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Plutonium End Game: Stop Reprocessing, Start Immobilizing

BY ARJUN MAKHIJANI

The problem of surplus military plutonium emerged quickly and with a high profile at the end of the Cold War because of widespread fears that black markets in such plutonium (and tactical nuclear warheads) might emerge from the collapse of the Soviet Union. But an equally important potential proliferation problem – that of separated commercial plutonium — has been quietly mounting in the past decade, without comparable attention.

The hope of the nuclear industry had been that commercial plutonium would be a valuable fuel. But economic events in the real world have negated these hopes, just as the political events have rendered obsolete the idea that large military plutonium stocks were a security asset.

Since essentially all isotopic combinations of separated plutonium, whether of commercial or military provenance, can be used to make nuclear weapons, plutonium is one of the most important links between the commercial and military nuclear industries. Management of separated plutonium, whatever its origin, is therefore crucial to sound non-proliferation policy.

A great deal has been written about surplus military plutonium, including a considerable amount of literature produced by IEER, the US National Academy of Sciences, and others. In January 2001, IEER released a report on management of commercial plutonium, and how its disposition could and should be integrated with that of surplus military plutonium. This article summarizes that work. For references, please see the full report.[1]

Plutonium-239 is made by irradiating relatively abundant, naturally-occurring uranium-238 in a nuclear reactor. This can be done for military purposes, whereby plutonium is extracted from the fuel and targets rods that have been irradiated in a nuclear

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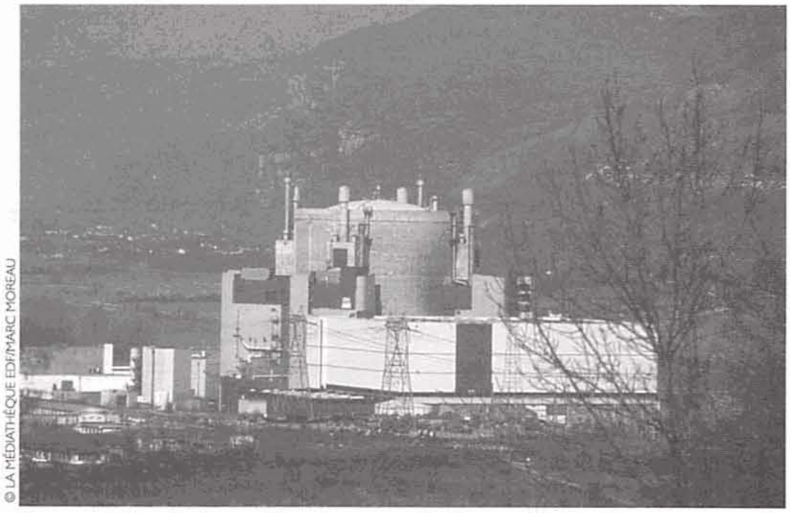

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Superphénix, the largest breeder reactor in the world, shutdown prematurely and permanently in 1998. France's breeder reactor program failed due to technical problems and high costs.

EDITORIAL

A Global Truth Commission on Health and Environmental Damage from Nuclear Weapons Production

BY ARJUN MAKHIJANI

Extensive research in the last two decades has shown nuclear-weapon states have, first of all, harmed their own people without informed consent, in the name of national security.[1] Nuclear weapons production workers have been on the front lines of this underside of the Cold War that nuclear-weapon states have waged on their own people. But the manner in which this slow attack on health and the environment was carried out is still largely unknown and little understood. In the last two decades, a substantial idea of the damage has begun to emerge from the fog of denial and

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reactor (collectively called the irradiated reactor fuel, or spent fuel). Plutonium is also created in commercial nuclear reactors, since uranium-238 is present in large amounts in commercial nuclear reactor fuel. Since there are a large number of such reactors (more than 400 worldwide), the total quantity of plutonium that has been generated in the commercial nuclear power industry has been far greater than that produced in military nuclear weapons programs. By the end of 1999, the total plutonium created in commercial power reactors amounted to over 1,400 metric tons, compared to about 270 to 300 metric tons in military programs.

Plutonium can also be used to fuel reactors. In order to be used as a nuclear fuel, plutonium must first be separated from residual uranium and fission products in the irradiated fuel rods. The chemical and electrochemical processes used to accomplish that separation go under the general rubric of "reprocessing." Of military plutonium, about 250 metric tons remains in government stocks. The rest was used up in nuclear tests, scattered about the world and in underground cavities, as the unused residue from tests, and stored or dumped as waste. Of the commercial plutonium, about 280 metric tons has been separated, while the rest remains in the spent fuel. Some of the separated commercial plutonium has been used as a mixed plutonium oxide-uranium oxide (MOX) fuel, while the rest is stored. Table 1 shows the current inventory of commercially separated plutonium in the world.

The stock of commercial plutonium is growing at roughly ten metric tons per year, since the amount of plutonium being used as MOX fuel is considerably lower than the amount separated. The military stock is growing at about one metric ton per year, mainly in Russia and the United States, both which claim that they are reprocessing for environmental, not military, reasons. At this rate, the stock of commercial separated plutonium is set to exceed the stock of military plutonium in the next few years. It is already so huge that it represents a serious proliferation problem. An Inter-agency Working Group of the US government on plutonium disposition has clearly stated that:

> *"Virtually any combination of plutonium isotopes – the different forms of an element having different numbers of neutrons in their nuclei – can be used to make a nuclear weapon. Not all combinations, however, are equally convenient or efficient."*[2]

One metric ton of weapon-grade plutonium could be used to make about 200 nuclear bombs – more, if sophisticated bomb designs are used. It takes roughly 40 percent more commercial-grade plutonium to make a similar bomb. Stored commercial plutonium is therefore sufficient to make at least 30,000 nuclear bombs of a size similar to the one that destroyed Nagasaki.

Background to the commercial plutonium predicament

For much of the period after World War II, plutonium was viewed not only as the currency of power in a nuclear weapons world, but also as a "magical" energy source. This was because a special type of reactor, called a breeder reactor, would convert uranium-238 into

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Editor: Lisa Ledwidge

TABLE 1: ESTIMATED SEPARATED COMMERCIAL PLUTONIUM STOCKS IN COUNTRY OF STORAGE, METRIC TONS

Country	Separated Plutonium	Date of stock	Comments
France	~80	End of 1999	Includes foreign plutonium stored in France
Britain	78.5	31 March 2000	Includes foreign plutonium stored in Britain
Russia	30	2000	
Japan	5.3	End of 1999	
USA	1.5	2000	
Other	11	End of 1998	Germany, Belgium, India
TOTAL	~206		*Total set to exceed 210 metric tons by the end of 2000.*

Note: Includes plutonium in the form of unirradiated MOX fuel.

more plutonium-239 than was actually needed to run the reactor. Hence there would be more fuel (plutonium-239) at the end of the process than at the beginning, even though electricity had been generated.[3]

The high hopes of the 1950s that plutonium would provide such a "magical" energy source – one that might even be "too cheap to meter" – have run aground on the shoals of a host of practical problems that have steadily grown worse over the past 25 years:

1. Uranium turned out to be far more plentiful than anticipated, and the price of uranium declined rapidly (with an upward blip in the 1970s). It is currently at or near historic lows.
2. Sodium-cooled breeder reactors, the technology of choice for creating a plutonium economy, and the one in which the greatest efforts and money have been invested, have turned out to be a very difficult technology to master and make economical. Despite over $20 billion (1999 dollars) in construction expenditures over more than four decades for just the large completed plants, the technology continues to be plagued by technical problems and high costs. Table 2 (next page) shows the approximate worldwide capital expenditures on major sodium-cooled breeder reactors (in 1996 dollars), and the current status of the various reactors.
3. Separated commercial plutonium can be used to make nuclear weapons, so that the development of a plutonium economy incurs considerably increased proliferation risks compared to those posed by uranium-fueled nuclear power reactors.
4. Reprocessing proved to be a costly technology, thereby increasing costs of plutonium relative to uranium.
5. Reprocessing results in discharges of large amounts of liquid radioactive waste and also creates other radioactive wastes that pose environmental problems and create safety and health risks.

These structural factors have been accompanied by recent events, all but one of which are highly unfavorable to continued commercial reprocessing and MOX fuel use:

1. After the election of the Social Democratic-Green coalition government in late 1998, Germany decided to phase out nuclear power. This phase-out schedule, as it stands at the present time, will be relatively slow, corresponding approximately to the lifetime of the existing power plants. But the phase-out necessarily includes a stoppage of reprocessing German spent fuel. This will make it even more difficult to rationalize continued operation of UP2 in France (a facility dedicated to foreign spent fuel reprocessing) and the reprocessing plant in Britain, called THORP, belonging to the government-owned company, British Nuclear Fuels (BNFL), also commissioned to serve foreign customers.
2. The German government's decision to phase-out nuclear power, and hence also reprocessing, is causing reverberations in France and elsewhere, where the topic of a phase-out of nuclear power is no longer as politically difficult as before. The subsidies to plutonium in France particularly stick out as a sore thumb. (See accompanying article on page 9.)
3. The Science and Technology Committee of the British House of Lords concluded in 1999 that most British commercial plutonium should be declared a waste. This was a severe blow to the prospects for plutonium fuel subsidies in Britain.
4. The sodium-fire accident at the Monju demonstration breeder reactor in Japan in 1995 – only about a

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TABLE 2: CAPITAL COSTS OF SODIUM-COOLED BREEDER REACTORS LARGER THAN 100 MEGAWATTS-THERMAL (MWt)

Reactor and Country	Capacity, MWt	Operation dates[a]	Capital cost, millions of US dollars (1996)
Fermi 1, USA	300	1966-72	403
BN350, Kazakhstan	1,000	1972-	724
Phénix, France	560	1973-	395
Dounreay PFR, Britain	600	1974-94	~395
Joyo, Japan	100	1977-	144
KNK-2, Germany	~100	1977-91	107
BN600, Russia	1,470	1980-	918
FFTF, USA	400	1980-1993	1,397
Superphénix, France	2,900	1985-98	6,028
Monju, Japan	714	1994-1995	5,134
SNR-300, Kalkar, Germany	762	Did not open	4,272
TOTAL	8,906		19,917[b]

Notes: a. Start of operation corresponds to achievement of criticality. b. The total does not include about $1.6 billion (current dollars) spent on the incomplete and abandoned Clinch River breeder reactor (about $3 billion in 1996 dollars) nor the costs of other incomplete reactors.

year-and-a-half after it went critical – and the September 1999 criticality accident at the Tokaimura plant (which killed two workers from high-level radiation exposure and injured many others) have increased opposition to Japan's MOX fuel use plans. The entire future of nuclear power in Japan is now far more open to question than seemed possible before the Tokaimura accident.

5. The revelation that some BNFL MOX fuel quality control data were fabricated, including data relating to some of the fuel shipped to Japan, has thrown the British MOX program as well as reprocessing into disarray.
6. Russia's Minatom, the nuclear energy agency with the strongest attachment to a plutonium economy, has been and continues to be strapped for funds and cannot pursue an ambitious breeder reactor program on its own. Russia also lacks a commercial-scale MOX fuel fabrication plant.
7. The sole recent factor favoring MOX fuel use comes from the military sector. The 1 September 2000 US-Russian agreement would fill the only gap in the Russian plutonium fuel cycle infrastructure, if it is fully funded by the West and proceeds as envisioned (see below). This agreement is aimed at putting military stocks of plutonium that have been declared surplus by the two countries into non-weapons usable form, mainly by using it as MOX fuel in light water reactors. Russia also wants the MOX fuel fabrication plant to be capable of making MOX fuel for breeder reactors. However, Russia and the United States have not been able to arrive at an agreement about who would bear the liability for the program, including in case of an accident. The agreement leaves that question open for further negotiations (see accompanying article on page 12).

The net result of the historical and current trends and events is that there is now a large policy issue of what should be done with the huge but uneconomical stock of commercial plutonium that is growing rapidly. The problem is exacerbated by the fact that the plutonium stocks and facilities are run by institutions that have a declining command of public confidence and respect, not least because of the data fabrication, safety, and environmental scandals that afflict BNFL. These factors have compounded the underlying problems arising from poor economic decision-making by governments and plutonium-related corporations.

Unsurprisingly, the plutonium industry continues to push for subsidies, upon which it should have no reasonable claim. A huge and unjustifiably large sum – on the order of $100 billion worldwide – has already been spent over the past five decades on attempts to

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create a plutonium economy. Much of this was on large breeder reactors, most of which are now shut. Most of the rest was on reprocessing and the use of the resulting uneconomical plutonium as a reactor fuel. These costs are summarized in Table 3. There is no end in sight to the subsidies and there is no reasonable way to resolve the many problems that are still outstanding in the foreseeable future.

By any rational economic and security criteria, the commercial plutonium fuel and breeder industries should have made a complete exit from the stage of energy choices at least a decade ago. Yet, commercial plutonium separation continues in several countries. Plans for breeder reactors also remain in place in some countries. Use of plutonium as a fuel (in the form of mixed uranium and plutonium oxide or MOX) in existing reactors grew considerably in the 1990s, creating a new set of subsidies for the plutonium industry.

These subsidies and unrealistic plans persist because those who fervently hope and believe in the long-term future of plutonium as an energy source have had enough muscle in the political and economic arenas to keep the plutonium flame alive. Indeed, they have been able to vastly increase the amount of plutonium being separated and used as MOX fuel in light water reactors – the most common kind of commercial reactor – the vast majority of which were not designed for plutonium fuels. In France alone, the use of MOX fuel amounts to a subsidy of about $1 billion per year for the commercial plutonium industry. (See accompanying article on page 9.)

Military plutonium disposition

The prospects for plutonium fuel have also received a boost from the end of the Cold War. The United States and Russia are proposing to use most of their declared surplus weapons plutonium as a fuel in commercial nuclear power plants. This would provide an immense new subsidy to the plutonium fuel industry, in the name of non-proliferation, and provide the nuclear establishments of both countries with the arguments they need to continue reprocessing and breeder reactor programs. In particular, Minatom, Russia's ministry of atomic energy, has explicit plans to use the infrastructure created with Western non-proliferation funds for its breeder reactor program.

Minatom has explicitly stated that that US-Russian weapons plutonium disposition program "must be seen as the first step in developing a technology for a future closed nuclear fuel cycle..." This would involve "the use of mixed uranium–plutonium fuel of fast reactors" (another name for breeder reactors).[4] The United States has agreed to such a system in Russia in the context of

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TABLE 3: SUMMARY OF THE APPROXIMATE NET WORLDWIDE COSTS OF ATTEMPTS TO DEVELOP PLUTONIUM AS A FUEL

Cost category	Cost (in 1999 US dollars)	Comments
Major breeder reactors	~20 billion	Larger than 100 megawatts thermal; completed reactors only
Incomplete breeder reactors, small breeders, net operating costs	~10 billion?	Net operating costs are the costs of reactor operation in excess of revenues derived from electricity sales
Reprocessing and MOX	~40 billion	Net of value derived in substituting MOX as a fuel for uranium. Rough estimate.
Rokkasho-mura reprocessing plant construction	~20 billion	Incomplete plant, now officially scheduled for completion in 2005
Other past costs (R&D, infrastructure, past decommissioning, long-term commercial plutonium storage)	Many billions	Includes closed reprocessing plants, (e.g. West Valley in New York), past reprocessing and breeder decommissioning, breeder and reprocessing R&D
Subtotal, costs to date	**~100 billion**	
Future continued reprocessing and MOX net costs	~2 billion per year	Assuming $1,000 per ton of heavy metal and reprocessing at current rates
Storage costs for old plutonium stock	0.4 billion per year	
Future decommissioning and commercial plutonium disposition costs	Billions or tens of billions total	

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weapons plutonium, even though it was rejected in the United States in the 1970s as too proliferation prone. (See accompanying article on the US-Russian agreement, page 12.)

Converting surplus military weapon-grade plutonium into a fuel and using it in commercial power reactors not only raises proliferation concerns but also concerns related to safety. The vast majority of commercial reactors were designed for uranium, not mixed oxide (MOX) fuel, in which plutonium isotopes provide the fissile material. Modifications to these reactors to accommodate more control elements may be needed. Weapon-grade plutonium has never been used as a commercial fuel in reactors, though plutonium derived from commercial spent fuel is now being used in commercial power reactors in France, Germany, Belgium, and Switzerland. The computer codes that would be used to evaluate the safety of MOX made from weapon-grade plutonium would be those developed for and tested for reactor-grade plutonium. How safety concerns arising from the different plutonium composition of weapon-grade plutonium and reactor-grade plutonium and the different patterns of loading MOX fuel will be resolved remains unclear.

The consequences of an accident in a reactor with MOX fuel would be more severe than one with uranium fuel because MOX fuel contains a larger proportion of plutonium and transuranic radionuclides. The regulatory infrastructure in Russia is relatively weak, leading to questions as to how safety concerns would be brought up or resolved. Moreover, new proliferation risks will also be created, since fresh MOX fuel would be transported on highways and stored at commercial nuclear power plants that do not now have military levels of security.

Immobilization

Even if all plutonium separation in the commercial and military sectors were to stop immediately, there would still remain an immense problem of the management of separated commercial plutonium and surplus military stocks. It is therefore urgent both to stop commercial reprocessing and to create a plan to put separated commercial plutonium and surplus military plutonium into non-weapons-usable form as expeditiously as is consistent with safety, health, and environmental protection.

IEER has shown in previous analyses that immobilization of plutonium in one of several ways would be a safer, faster, and cheaper way to put separated plutonium into non-weapons-usable form.[5] The primary purpose of this immobilization should be to prevent theft of plutonium by non-nuclear weapons states or terrorist groups. The idea of immobilizing all separated commercial plutonium and all surplus military plutonium has not made progress because of two reasons:

- It is generally believed that Russia will not accept any other alternative than to use plutonium as a fuel. Hence the MOX fuel option for surplus military plutonium is seen as essential for putting Russian weapons plutonium into non-weapons-usable form (spent fuel in this case).
- The plutonium lobby in the West and Japan has been steadfast in their support of the creation of a MOX fuel infrastructure using non-proliferation funds.

While it is true that Minatom wants western funds to create a MOX fuel infrastructure, this does not mean that a different proposal would be rejected by all parts of Russian society or government. For instance, no offer to purchase all Russian separated commercial plutonium and all surplus weapons plutonium for immobilization and storage in Russia under international safeguards has ever been officially presented to the Russian government. It would cost at most $2 billion for the purchase of 80 metric tons of plutonium, if is valued at its maximum possible theoretical price (that is if it were magically transformed into MOX fuel at zero cost).[6] It would cost a comparable sum to immobilize the plutonium. Existing cooperative nuclear security arrangements indicate a Russian willingness to consider programs that it would not otherwise have undertaken. Yet no Western offer to purchase Russian surplus plutonium for immobilization has officially been made to the Russian government. Such an approach, coupled with a complete halt to reprocessing all over the world, deserves urgent consideration for non-proliferation, safety and environmental reasons.

1 Arjun Makhijani, *Plutonium End Game: Managing Global Stocks of Separated Weapons-Usable Commercial and Surplus Nuclear Weapons Plutonium*. Takoma Park, Maryland: Institute for Energy and Environmental Research, January 2001. On the web at http://www.ieer.org/reports/pu/index.html.

2 U.S. DOE, *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives*, DOE/NN-007. Washington, DC: U.S. Department of Energy, January 1997, p. 37.

3 The process is of course theoretically limited by the availability of uranium-238, which is abundant.

4 Source of quotes: *Strategy for the Development of Power Engineering in Russia for the First Half of the 21st Century: Principal Provisions*. Moscow: Ministry of Atomic Power Engineering of the Russian Federation, 2000, pp. 17-18.

5 IEER's technical analyses and commentary on weapons plutonium disposition are available on-line, at http://www.ieer.org/latest/pu-disp.html.

6 The actual economic value of plutonium as a fuel (whether of commercial or military origin) is negative since it is more costly than uranium fuel.

GLOBAL TRUTH

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propaganda in only one nuclear-weapon state – the United States.

The US record that is public so far is not at all reassuring. It features deliberate emphasis on production compared to health protection, massive and routine violation of health and safety regulations, deliberately misleading workers so as not to arouse concerns or give hazardous duty pay when both were clearly warranted, and subversion of democratic process.

Sloppy, incompetent science was a routine part of the dismal picture. The Department of Energy has admitted that, until 1989, no effort was made to calculate internal radiation doses to workers arising from the inhalation or ingestion of radioactive materials.[2] IEER's work on data from the Fernald plant near Cincinnati, Ohio, where uranium for plutonium production reactors was processed, showed that in the 1950s and early 1960s, most workers were in fact overexposed due to uranium inhalation.[3] Many probably also suffered kidney damage due to the toxicity of uranium as a heavy metal. Yet they were reassured that they were not being harmed.

US DEPARTMENT OF ENERGY

The world's first test of a thermonuclear device, code-named Ivy Mike, was detonated at Enewetak atoll on October 31, 1952. Ivy Mike was one of 67 nuclear tests conducted by the United States in the Marshall Islands. (For more information, visit the web site of the Republic of the Marshall Islands at http://www.rmiembassyus.org/geninfo.html#NUKE.)

As such information has become public, calls for redress of injustice, and for public disclosure, health care, and compensation have risen. The United States recently passed legislation giving most radiation workers the right to apply for compensation and medical treatment in case they get certain diseases. No other government has yet made as broad an admission of potential harm from radiation as has the United States, though some modest programs are in effect for a limited number of people in some places. Raw data on worker doses and working conditions (with due respect for worker privacy) are, for the most part, still secret. While Russia has become more open since the mid-1980s, and some data on worker exposures are emerging, there are still practically no raw data available to independent Russian researchers. Secrecy also holds sway in the other relatively open countries – France, India, and Britain. The situation in China, Pakistan, and Israel is far worse.

Calls have risen for redress of injustice and for public disclosure, health care and compensation

The pattern of keeping health and environmental abuses of their own people secret in the name of national security is anti-democratic to the core. It presumes that the people would not make sacrifices for the security of their countries. It presumes that top nuclear bureaucrats can make life or death decisions in defiance of established laws, norms, and regulations without the informed consent of the people.

The harm has extended well beyond factory boundaries to workers' families, neighbors of the plants, and the general public. For example, an official study by the U.S. National Cancer Institute showed that during the 1950s, a large portion of the US milk supply was contaminated with iodine-131 due to fallout from atmospheric nuclear weapons testing at the Nevada Test Site.[4] No other nuclear-weapon state has conducted a similar effort at being accountable to its own public. Moreover, the atmospheric testing of the weapon states contaminated milk supply well beyond their borders. It is interesting to note that maps of milk contamination and dose estimates published by the National Cancer Institute magically stop at the borders of Canada and Mexico. Uranium miners in non-nuclear-weapon states have been injured by nuclear-

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weapon states. Test sites have polluted former colonial areas, such as Algeria and Polynesia. Yet, no proper accounting has been forthcoming. But then, why would nuclear-weapon states be accountable to people beyond their borders when they have failed to be accountable to those within?

The deliberate harm inflicted upon workers and the public at large in the course of nuclear weapons production and testing raises troubling questions about how national security policy has been formulated. If the nuclear weapons establishment can engage in deliberately harming the very people it claims to protect without informing them, how can one be sure that the security policies themselves are not largely motivated by bureaucratic self-preservation rather than by the security and health interests of the community at large? This is by no means a rhetorical or theoretical question. There is strong evidence, for instance, that the decision to bomb Hiroshima and Nagasaki was motivated in part by the desire to justify the huge expenditure on nuclear bombs during the Manhattan project. The nuclear establishment feared that if the bombs were not seen as highly useful in the war effort, there would be relentless investigations for waste of money after the war.[5] Such investigations would, no doubt, also have dimmed the prospects for continued large nuclear weapons budgets after the war.

A wide-ranging public discourse is needed within every nuclear-weapon state about the health and environmental harm that they have inflicted

A wide-ranging public discourse is needed within every nuclear-weapon state about the health and environmental harm that they have inflicted upon their own people. A global debate is needed about harm outside the borders of those states. Much of that harm was knowingly inflicted. For instance, an editorial in the Engineering alumni magazine of the University of California in 1960 noted that "nuclear testing has so far produced about an additional 6,000 babies born with major birth defects [worldwide]." Yet, it added that "you must weigh this acknowledged risk with the demonstrated need of the United States for a nuclear arsenal."[6] The editorial did not explain why children in Nigeria or Costa Rica or Indonesia should have major birth defects so that the United States could have a nuclear arsenal.

The deliberate harm inflicted upon workers and the public at large in the course of nuclear weapons production and testing raises troubling questions about how national security policy has been formulated

It is time for the United Nations General Assembly to establish an independent and open Truth Commission on the ravages that have been inflicted upon the world by nuclear weapons production and testing. That commission should not only examine the nature and extent of that harm, and whether and how deliberately it was inflicted; it should recommend ways in which the world's people can hold nuclear weapons establishments accountable. It should also examine whether and to what extent the security arguments that have been claimed for nuclear weapons have been constructed with the aim of keeping people ignorant and fearful so that the weapons bureaucracies might perpetuate themselves. Such an examination would be of some considerable relevance today, given that nuclear weapons establishments are still refusing to meet their nuclear disarmament commitments under the Nuclear Non-Proliferation Treaty and that people are still getting ill and dying from the harm that nuclear weapons establishments have inflicted upon them.

1 Arjun Makhijani, Howard Hu, and Katherine Yih, eds. *Nuclear Wastelands: A Global Guide to Nuclear Weapons Production and Its Health and Environmental Effects*. Cambridge, Mass.: MIT Press, 1995.

2 See Arjun Makhijani and Bernd Franke, "Worker Radiation Dose Records Deeply Flawed," *Science for Democratic Action*, vol. 6 no. 2, November 1997. (On-line at http://www.ieer.org/sdafiles/vol_6/6-2/workers.html.)

3 See *Science for Democratic Action*, vol. 5 no. 3, October 1996. (On-line at http://www.ieer.org/sdafiles/vol_5/v5n3_1.html.)

4 Pat Ortmeyer, "Let Them Drink Milk," *Science for Democratic Action*, vol. 6, no. 2, November 1997. (On-line at http://www.ieer.org/sdafiles/vol_6/6-2/iodine.html.)

5 Leslie Groves, *Now it Can Be Told: The Story of the Manhattan Project*. New York: Harper and Row, 1962, Chapter 26. David Robertson, *Sly and Able: A Political Biography of James F. Byrnes*. New York: Norton, 1994, Chapter 15. See also Arjun Makhijani, "Japan: Always the Target?", *Bulletin of the Atomic Scientists*, May-June 1995.

6 April 1960 editorial in the *California Engineer*, reprinted in the *California Engineer* in 1990.

French Report Doubts Merits of Reprocessing and MOX

BY ANNIE MAKHIJANI

Nuclear proponents like to point to France as the success story of nuclear energy. Nuclear power plants generate 75 to 80 percent of France's electricity and this is often held up as a symbol of the presumed wide acceptance of nuclear energy among the French public.[1] However, since the late 1980s, when the French government first tried to start local investigations for possible repository sites, one of the public's top concerns has been the management of nuclear waste. This concern has, in turn, fueled a debate regarding the phase-out of nuclear power. Within this context the more narrow, but crucial, debate of putting and end to reprocessing has for the first time received official consideration.

A July 2000 report, entitled *Etude économique prospective de la filière électrique nucléaire* ("The Economic Prospects of the Nuclear Electricity Sector"), was commissioned by the French Prime Minister, Lionel Jospin, to provide the government[2] with an economic analysis of nuclear power, including reprocessing and the use of MOX (mixed [plutonium and uranium] oxide) fuel.[3] The report is known as the Charpin report, after its primary author, Jean-Michel Charpin, who is the head of the Commissariat du Plan.[4] The other two co-authors are Benjamin Dessus, Director of the ECODEV (Ecodéveloppement) program at the Centre National de Recherche Scientifique,[5] and René Pellat, Haut Commissaire à l'énergie atomique (Commissioner of the Atomic Energy Commission).

Given the diverse constituencies represented by the authors, including the French nuclear establishment, the report must be viewed as something of an official technical consensus document. In the introduction of the report, the authors state that:

> *"We did not try to define the most desirable outcomes, even less how to get there. Therefore, this study does not make any recommendation. [...] Our ambition was not to guide the choices of the authorities, or even to influence public opinion. It was to allow the necessary democratic debate to take place on the basis of verified information and explicit technical, economic and environmental reasoning."*

Although the report did not make any recommendations, its two main conclusions regarding reprocessing are clear. They are, moreover, based on data furnished by the nuclear industry itself. First, reprocessing and MOX fuel use are uneconomical and will remain so for the foreseeable future. Second, reprocessing and MOX fuel use will contribute little to the reduction of the inventory of the transuranic radionuclides in waste, including plutonium.

The report is structured to show a comparative economic analysis of possible various modes of electricity generation. It also evaluates the long-term impact of those options on the environment, notably carbon dioxide emissions. What follows is a summary of Chapter I of the report, "Pour la France: l'héritage du passé" ("Regarding France: the legacy of the past"), in which the two conclusions regarding reprocessing are reached. In order to put the report in context, we first provide a quick overview of the electricity sector and MOX fuel use in France.

Electricity production in France

The overall electricity production in France in 1997 was 481 TWh (terawatt-hours)[6], with 376 TWh (78 percent) coming from the nuclear sector. The civilian nuclear sector is comprised of 58 pressurized water reactors. Of these, 20 are currently using MOX, 8 can be modified to use MOX but are not presently using it, and the remaining 30 reactors use UO_2 (uranium dioxide) fuel and cannot be modified to use MOX.

The reactors that are loaded with MOX use a 30 percent MOX core. The rest of the fuel is low enriched uranium. The MOX load of these 20 reactors is comprised of almost all the plutonium that is separated from French spent fuel. Table 1 shows the total amount of spent fuel unloaded from French reactors and the amount of that which is reprocessed. Were MOX to be loaded into all twenty-eight reactors that can use it, all of the approximately 1,100 metric tons of UO_2 spent fuel generated annually in France could be reprocessed.

TABLE 1: TYPES AND AMOUNT OF FUEL REPROCESSED IN FRANCE

Type of spent fuel	Annual unloading, in metric tons	Amount reprocessed, in metric tons
UO_2	~ 1100	850
MOX	~ 100	0
TOTAL	1200	850

Source: Commission Nationale d'Evaluation Relative aux recherches sur la gestion des déchets radioactifs, Instituée par la loi 91-1381 du 30 décembre 1991, Rapport d'Evaluation N°4, October 1998.

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There is, however, a considerable backlog of unused separated plutonium that is stored in France, since the extensive use of MOX is far more recent than commercial reprocessing.

The scenarios

The report did its analysis by constructing seven scenarios. Six of these postulate various future levels of reprocessing and MOX fuel use. These are basically divided into two sets of three scenarios each, which differ only in the assumed life for the reactors (41 versus 45 years). The seventh, called S7, is a fictitious scenario that estimates the price of electricity in France assuming that reprocessing had never been initiated.

The difference in the assumed average lifetime is so small that we focus discussion here only on the second set, S4 through S6, which assume a reactor lifetime of 45 years. This is the assumption also made in the no-reprocessing scenario and therefore allows a comparison of the costs of various levels of reprocessing with no reprocessing.

Scenarios S4 through S6 involve the following assumptions:

- Scenario S4 assumes that reprocessing would stop in 2010.
- S5 corresponds to the current situation in France, in which 70% of the spent fuel is reprocessed and the extracted plutonium is fabricated into MOX and irradiated in 20 reactors.
- S6 corresponds to the situation where all newly generated spent fuel (but not the past stocks of the unreprocessed spent fuel) is reprocessed and the extracted plutonium is fabricated into MOX and irradiated in 28 reactors.

Note that no scenario assumes an early halt to reprocessing. The report notes that before rejecting it, the authors had contemplated a scenario involving the termination of reprocessing in 2001, date for the renewing of Electricité de France's reprocessing contracts. The rationale given for not considering an early halt to reprocessing is that a sudden stop would entail numerous technical (storage of irradiated fuel), social, and legal problems. Roland Lagarde, who is Environment Minister Dominique Voynet's point person on this, has recently broached the possibility of ending reprocessing in 2002.

Economic analysis

Table 2 summarizes the costs of scenarios S4 to S7, where the same 45-year lifetime per reactor is assumed. The costs shown include deferred decommissioning costs. (Immediate decommissioning is more expensive.) All cost figures are in constant 1999 French francs.

Several conclusions can be drawn from these results. It is clear that France would have been far better off economically without reprocessing. The cumulative cost difference between the nuclear establishment's desire for full reprocessing and no reprocessing amounts to 165 billion francs (about $25 billion, assuming 6.55 francs = one US dollar). This amounts to a difference of about 3.7 billion francs per year (about $560 million), averaged out over the entire assumed life (45 years) of all the reactors. However, MOX is used in only some reactors and for only a portion of the life of these reactors. Hence, the cost difference between the full reprocessing and no reprocessing scenarios per reactor using MOX per year of MOX use is roughly $50 million (including the related reprocessing costs).

Stopping reprocessing in 2010 would save almost 40 billion francs cumulatively ($6 billion) whereas increasing the plutonium reuse from 70 to 100% of the UO_2

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TABLE 2: ELECTRICITY COST AND GENERATION UNDER DIFFERENT REPROCESSING SCHEMES IN FRANCE

Scenario	S4 (end reprocessing in 2010)	S5 (70 % reprocessing)	S6 (full reprocessing	S7 (no reprocessing)
Cumulative cost, billions of francs	2,888	2,910	2,927	2,762
Total cumulative electricity generation, billion kilowatt-hour (billion kWh)	20,238	20,238	20,238	20,238
Average cost of electricity, in centimes/kWh	14.27	14.38	14.46	13.65

Notes: The dollar-franc exchange rates fluctuate. An approximate conversion may be made by assuming one US dollar is approximately equal to one euro. The euro and franc have a fixed relationship at 1 euro = 6.55 francs. One centime = 0.15 cents.

spent fuel generated annually would cost an extra 17 billion francs ($2.6 billion). Unfortunately, the figures for stopping reprocessing in 2001 or 2002 are not given. But an extrapolation from the figures given indicates that the savings would be considerably higher.

Material balance analysis

Table 3 shows the projected stocks of plutonium and americium at the end of reactor operating lifetimes, assumed to be 45 years, in metric tons.

TABLE 3: QUANTITIES OF PLUTONIUM AND AMERICIUM CONTAINED IN UNREPROCESSED SPENT FUEL (UO_2 AND MOX) GENERATED UNDER VARIOUS REPROCESSING SCHEMES IN FRANCE

Scenario	S4 (End reprocessing in 2010)	S5 (70% reprocessing)	S6 (full reprocessing)	S7 (no reprocessing)
Final stock of plutonium and americium, in metric tons	602	555	514	667

Note: Americium contributes only a few percent to the quantities listed.

Hence maximum reprocessing compared to no reprocessing reduces the plutonium stock by only 153 metric tons (S6 versus S7), or only about 23%. The difference in plutonium stock between phasing out reprocessing by 2010 and full reprocessing is even smaller (15%). The reasons that reprocessing has only small impacts on plutonium stocks are:

- Spent MOX fuel still contains a large amount of residual plutonium.
- France has a backlog of separated plutonium from the long period when it had no reactors or few reactors using MOX. [7] France does not have the reactor capacity to use this backlog. Moreover, aged plutonium contains americium-241, a strong gamma emitter resulting from the decay of plutonium-241. Its presence is a hazard to workers and would necessitate its removal from the plutonium prior to MOX fabrication.
- France's plan to use large amounts of plutonium in breeder reactors has fallen apart because of the severe technical problems and the very high costs of the breeder reactor program. France has permanently shut down its star of this program, the Superphénix, by far the largest breeder reactor in the world, well ahead of the original schedule.
- There is plutonium in the spent fuel that France does not plan to reprocess, because it could not use the plutonium without engaging in a transmutation program.[8]

IEER conclusions

The Charpin report provides the public with first detailed look at the official data on reprocessing and MOX fuel use in France. Its conclusions clearly point the way towards an early end to reprocessing since no significant problem in the energy or waste management sectors can be addressed by it. A rapid phase-out of reprocessing and therefore MOX fuel use would appear to be in the economic interest of Electricité de France, which, like utilities elsewhere, is facing an era of deregulation and competition. The company that would be opposed to such a policy would be Cogéma, the primarily government owned company which operates all of France's reprocessing and MOX fuel fabrication plants.

1 See, for example, Frontline documentary, "Nuclear Reaction" aired on PBS on April 15, 1997.

2 The current French government is a coalition of five left-leaning parties, including the Socialist and Green parties. The Environment Ministry is headed by a Green Party member, Dominique Voynet.

3 Jean-Michel Charpin , Benjamin Dessus and René Pellat, *Étude économique propective de la filière électrique nucléaire*, La Documentation française, July 2000. This report can be found on the web in French at http://www.plan.gouv.fr.

4 The Commissariat du Plan reports to the Prime Minister. Its mission is to help guide public choices on economic and social issues by producing expert studies.

5 The CNRS is government-affiliated, and has branches in various regions of France. It conducts research in many fields, including physical and biological sciences, health, as well as economics and social sciences.

6 One terawatt is one trillion watts (10^{12} or 1,000,000,000,000 watts).

7 At the end of 1996, this backlog was approximately 35 tons. If foreign plutonium is included, the figure increases to about 65 tons.

8 IEER's analysis of transmutation as a waste management method — including environmental, waste management, cost, and proliferation concerns — is summarized in *Science for Democratic Action*, vol. 8 no. 3 (May 2000), on the web at: http://www.ieer.org/sdafiles/vol_8/8-3/transm.html.

US-Russian Plutonium Disposition Agreement

BY MICHELE BOYD

On September 1, 2000, former US Vice President Al Gore and Russian Prime Minister Mikhail Kasyanov signed the US-Russian agreement on plutonium disposition.[1] The agreement requires that 68 metric tons of weapon-grade plutonium, 34 metric tons for each Party, be put into non-weapons usable form by either irradiating it as fuel in reactors (MOX fuel) or by immobilizing it in glass with high-level radioactive waste.

The US has decided to use 25.57 metric tons of plutonium in MOX fuel and to immobilize the rest (8.43 metric tons), while Russia will use all 34 metric tons of its plutonium to make MOX fuel. Some characteristics of the surplus weapons plutonium stocks are summarized in the adjacent table.

According to the agreement, the immobilized plutonium can never be separated, but a country may reprocess its spent MOX fuel after all 34 metric tons of its plutonium are dispositioned. Russia's Ministry of Atomic Energy (Minatom) has clearly stated that it intends to reprocess the MOX fuel as part of the first step in developing a "closed" nuclear fuel cycle (see main article, page 1). Given the timeline of the MOX program in the agreement, Russia will be allowed to re-extract residual plutonium from the spent MOX fuel by 2025, perhaps earlier. While the majority of the declared surplus plutonium is slated for use in light water reactors in the US and Russia, Russia also intends to use some of its MOX fuel in fast breeder reactors.[2] MOX fuel for fast reactors contains a much higher percentage of plutonium than that for light water reactors.

Two crucial issues in the agreement, financing of and liability for the Russian program, have been left to future negotiations, and until they are resolved, the MOX program in Russia cannot proceed. Furthermore, the deal stipulates that within one year, an agreement shall be reached on doubling the disposition rate, though how this is to be done is not entirely clear at the present time. These three issues are discussed in more detail below.

QUANTITIES AND METHODS OF DISPOSITION

For the United States of America

Quantity (metric tons)	Form	Method of Disposition
25.00	Pits and Clean Metal	Irradiation as MOX
0.57	Oxide	Irradiation as MOX
2.70	Impure Metal	Immobilization
5.73	Oxide	Immobilization

For the Russian Federation

Quantity (metric tons)	Form	Method of Disposition
25.00	Pits and Clean Metal	Irradiation as MOX
9.00	Oxide	Irradiation as MOX

Forms

Pits and Clean Metals: plutonium in or from weapon components or weapon parts, and plutonium metal prepared for fabrication into weapon parts. Plutonium in pits may be alloyed, notably with gallium.

Impure Metals: plutonium alloyed with one or more other elements in the form of a homogenous metal, and unalloyed plutonium metal that is not clean metal.

Oxide: plutonium in the form of plutonium dioxide.

Source: *Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes and Related Cooperation.* Annex on Quantities, Forms, Locations, and Methods of Disposition, Sections I and II. (Sept. 1, 2000).

Financing

The financing plan for the Russian MOX program has been left to future negotiations, with a goal of concluding a multilateral agreement by September 1, 2001. If an agreement is not completed by March of the following year, the US and Russia can either agree to adjust the schedules of their programs or terminate the program altogether.

The current estimate for the cost of the Russian MOX program is between $1.7 and 2.5 billion, while the US program is estimated to be approximately $4 billion.[3] The United States has allocated $200 million for implementing the Russian program, and promised another $200 million, which has not yet been appropriated by Congress. The United States and Russia discussed multilateral financing of the Russian MOX program with the other leaders from the G-8 countries (Britain, Canada, France, Germany, Italy, and Japan) at a meeting in Okinawa, Japan, last July. Britain has committed $100 million and France is contributing $60

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million, which, with the US contribution, adds up to $560 million of the $900 million needed to begin design and construction of Russian MOX facilities.[4]

The G-8 agreed to work out an international financing plan for the Russian program before they meet again in Genoa, Italy, next July. A special task force within the G-8 Nonproliferation Experts Group has been established to develop a financing package and multilateral project structure, including issues such as how the project management would be structured and the oversight rights of donor countries. The European Bank for Reconstruction & Development has been approached about whether they would manage the implementation of the Russian MOX program.[5]

Liability

The United States and Russia have not yet agreed on who would be held financially accountable for any claims relating to the Russian MOX program. In the United States, the Price-Anderson Act provides up to $10 billion dollars to nuclear power plant owners in case of an accident.[6] Such a level of financial compensation on the Russian side, though insufficient for addressing a large nuclear accident, would be unlikely given Russia's economy. Moreover, there may be less regulatory oversight of the MOX program in Russia. A bill was recently introduced in the Duma that would, if passed, transfer authority to license civilian-related nuclear activities from the federal regulatory agency, Gosatomnadzor (GAN), to Minatom.

Although Minatom would prefer to use MOX in a "new generation" of fast reactors, which would take many years to build, it has agreed to the US plan to use MOX in existing light water reactors (LWRs). Given that the US is funding this plan, at least in part, an accident in a Russian LWR using MOX fuel could cause a serious political crisis over liability between the two countries, even if an agreement is reached.

The deal stipulates that the US and Russia shall conclude an agreement on liability no later than the entry into force of a multilateral financing agreement, which is to be completed by September 1, 2001. Meanwhile, assistance to Russia is limited to pre-construction design work, which Russia is not permitted to use to build or operate a MOX plant until the question of liability is resolved.

Rate of disposition

The agreement sets December 31, 2007, as the target date to begin operating the plutonium disposition facilities with a minimum disposition goal of two metric tons per year in each country. Russia promoted a "western option," in which Russian-made MOX would be used in western European reactors. However, the French reprocessing company, Cogéma, which fabricates MOX fuel for western reactors, has been opposed to the plan because the Russian-made MOX could be sold at subsidized prices. Russia has since agreed to use the MOX fuel in its own reactors before selling any MOX fuel to other countries.[7]

As the US-Russian agreement on the disposition of highly enriched uranium[8] illustrates, the commercial component of disposition programs can slow the disposition rate. According to a recent report by the General Accounting Office, the deliveries of Russian-made low enriched uranium (LEU) to the US have been delayed because Russia was dissatisfied with the level of revenue that it was receiving under the agreement. Moreover, USEC, Inc., the private US company that implements the commercial contract, considered resigning as the executive agent in 1999 because the decline in market prices for LEU had reduced their profits.[9]

The plutonium agreement also stipulates that the US and Russia develop a detailed action plan by September 1, 2001, to at least double this disposition rate. Several options for increasing this rate are listed, including:

- **Exporting MOX fuel for use in other countries:** Minatom is particularly interested in this option. Sweden and Canada have expressed interest in using Russian MOX fuel in their reactors. Both Russia and the US have sent MOX samples to Canada for testing in a CANDU reactor, but the US has decided not to export its MOX fuel as part of its disposition program.
- **Increasing the number of reactors that use MOX within Russia:** This option appears unlikely at this time, because the number of Russian reactors that can use MOX fuel is limited and Russia does not have the funds to complete the several reactors that have been under construction for years. US assistance under the agreement does not include funding for completing these reactors or for building new ones. However, the agreement does allow for US assistance for modifying existing Russian reactors to use MOX.
- **Using greater than 1/3 core MOX:** New reactors can be designed to take 100% MOX cores, but all of Russia's existing reactors would require modifications for any MOX use. Even a partial MOX core in a LWR makes operation and control of the reactor more complicated.
- **Using "advanced nuclear reactors":** Minatom has stated that it wants to build a "new generation" of breeder reactors. General Atomics and Framatome, with the US Department of Energy, Minatom and Fuji Electric, are researching a Gas Turbine Modular Helium Reactor, potentially for MOX fuel use after 2010.[10]
- **Increasing the capacity of the conversion and MOX fuel fabrication facilities.**

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QUOTES FROM THE US-RUSSIAN AGREEMENT ON PLUTONIUM DISPOSITION

"Neither Party shall separate plutonium contained in spent fuel until such time as that Party has fulfilled the obligation set forth in paragraph 1 of Article II of this Agreement [disposed of no less than thirty-four (34) metric tons of disposition plutonium]."

— Article VI, paragraph 2

"No Party shall separate disposition plutonium contained in immobilized forms."

— Article VI, paragraph 3

"Assistance provided by the Government of the United States of America [to the Russian Federation] shall be for such activities as the research, design, development, licensing, construction and/or modification of facilities (including modification of nuclear reactors), and technological processes, systems and associated infrastructure for such activities."

— Article IX, paragraph 1

"[T]he Parties shall cooperate with a view toward concluding within one (1) year after entry into force of this Agreement a multilateral agreement that documents the assistance arrangements necessary for [a disposition rate of two metric tons per year.]"

— Article IX, paragraph 8

"In the event the Government of the Russian Federation suspends any implementation activities..., the Government of the United States of America shall have the right to suspend proportionately its implementation activities under this Agreement."

— Article IX, paragraph 14

"No spent plutonium fuel shall be reprocessed by either Party after termination of this Agreement unless such reprocessing is subject to monitoring agreed by the Parties...."

— Article XIII, paragraph 7

"The Parties shall continue negotiations on liability provisions to apply to all claims that may arise from activities undertaken pursuant to the Agreement and shall seek to conclude an agreement ... at the earliest practicable date, and, in any event, not later than entry into force of the multilateral agreement...."

— Annex on Assistance, Section II, paragraph 1

"Until entry into force of the agreement containing liability provisions referred to in paragraph 1 of this Section: a) assistance activities under the Agreement shall be limited to appropriate pre-construction design work; b) neither Party shall be obligated under the Agreement to construct, modify, or operate disposition facilities, including reactors; and c) the Russian Federation shall not utilize in any way the pre-construction design work conducted under the Agreement including for the construction, modification, or operation of disposition facilities (including reactors)."

— Annex on Assistance, Section II, paragraph 2

Source: *Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes and Related Cooperation*, September 1, 2000.

1 The full title is the *Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes and Related Cooperation.* It can be found on the internet at http://twilight.saic.com/md/bilatagreement1.htm (pudispagree.pdf).

2 The agreement specifically lists the BOR-60 reactor in Dmitrovgrad and BN-600 in Zarechnyy. Fast breeder reactors can be operated to yield a net increase or net decrease in plutonium, depending on how the reactor is operated and the configuration of its core and fuel blanket.

3 Russian cost estimate from *Preliminary Cost Assessment for the Disposition of Weapon-Grade Plutonium Withdrawn from Russia's Nuclear Military Programs*, Joint US-Russian Working Group on Cost Analysis and Economics in Plutonium Disposition, April 2000, p. iii. On the Internet at http://www.doe-md.com/ (under "Work with Russia"). US cost estimate from Laura Holgate, Presentation to the Advisory Board to the Secretary of Energy on Plutonium Disposition in Russia, March 13, 2000. Transcript provided by Kevin Kamps, Nuclear Information and Resource Service, Washington, DC.

4 Hisane Masaki, "G-8 to tackle disposal of Russian plutonium," *Japan Times*, October 25, 2000; *Post-Soviet Nuclear & Defense Monitor*, Nov. 13, 2000, p.15.

5 *NuclearFuel*, Dec. 11, 2000, p.7.

6 As of August 20, 1998, the total maximum insurance incident was \$9.43 billion. (Source: NUREG/CR-6617: *The Price-Anderson Act—Crossing the Bridge to the Next Century: A Report to Congress*, Prepared by ICF Incorporated for U.S. Nuclear Regulatory Commission, August 1998.) The Price-Anderson Act was enacted in 1957 as an amendment to the Atomic Energy Act. The most recent amendment occurred in 1988 with the enactment of the Price-Anderson Amendments Act of 1988 (Public Law 100-408).

7 *NuclearFuel*, Dec. 11, 2000, p.9.

8 The full title is *The Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted From Nuclear Weapons* (February 18, 1993).

9 General Accounting Office, *Implications of the US Purchase of Russian Highly Enriched Uranium*, GAO-01-148, December 2000

10 *NuclearFuel*, Dec. 11, 2000, p.9

Sharpen your technical skills with Dr. Egghead's
Atomic Puzzler

Gamma has been reading a lot lately about plutonium disposition, breeder reactors, and MOX fuel. However, being a canine, much of it goes over his head. To help him brush up on his skills, Dr. Egghead administered to Gamma a lengthy exam. Gamma is stuck on the following questions. Can you help? (Hint: some of the answers are found throughout this issue of SDA.)

1. How is plutonium made?
   a. By sending an unmanned spacecraft to Pluto where it retrieves samples from the planet's surface and returns them to earth.
   b. By a magic dog that lives in Disney World.
   c. By heating water under high pressure, then cooling it very rapidly.
   d. By irradiating uranium-238. (Plutonium is also found naturally in trace quantities.)

2. Which one of the following countries draws the highest percentage of its electricity supply from nuclear power?
   a. USA
   b. Germany
   c. France
   d. Russia

3. Characteristics of plutonium include:
   a. known carcinogen
   b. used to strengthen dental braces
   c. non-radioactive
   d. all of the above

4. True or False: Most of the plutonium generated in the United States is a result of military activities.

5. True or False: Plutonium first began to be used as a fuel source because it was thought that reliance on nuclear power would increase and that the scarcity of uranium would make plutonium a cost effective fuel source.

6. True or False: Germany is the only country with operating nuclear power plants that has decided to phase out nuclear power.

7. Given that (i) the rate of increase of commercially separated plutonium stocks = 10 metric tons per year, (ii) the rate of increase of separated military plutonium = 1.0 metric ton per year, (iii) as of December 1, 1999, the stock of commercially separated plutonium = 205 metric tons, and (iv) as of December 1, 1999, the stock of separated military plutonium = 250 metric tons, answer the following:
   a) Estimate, in metric tons, the stocks of both commercial and military separated plutonium on the following dates: December 1, 2000, December 1, 2001, and December 1, 2002. (Assume rates of increase remain constant.)
   b) At what date (month and year) will the weight of the stocks of commercially separated plutonium and separated military plutonium be equal?
   c) Assuming that it takes one metric ton of weapon-grade (military) plutonium to manufacture 200 nuclear weapons, use your answers from question 7(a) to calculate the number of nuclear weapons that could be manufactured with the entire stock of separated weapon-grade plutonium on December 1, 2000.
   d) Assuming that it takes 1.4 metric tons commercial-grade plutonium to manufacture 200 nuclear weapons, use your answers from question 7(a) to calculate the number of nuclear weapons that could be manufactured with the entire stock of separated commercial-grade plutonium on December 1, 2000.
   e) What is the total number of nuclear weapons that could be created out of the total separated plutonium stocks (combined military and commercial) on December 1, 2000?

Send us your completed puzzler via fax (1-301-270-3029), e-mail (ieer@ieer.org), or snail mail (IEER, 6935 Laurel Ave., Suite 204, Takoma Park, Maryland, 20912, USA), postmarked by March 23, 2001. IEER will award a maximum of 25 prizes of $10 each to people who send in a completed puzzler (by the deadline), right or wrong. One $25 prize will be awarded for a correct entry, to be drawn at random if more than one correct answer is submitted. International readers submitting answers will, in lieu of a cash prize (due to exchange rates), receive a copy of IEER's newest report, *Plutonium End Game: Managing Global Stocks of Separated Weapons-Usable Commercial and Surplus Nuclear Weapons Plutonium.*

It pays to increase your jargon power with Dr. Egghead

BNFL

a. Term used to describe the least desirable fruit on the grocer's shelf (bruised, nicked, flavorless, and limp)

b. British slang for male "old maids" (blokes that never found love)

c. British Nuclear Fuels, Plc., a British government-owned company in the nuclear business, including reprocessing British and foreign spent fuel

Minatom

a. A smaller than average atom

b. Colloquialism for "Miner Tom," a cartoon character used in government efforts to promote safety in uranium mines

c. The Russian Ministry of Atomic Energy (comparable in the United States to the Department of Energy)

Cogéma

a. French for "love of plutonium"

b. Slang for a female assembly line worker, originating from the subject of the famous folk song, *"Cog in the wheels of progress" Emma*

c. Compagnie Générale des Matières Nucléaires, a state-owned company in France that operates uranium mines, uranium enrichment facilities, reprocessing plants, and fuel fabrication facilities for French and foreign clients

Superphénix

a. Superman's evil twin

b. The metropolitan area around the capital of the state of Arizona

c. A 2,900 megawatt-thermal sodium-cooled fast breeder reactor, now closed, located at Creys-Malville in the Lyon area in France. Superphénix, the largest breeder reactor in the world, was shutdown permanently in 1998.

Gosatomnadzor

a. What Russians say after someone sneezes

b. The Great Spirit Electricity (literally translated from the Old Russian: "Ghost that resides in high tension power lines")

c. Established in 1992, Russia's nuclear regulatory agency (counterpart of the United States Nuclear Regulatory Commission)

MOX

a. *M*issile *Ox*ide, the common name for to a certain type of rocket fuel.

b. *M*ine *Ox*ygen, a special type of oxygen tank that is used by people who mine uranium.

c. *M*ixed *Ox*ide fuel, a mixture of plutonium dioxide and uranium dioxide.

Answers: c,c,c,c,c

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