since a new automated line began operating in 1988.[8] The Japanese government had asserted that this plutonium, amounting to about 70 kilograms, or more than enough for eight nuclear bombs, was not missing, because it had been measured as "hold-up" material—that is, as plutonium that stuck to surfaces and got held up in the plant's process equipment. But such measurements were taken indirectly by assaying devices, and were subject to significant uncertainties—as large as 30 percent in some instances.

To deal with the uncertainty, the IAEA required Japan to cut open the glove boxes and physically produce and measure the held-up plutonium so that inspectors could verify the plant's inventory. At a reported cost of more than $100 million, and after more than two years of clean-out operations, about 10 kilograms of plutonium (more than a bomb's worth) remained unaccounted for, which fails to meet the safeguards criteria required by the IAEA. Plutonium scrap is another significant source of measurement uncertainty at the Japanese MOX fabrication plant. Scrap containing about 100 to 150 kilograms of plutonium has been put into cans, but the actual plutonium content still must be verified before the inventory balance of the plant can be closed.[9]

In Europe, MOX fabrication plants have not disclosed the operating history of their material control and accounting systems (which are under the control of EURATOM, the EU's nuclear agency, rather than the IAEA). The IAEA is unable to oversee EURATOM safeguards at these facilities and therefore declines to make any judgment about the effectiveness of material accounting and control at European MOX plants. In addition, the adequacy of EURATOM safeguards over MOX fuel at reactor sites is open to question. Indeed, IAEA safeguards director Bruno Pellaud complained to the IAEA director general in 1996 that the IAEA was being denied access to MOX fuel at a reactor site in Germany and being asked to accept EURATOM verification solely on faith.[10]

There is also the crucial question of safeguarding fresh MOX fuel in storage at reactor sites. Weapon-usable plutonium can be separated from fresh MOX fuel by straightforward chemical means. For this reason, the US National Academy of Sciences recommended that fresh MOX fuel be provided the same degree of physical protection accorded to nuclear weapons.[11]

WHY IS THE PLUTONIUM INDUSTRY IN TROUBLE?

More than 20 years after the enactment of the Nuclear Non-Proliferation Act, the Act's critics in the nuclear industry still describe it as a mistake, viewing it as the source of anti-plutonium obstructionism they believe is responsible for the demise of reprocessing and MOX fuel in the United States and for the present difficulties of these industries in Europe and Japan. These critics point with pride at the commercial reprocessing programs of Europe and Japan, and at the official government policy of these nations to "close" the nuclear fuel cycle by recovering plutonium and recycling it as MOX fuel.[12]

In fact, the NNPA was years ahead of its time—a pointer in the right direction. Its central premise—full-scope safeguards as a condition of nuclear supply—not only became the law of the land; it has since become the universally accepted operating principle of the NPT regime. Likewise, its restrictive approach to plutonium commerce anticipated the security threats and the economic liabilities that the plutonium industry faces today.

Plutonium advocates, who are quick to blame the Ford and Carter policies and the NNPA for their misfortunes, do not like to acknowledge what *actually* has happened to the plutonium industry since 1978. It is afflicted with a fatal condition, one with numerous causes. The demise of the fast-breeder reactor (FBR), the original rationale for closing the fuel cycle, was the first and primary etiology.[13]

The United States abandoned its FBR program in 1983 with the cancellation of the Clinch River Breeder Reactor. Since then, the major nuclear industrial nations have followed one by one, until today only India, Russia, and Japan still plan to develop FBRs. Japan's program is on hold after a serious sodium leak crippled the experimental Monju FBR in December 1995, and a follow-on demonstration FBR was postponed indefinitely. Russia's economic crisis will block its FBR development program for the foreseeable future. India's breeder is essentially a non-starter,[14] and its May 1998 nuclear tests confirmed what the world long suspected: its civilian plutonium facilities (including the US/Canadian-supplied CIRUS research reactor) have been a front and a source of material for its nuclear weapons program.[15] Even today, Japan, France, and Russia still cling stubbornly to the FBR pipe dream, and have begun discussions on how they can pursue cooperative breeder reactor R&D.[16]

Other causes of this terminal disease include substantially diminished prospects for future nuclear power capacity. A quarter-century ago, President Ford's "Project Independence" energy policy anticipated that 1,000 commercial nuclear power plants would be operating in the United States by the year 2000. One year short of that milestone, less than half that number are operating *in the world*. As a result, uranium resources and enrichment capacity are cheap and abundant. The enormous capital costs of plutonium fuel cycle facilities have proved to be a millstone around the neck of the nuclear power industry, aggravated by the fact that mixed-oxide fuel is at least four to eight times more expensive than standard low-enriched uranium (LEU) fuel.[17] Finally, there is a growing if somewhat reluctant recognition of the safety and proliferation risks associated with the plutonium fuel cycle.

The truth of the matter was summed up by a top American utility industry executive who once confided to one of the authors—after cautioning that if quoted by name he'd deny it—that we did the US nuclear power industry a "great favor" by killing off the domestic plutonium industry. (It was actually Ronald Reagan who performed the *coup de grace*, on economic grounds.)

Status of the Plutonium Fuel Cycle

The terminal condition of the plutonium industry can be illustrated by briefly examining its status in each of the major nuclear-power nations. We will begin with the *producer states*, that is, France, Great Britain, and Russia. Each of these nations maintains a significant state-owned reprocessing industry, primarily to bring in foreign exchange.

Is it hypocrisy, or mere irony, that Great Britain and Russia do not even load MOX into their own commercial power reactors? Both nations must, as a consequence, maintain enormous surplus stocks of separated civil plutonium (over 54 tons in Great Britain,[18] and over 30 tons in Russia[19]), with no firm plans for their disposition. Great Britain withdrew its support for development of a European FBR, and has shut down its own experimental breeder reactor and the associated reprocessing plant in Dounreay, Scotland. It has even decided against using MOX fuel in its single light-water reactor (LWR), which unlike British gas reactors is presumably suitable for MOX use.

Russia's FBR program languishes for lack of capital; nor does Russia have funds to complete construction of the RT-2 reprocessing plant at Krasnoyarsk. Last November, Ministry of Atomic Energy (Minatom) First Deputy Minister Ivanov predicted that it may take two decades to commercialize the technology required to reprocess spent fuel from Russia's more modern VVER-1000 reactors, and that Russia would rely on dry storage in the meantime.[20] This year, according to a trade press report, "Russia has launched a government-wide campaign to reprocess spent fuel from around the world, including the United States," but there are no indications that Minatom is close to signing any new contracts.[21] Russia plans to fuel LWRs with MOX fuel as a means of disposing of warhead plutonium, but insists on acquiring outside funding to cover the entire cost of this project.[22] To date, the United States has pledged $200 million to help implement warhead-plutonium disposition in Russia,[23] a sum far short of the total amount required. France and Germany have pledged cooperation in construction of a MOX fuel-fabrication plant in Russia, but, not surprisingly, are refusing to put up the money to build it. Nor has anyone offered to guarantee the $45 billion total life-cycle cost of operating Russian VVER-1000 reactors to irradiate MOX fuel,[24] nor for that matter the $120-180 million that would be required to upgrade each of the reactors to Western safety standards.[25]

France, despite a long-standing commitment to close its fuel cycle, canceled its breeder-reactor development program. After a series of technical problems, shutdowns, and sodium coolant leaks, the Superphenix FBR has been permanently shut down and now awaits decommissioning.[26] France also has been slowing down the introduction of plutonium fuels into its light-water reactors. Indeed, a Socialist/Green election platform in early 1997 called for a moratorium on further MOX fabrication, and license applications for eight more reactors to use MOX were put on hold.[27] Nor is France in any hurry to reprocess domestic spent fuel from its national electric utility, Electricite de France (EDF). Most reprocessing has been of foreign spent fuel, thus making it clear that France's reprocessing industry, like Britain's, is intended primarily to be a major foreign-exchange earner. Indeed, in 1995 EDF changed its bookkeeping practices to assign an economic value of zero to its own plutonium stocks.[28]

Of the *consumer states*, Japan has the most ambitious plutonium fuel cycle plans, but they continue to be set back by accidents, scandals, and delays. As noted, the FBR program was left in limbo by the Monju accident. Efforts by investigators to cover up and doctor evidence from the Monju FBR and Tokai reprocessing plant accidents led to the dismantlement of the Power Reactor and Nuclear Fuel Development Corporation (PNC), which had been in charge of FBR development in Japan. In October 1998, data used to certify Kansai Electric's MOX-fuel transportation cask was found to have been falsified, and the cask is now undergoing relicensing. Construction of a large reprocessing plant at Rokkasho-mura is still not complete, and it is now estimated that the project's total cost will reach 2.14 trillion yen (about $17.8 billion), more than twice the original estimate of 840 billion yen.[29] The first shipment of MOX fuel from Europe to Japan may occur sometime this year, but the Japanese national government has only granted final approval for MOX to be loaded into two of the four LWRs selected to initiate the "Pluthermal" program. Nor has one of the governors of the three prefectures where these reactors are located given his approval.

Germany is now in the forefront of rethinking of the plutonium fuel cycle. Some years ago, the Kalkar FBR and Wackersdorf reprocessing plant projects were canceled, because of strong public opposition. In 1995, Siemens was forced to abandon plans to operate its near-complete MOX fuel-fabrication plant at Hanau because of technical violations and local political opposition. Current developments in Germany illustrate the lengths to which the plutonium industry and bureaucracy will go to maintain its base in the absence of market demand for its product. The "Red-Green" coalition won the federal election last October on a platform that called for phasing out nuclear power and reprocessing. By mid-January, the Social Democrats and Greens had agreed on a draft revision of the German Atomic Energy Act that would outlaw reprocessing of spent fuel beginning in 2000.[30]

The German utilities' post-2000 reprocessing contracts contained *force majeure* clauses allowing their termination in case of a decision by the German government that reprocessing is unnecessary or undesirable. Nonetheless, Cogema (the government-owned French reprocessing company) argued that a 1990 Franco-German exchange of notes, requiring that neither government interfere in reprocessing, had the force of a treaty and "cannot be overruled by a law."[31] As a result, German Chancellor Gerhard Schroeder pressed Environment Minister Juergen Trittin to remove the reprocessing ban from the draft nuclear law, which he did.[32] At this point, it is not clear how the German government will proceed on the reprocessing question, given the approximately 30 tons of separated plutonium already being stored in Britain and France[33] and the strong public opposition to its use as MOX fuel, as well as to any further separation of plutonium from German spent fuel in French and British reprocessing plants.

Belgium and Switzerland each plan to irradiate small amounts of MOX fuel to deal with plutonium recovered from their spent fuel under old reprocessing contracts, but do not plan to continue to use plutonium fuel thereafter. In fact, the Belgian government recently canceled a major post-2000 reprocessing contract with Cogema and began a year-long review of its spent-fuel management policy.[34]

The third category, *future candidate states*, includes nations such as South Korea, Taiwan, and the People's Republic of China. These states have growing nuclear power sectors, and are attempting to develop policies to deal with the back end of the fuel cycle. Over the last several years, both South Korea and Taiwan have expressed interest in exploring reprocessing and MOX options, and Cogema, BNFL (formerly British Nuclear Fuels Limited), and Minatom have aggressively sought their business despite US opposition to the recovery of plutonium from fuel originally supplied by the United States to South Korea and Taiwan.[35] China has begun construction of a small reprocessing plant, which it hopes to complete by next year.[36] Nuclear utility and government officials in these candidate states should be paying close attention to the plutonium quagmire that Europe and Japan now find themselves in.

There are some common threads among these twists and turns of policy. First, the producer states do not utilize FBRs at all, and as for utilizing MOX fuel in LWRs, they either do not use it at all, or not to a great extent. But they nonetheless continue to market plutonium technologies and services aggressively to the consumer and candidate states.

Second, nuclear electric utilities in consumer states do not welcome plutonium fuel. They would be opting out of the closed fuel cycle if they were not subject to severe pressure from domestic and foreign plutonium interests. Such pressure takes the form of being held to reprocessing contracts the utilities no longer want or need, as was most recently demonstrated by the successful effort by Cogema and BNFL to derail the new German government's effort to phase out reprocessing. A physics expert working for a German utility said, in the context of efforts to make Germany's nuclear electric utilities competitive in a future European market, that "MOX is a pain in the neck." And a German utility official expressed concern that foreign reprocessors would attempt to "blackmail" utilities with Germany's "plutonium mountain," presumably by insisting upon repatriation of separated plutonium to Germany if utilities attempt to renegotiate or cancel contracts.[37]

The utilities now understand too well that they shoulder far greater risks and expense with MOX fuel than with conventional uranium fuel. In addition to complicating safeguards and security, MOX fuel is several times more expensive than LEU fuel. Because of its cost, the French-German European Power Reactor (EPR) project to develop an advanced light-water reactor recently proposed that MOX fuel not be used, in an attempt to make the reactor design economically competitive—despite the public pro-MOX posture of Electricité de France, one of the project's partners.[38]

These are the real reasons why no new reprocessing contracts are being signed, despite the fact that the price of such contracts has dropped by nearly 50 percent over the last decade. That is also why BNFL, the government-owned British plutonium company, has been unwilling to "market test" its 54-ton stockpile of surplus separated plutonium—that is, to offer it to customers for fabrication into MOX instead of separating yet more unwanted plutonium at its Sellafield reprocessing plant.[39]

Plutonium simply makes no sense, especially in the increasingly deregulated electricity market in which nuclear utilities now find themselves. There is *no* market for plutonium when nuclear utilities must compete against cheaper sources of electrical power.

WHAT ABOUT THE UNITED STATES?

The United States, neither a producer nor a consumer of commercial plutonium fuel-cycle services, still retains a unique position of global influence on the issue. One-quarter of the world's nuclear power plants are located in the United States, as are the tens of thousands of tons of spent fuel generated by these reactors. The United States is also the largest supplier of uranium-enrichment and fuel-fabrication services. It exercises "consent rights" under the terms of the NNPA to permit or prohibit the separation of plutonium from vast amounts of foreign spent fuel containing "US-origin" uranium. The Department of Energy (DOE)'s Office of Arms Control and Nonproliferation characterized this influence as follows in a recent nonproliferation assessment:

> Because of its pivotal role in preventing the proliferation of nuclear weapons and its own extensive nuclear programs and activities, the manner in which the United States manages its nuclear materials has an influence on other states, both by example and in the way it supports US diplomatic efforts and initiatives. US technical and policy choices frequently influence other countries. Thus, management decisions taken in the United States can positively

> or negatively affect initiatives to further enhance the global nonproliferation regime and bolster the international norm against the acquisition of nuclear weapons.[40]

There are now no elements of a commercial plutonium fuel cycle (reprocessing, MOX fuel fabrication, or irradiation) operating in the United States. US nuclear electric utilities abandoned efforts to develop such a fuel cycle more than a decade ago. However, the European plutonium industry is now avidly attempting to penetrate this largest potential market for its services. BNFL and Cogema have each established a major corporate presence in the United States.

One attempt to break into the US market came in late 1992, when the Long Island Power Authority attempted to enter into a contract with Cogema to reprocess the slightly irradiated initial core of the defunct Shoreham reactor being decommissioned. Ultimately the export of the fuel to France was disapproved by the Executive branch, but only after the Nuclear Control Institute intervened in NRC export licensing proceedings, and after Defense Department officials objected that they had not been given an appropriate opportunity, as required by US law, to review the proposed export.

British and French reprocessors are likely to make further attempts to win reprocessing contracts as additional US reactors permanently shut down (Maine Yankee, for example), and as DOE's inability to accept utilities' spent fuel for final disposal in a repository, as required by the Nuclear Waste Policy Act of 1992, compels utilities to face the issue of crowded spent-fuel pools at reactor sites. While getting rid of spent fuel may seem attractive to American nuclear utilities, taking back separated plutonium and vitrified reprocessing waste, materials they have no experience with handling, will not be welcomed at all. Nor will Britain and France be willing to store surplus plutonium and the waste byproducts indefinitely.

Despite these problems, plutonium has found some powerful friends on Capitol Hill. One of the most influential has been Senator Pete Domenici of New Mexico, chair of the Senate Budget Committee and the Energy Appropriations Subcommittee. Senator Domenici holds that the United States should abandon its no-reprocessing policy:

> The 1977 decision by the United States to halt research into reprocessing and mixed-oxide fuel did not curtail other countries' pursuit of these technologies. Now the United States is unable to use these technologies to meet urgent energy or nonproliferation needs and has been largely left out of international nuclear fuel cycle issues.... Reprocessing—even limited reprocessing—could help mitigate the potential hazards in a repository, and could help us recover the energy content of the spent fuel.[41]

Such plutonium evangelism was also evident in a provision of S. 1271, the Nuclear Waste Policy Act of 1996, which would have allowed US utilities to ship their spent fuel overseas for reprocessing on an emergency-relief basis.[42] This provision was removed after NCI and a coalition of public interest groups objected to it as a major breach of US nonproliferation policy against promoting civil use of plutonium.[43] Nuclear waste bills introduced in subsequent sessions of Congress, including the current one, have emphasized centralized interim storage prior to completion of a geologic repository. In our opinion, centralized storage is unwise because it could add an additional transportation stage if a final repository next to the proposed storage site (presently Yucca Mountain in Nevada) fails to open. Also, centralized storage of spent fuel could be an invitation to future reprocessing, especially if the initial attempt at final disposal does not work out as planned.

Meanwhile, large-scale non-commercial reprocessing continues in the F and H canyons at the Department of Energy's Savannah River Site (SRS) in South Carolina. The materials being reprocessed are mostly defense-related. They include residual waste materials being stabilized pending their disposition, as well as some fuel and targets from defense programs and research reactors. There is no definite timetable for canyon shutdown, and various reprocessing campaigns proposed by DOE could delay closure of the canyons until 2035.[44]

The SRS canyons do not now reprocess spent commercial nuclear power fuel, but Westinghouse did prepare an economic analysis of just such an option, in response to a request by Representative Norwood of Georgia.[45] This alternative has never been formally ruled out, and could be revived if the political winds proved more favorable in the future. But even DOE, not noted for its enthusiastic implementation of US nonproliferation policy on plutonium, is on record as recognizing that continued reprocessing of DOE's non-commercial spent fuel in the SRS canyons could send the wrong signal to the rest of the world about US efforts to discourage use of plutonium:

> A decision to reprocess the aluminum-based spent nuclear fuel at the Savannah River Site could negatively affect the credibility of US policy not to encourage reprocessing. First, as long as the United States continues to operate some reprocessing facilities, reprocessing advocates in other countries will point to this activity and argue that even the United States understands the need for reprocessing in some circumstances. A decision to reprocess this material would extend the time that reprocessing operations must continue at the Savannah River Site.[46]

With regard to the aluminum-based spent fuel, DOE to its credit is attempting (despite considerable resistance among some reprocessing enthusiasts at the Savannah River Site) to develop and implement an alternative to reprocessing, known as "melt and dilute."

On the other hand, the US government is giving its full support to a plan to introduce MOX fuel into US nuclear power plants, despite a warning by the Arms Control and Disarmament Agency (ACDA) that this approach could send precisely the wrong signal to the rest of the world.[47] The Clinton administration has devised a "two-track" approach for disposing of weapons plutonium that includes turning most of the surplus plutonium (at least 33 tons) into MOX fuel. The second track is to dispose of some of the plutonium by combining it with (and thereby "immobilizing" it in) highly radioactive waste. Proponents insist this two-track, MOX-and-immobilization approach is the only way to win the cooperation of Russia, which believes in the economic value of plutonium and won't think of throwing it away. They also claim that those who oppose any use of mixed-oxide fuel in a plutonium disposal plan are relying on simple ideological positions.[48]

But a one-track approach that treats plutonium as waste cannot be so neatly dismissed. It is practical. DOE acknowledges that immobilization can do the whole job, while MOX cannot. All surplus plutonium, pure and impure, can be immobilized in waste, while only the purest forms can be turned into MOX fuel. The waste approach is fast, cheap, and efficient compared to MOX. Concentrating limited resources on validating immobilization in both the United States and Russia would help, not hinder, the pace and scope of the disposal effort.

Dual-track proponents in the United States, including the Clinton administration, contend that, since Russia rejects the proposed immobilization method of plutonium disposition, a MOX approach is the only way to get Russia to cooperate and dispose of its own warhead plutonium. This argument simply doesn't make sense. The US-Russian nuclear disarmament process is fundamentally bilateral in character, and the United States will always have substantial influence in the areas of safeguards, security, and verification, whatever the means of disposal. Also, the joint US-Russian government plutonium disposition study recognized that "[t]he United States and Russia need not use the same plutonium disposition technology. Indeed...it is likely that the best approaches will be different in the two countries."[49] In short, the Russian government has formally acknowledged that the United States need not use MOX as its plutonium disposition method. Moreover, the United States possesses the ultimate tool for exerting leverage over the Russian program—money. There is little question that the United States will end up bearing most of the financial burden of Russian plutonium disposition. If the United States simply acquiesces in Russia's desire to pursue MOX, it could lose the leverage it already has. Since the MOX technology that Russia and the United States would acquire is of European origin, US participation in fundamental technology and design issues would automatically be marginalized. The better approach for the United States is to promptly demonstrate an immobilization technology that it can offer Russia, and to make it financially attractive to Russia to cooperate in a joint vitrification program.

Nonetheless, DOE recently awarded a contract for the MOX portion of the plutonium disposition program to a consortium that includes Cogema, which would build the MOX fabrication plant, and Duke Power and Virginia Power, which would irradiate the warhead-plutonium MOX fuel in nuclear power plants in Virginia, North Carolina, and South Carolina.

The MOX approach presents two sets of problems that US utilities and their customers have been spared thus far. First, as discussed earlier in this paper, the MOX option presents greater risks of diversion and theft of plutonium. This is primarily because the fuel-fabrication process is difficult to safeguard effectively, and also because of the need to transport MOX fuel long distances to reactors. Uncertain safeguards and verification, an especially acute problem in Russia, could severely limit the trust nations place in an international nuclear arms reduction and nonproliferation regime.

Second, the use of tons of plutonium from dismantled nuclear warheads as fuel in civilian nuclear power reactors will result in a significant increase in cancer risk to residents in and near the plants. In particular, because of the greater concentrations of toxic radioactive isotopes, such as plutonium, americium, and curium, in a reactor operating with MOX fuel compared to one operating on LEU fuel, the consequences for public health of a core-meltdown accident would be greater. A recent NCI report[50] identified a number of technical flaws and misleading statements in earlier analyses by DOE that had found only a slight increase or even a decrease in cancer risk in the event of a severe accident at a power reactor using warhead plutonium in its fuel. We found that within a 1,000-mile radius of a plant, the number of "early" cancer fatalities among the public (those that will occur due to radiation exposures within one week after a severe accident) will be 81 to 96 percent greater on average for a plant with a full core of weapons-grade MOX fuel, and 27 to 32 percent greater for a plant with a one-third core of this type of MOX fuel, than for a plant with an LEU core. We found that in such an area, with a surrounding population density similar to that near Duke Power's Catawba and McGuire plants, the actual number of additional fatalities would be 1,430 to 6,165 if the plant had a full core of warhead-plutonium MOX fuel, and 477 to 2,055 if the plant had a one-third core of this fuel.

THE FAILURE OF US NONPROLIFERATION POLICY TO CONTROL PLUTONIUM

The MOX approach to plutonium disposition is simply the latest example of the Clinton administration's infinitely flexible nonproliferation policy on plutonium. When the policy was first unveiled in 1993, plutonium advocates criticized the restrictions on plutonium use as Carter policy reborn. But in practice the Executive branch has followed a "don't ask, don't tell" approach to plutonium use that is virtually indistinguishable from the Reagan and Bush years. That is, the policy on plutonium is repeated, almost like a mantra, when State Department officials are asked about it, but, in fact, the Clinton administration does *not* actively "seek to eliminate where possible the accumulation of stockpiles of highly enriched uranium or plutonium," or "explore means to limit the stockpiling of plutonium from civil nuclear programs," as it pledged in the 1993 policy. This policy announcement also stated:

> 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.[51]

In pursuing this policy over the past five years, the administration has managed to expand the concept of "existing commitments," to the detriment of efforts to limit or eliminate reprocessing and the civil use of plutonium. Time and again, the State Department has deferred to Western European and Japanese interests on civil plutonium matters. Whether the issue has been the European demand for sweeping programmatic approvals of reprocessing and MOX use in the US-EURATOM nuclear cooperation agreement, or Japan's demand for approval of European fabrication of MOX fuel for Japanese reactors before the use of such fuel was approved in Japan, or Japan's demand for an easing of US security requirements on MOX fuel shipments from Europe, nonproliferation objectives invariably have taken a back seat to avoidance of political friction with allies.

The Department of Energy aptly described the devolution of the plutonium-use policy in a December 1998 nonproliferation assessment:

> Under this policy, the United States will continue its commitments *not to interfere* with civilian nuclear programs that involve the reprocessing and recycling of plutonium in Western Europe and Japan. In regions of proliferation concern, however, the United States actively opposes plutonium reprocessing and recycling.[52]

Thus, over the last five years, the policy has degenerated from an assurance that *existing* commitments (such as the 1988 advance programmatic consent for Japanese reprocessing) would continue to be honored, to the de facto creation of a new, sweeping commitment to *non-interference*—in other words, a laissez-faire approach to plutonium fuel cycles.

A basic flaw in the US policy on plutonium is that, while it purports to take "a comprehensive approach to the growing accumulation of fissile material from dismantled nuclear weapons and within civil nuclear programs," in reality it takes a highly discriminatory approach. It indulges the plutonium (and highly enriched uranium) fuel programs of Europe and Japan, and it advocates a fissile material cut-off treaty that is applicable only to plutonium and bomb-grade uranium produced for *weapons,* turning a blind eye to *civilian*, weapons-usable nuclear materials worldwide.

The answer to the question—"Is the United States opposed to civil reprocessing and plutonium use?"—apparently depends on what the meaning of the word "is" is.

THE REPROCESSING FALLACY REVISITED

European and Japanese plutonium enthusiasts, freed from even a hint of disapproval from the United States, have had to contend only with their own foibles, not to mention the immutability of the plutonium fallacy itself. The demise of the breeder reactor has forced the plutonium industry to come up with other justifications for reprocessing and plutonium use. Before concluding, we briefly examine and rebut two of the principal ones: energy security and waste management.

Reprocessing is Not Needed for Energy Security

Advocates of plutonium recycling claim that world uranium reserves will prove insufficient, perhaps facing total depletion within a few decades.[53] Such predictions are based on the narrowest available estimates of total uranium reserves, that is, "Reasonably Assured Resources" (RAR) recoverable at a cost below $80 per kilogram of uranium oxide.[54] However, RAR includes only well-known, completely explored deposits. If Estimated Additional Resources, Category I (EAR-I)—known resources in deposits that have not been completely explored—are also included, estimates of world reserves increase by more than half.[55] Further, according to these OECD/IAEA estimates, "There remains very good potential for the discovery of additional uranium resources of conventional type, as reflected by estimates of EAR-II and Speculative Resources."[56]

Even if Speculative Resources are excluded, uranium reserves would suffice to fulfill projected world demand until the year 2062 from resources recoverable up to $80/kg of uranium oxide, or until the year 2075 from resources recoverable up to $130/kg.[57] Ample uranium exists to fulfill world demand far into the future. Additionally, long before these conventional uranium resources are depleted, rising prices would make uranium production from unconventional sources, such as seawater, economically competitive, providing nearly boundless uranium supplies without the need to resort to breeding plutonium.[58]

Reprocessing is Not Needed for Waste Management

Reprocessing proponents also claim that reprocessing and recycling represent a superior waste management alternative to the direct disposal of spent fuel in a geologic repository. They cite the reduced volume of high-level waste when uranium and plutonium are recovered and fission products are mixed in a glass matrix to create vitrified high level waste (VHLW). They also claim that VHLW contains less toxic and radioactive content than the equivalent amount of spent fuel.

First, to state the obvious: If plutonium and recovered uranium from reprocessing are *not* recycled as MOX fuel, no volume-reduction or toxicity-reduction benefits ensue, because the plutonium and uranium must still be disposed of. In fact, uranium recovered from reprocessing is not being widely used on a commercial basis, because it is far more expensive than unirradiated uranium oxide, and also contains isotopes such as U-232 that complicate its re-use and pose environmental safety and health risks. Nor at this time is there widespread recycling of plutonium, because of the high costs and risks, discussed earlier, that make MOX fuel so unattractive to utilities and so threatening to the survival of the nuclear power industry.

Even if the uranium and plutonium were recycled, the irradiated MOX fuel must still be disposed of in a repository. Plutonium advocates often imply, when addressing non-technical audiences, that plutonium can be recycled in a closed fuel cycle until it is entirely used up. However, such complete burning of plutonium in MOX is impossible. After only two or three recycles, the isotopics of plutonium are such that it cannot continue to be re-irradiated in fresh MOX fuel, and it must be disposed of.[59] Moreover, even the most fervent MOX supporters (France and Russia) do not currently plan to reprocess LWR MOX fuel even once for recovery and re-use of plutonium.

Once MOX fuel enters into the equation, any purported waste-management benefits of reprocessing are forfeited. In fact, in regard to volume and toxicity, irradiated MOX is considerably worse than irradiated LEU for three reasons. First, reprocessing itself creates substantial intermediate- and low-level waste streams. When this waste is taken into account, the volume of reprocessing waste products requiring deep geological disposal is greater than the volume of waste from the equivalent amount of once-through LEU fuel by at least a factor of ten.[60] Second, the key variable determining the volume requirements for a geologic repository is the total heat loading, not the physical volume of the spent fuel.[61] In this regard, MOX spent fuel creates much greater heat loading than the comparable amount of LEU spent fuel, at least during the first 100 years or so when heat loading is most significant.[62] Third, irradiated MOX fuel has considerably more radiotoxic content than its LEU fuel equivalent.[63]

It is worth noting (but it is not surprising) that the only assessments claiming waste-management advantages for reprocessing and recycling are those prepared by the plutonium industry itself. Independent studies invariably conclude either that there would be no significant waste-management difference between the two cycles,[64] or that reprocessing-recycle would be worse than once-through.[65] Thus, a review of the literature by the US Office of Technology Assessment concluded:

> Despite such potential advantages, major studies that have considered reprocessing in the context of waste management have concluded that reprocessing of commercial spent fuel is not required for safe waste isolation. … Moreover, reprocessing—which generates additional radioactive waste streams and involves operational risks of its own—does not appear to offer advantages that are sufficient to justify its use for waste management reasons alone. Thus, while large-scale reprocessing of commercial spent fuel would have significant implications for waste management, those implications would not be a major factor in the decision on whether to undertake such reprocessing.[66]

CONCLUSION

When the economic, health and safety, and proliferation liabilities of reprocessing and recycling are tallied up, it is not surprising that the plutonium industry is dying. Yet proponents of the closed fuel cycle are attempting a comeback in the United States, masquerading as arms controllers and pushing the warhead-plutonium MOX fuel disposition program. It should be clear that these plutonium advocates will not be satisfied unless and until the limited use of warhead-plutonium MOX fuel establishes a beachhead in the United States for widespread commercial use of reactor-grade MOX fuel. Of course, commercial MOX fuel would be fabricated from plutonium recovered in reprocessing plants from the spent fuel of power reactors.

It is not too late to reverse these disturbing trends. The Clinton administration should implement its nonproliferation policy pledges that the United States will "seek to eliminate where possible the accumulation of stockpiles of highly enriched uranium or plutonium," and will "explore means to limit the stockpiling of plutonium from civil nuclear programs."[67] One option would be for the United States to promote implementation of the National Academy of Sciences (NAS)'s "spent fuel standard," a benchmark of the US warhead-plutonium disposition program, in civilian nuclear programs around the world. As posited by the NAS, the spent fuel standard:

> ...means making the excess WPu [weapons plutonium] roughly as inaccessible for weapons use as the much larger and growing quantity of plutonium in spent fuel from commercial nuclear-power reactors. The 'reactor-grade' plutonium found in commercial spent fuel, while it could be used to make nuclear bombs, poses much smaller risks than separated plutonium in this regard because of the mass, bulk, and intense radiation field of the spent fuel assemblies and because of the additional technical sophistication and resources required for the chemical separation of the spent fuel plutonium from the accompanying fission products and uranium.[68]

If it were broadly applied to civilian nuclear power programs, the spent fuel standard would require halting further reprocessing—i.e., keeping plutonium safely in spent fuel rather than separating it into weapon-usable form. But what about the large and growing stockpiles of civilian plutonium that have already been separated? In order to avoid the serious proliferation and safety risks of MOX fuel, reprocessing customers should request that

Cogema and BNFL immobilize their separated plutonium in highly radioactive waste (left over from reprocessing) prior to its return. The plutonium would be mixed with ceramic or glass and placed in small cans. These cans then would be placed inside canisters at Cogema and BNFL's waste-vitrification facilities, which are already operating. There, the canisters would be filled with molten, vitrified high-level waste, locking the plutonium into the equivalent of spent fuel with a self-protecting radiation barrier. This approach, known as "can-in-canister," is currently under development in the United States for disposition of at least some of its surplus weapons plutonium.[69]

To immobilize their plutonium, reprocessing customers would have to pay Cogema and BNFL either to build a special process line or to modify an existing one. For a ceramic immobilization facility with a throughput of five tons of plutonium per year, the US Department of Energy estimated that the investment cost would be $450 million. This is less than half of the $1.1 billion that German utilities alone might wind up paying reprocessors for overseas storage of their separated plutonium over the next decade.[70] If a number of reprocessing consumer nations, in particular Japan, were to request this option, their shared costs would be minimal, and their combined savings enormous compared with the expensive MOX-fuel and plutonium-storage options.

The United States should also rely on immobilization, rather than MOX, for disposition of warhead plutonium. Russia has expressed a strong preference for the MOX approach, but the Clinton administration has been excessively deferential to this preference in its negotiations with Moscow. Given that Russia does not have the economic wherewithal to pay for either MOX or immobilization, the United States will likely have to pay the lion's share of the cost of disposing of Russian plutonium. This gives the United States a good deal more leverage than it has exercised to date.

The liabilities of reprocessing and MOX fuel are even greater now than they were when the NNPA became law. As a result, plutonium proponents have begun to espouse creative new justifications for plutonium fuel cycles. For example, Senator Domenici and other proponents of commercial reprocessing and MOX fuel advocate using plutonium instead of fuels that produce greenhouse gases, in a nuclear solution to global warming. But Princeton University scientists have calculated that replacing just one-fourth of global fossil-fuel use would require a ten-fold increase in nuclear capacity (to 3,000 large reactors worldwide) and would place about five million kilograms of separated plutonium into global commerce each year. That's equivalent to at least 700,000 nuclear bombs.[71]

Who will guarantee that the eight kilograms or less of plutonium needed to destroy a city will not go astray from time to time? It is to be hoped that nuclear power decisionmakers, electric utilities, and electricity consumers, both here and abroad, will come to recognize these liabilities before additional millions of dollars are squandered and millions of lives are put at risk by these dangerous non-solutions to energy-security and nuclear-waste-management problems.

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[5] Ibid., Table 14.10, p. 412.

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Case Study of the Challenges of Nuclear Materials Accountancy," Presented to the 39th Annual Meeting of the Institute of Nuclear Materials Management (INMM), Naples, FL, July 27, 1998.
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[11] Committee on International Security and Arms Control, National Academy of Sciences, *The Management and Disposition of Excess Weapons Plutonium* (Washington, DC: National Academy Press, 1994), p. 31.
[12] For example, David Rossin, former head of the American Nuclear Society, recently wrote: "By the end of the Carter administration in 1981, the NNPA was law, the nine-volume report of INFCE [the International Nuclear Fuel Cycle Evaluation, promoted by the Carter administration] could be found gathering dust on countless bookshelves, and U.S. influence in international nuclear affairs had receded significantly. In early 1982, President Reagan effectively rescinded Carter policy, and allowed programmatic approvals for reprocessing of U.S. origin fuel by Euratom nations and Japan. But by that time all the remaining industrial momentum in the United States was gone. No serious effort to revive commercial reprocessing in the United States has emerged since then." A. David Rossin, "U.S. Policy on Spent Fuel Reprocessing: Where Did It Come From?," Center for International Security and Arms Control, Stanford University, 1999, <http://www.stanford.edu/group/CISAC/test/people/spentfuel.html>.
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