SCIENCE FOR DEMOCRATIC ACTION

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1994 at IEER

by Arjun Makhijani

In each issue of *Science for Democratic Action* we list ongoing projects at the Institute. Since we have successfully completed a number of long-term projects this year and have begun one major new effort, we decided to include a longer description of these projects.

Rongelap

Our study of the habitability of Rogelap Atoll was completed in May. Rongelap is one of the Marshall Islands in the Pacific that was contaminated by fallout from the March 1, 1954 hydrogen bomb test at Bikini. IEER Senior Scientist and Executive Director, Bernd Franke, was part of an international scientific management team appointed jointly by the representatives of Rongelap Atoll, the government of the Marshall Islands, and the Departments of Energy and Interior. The project concluded that the fears of the people of Rongelap, who went into self-imposed exile in 1985, were well-founded. The doses to maximally-exposed persons eating locally-grown food on the less contaminated portions of the atoll would exceed 100 millirem per year, the maximum allowed for civilians under U.S. regulations, and far in excess of what is now being proposed for clean-up rules. The work of the Scientific Management Team was

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The signing of the Non-Proliferation Treaty in 1968.

Beyond the Nuclear Bargain

Extending the Non-Proliferation Treaty

by Ellen Kennedy, Arjun Makhijani, and Noah Sachs

Next spring, more than 160 countries will re-examine one of the most important and controversial treaties of the Cold War period. The Non-Proliferation Treaty (NPT)—the cornerstone of international efforts to control nuclear weapons and technology—may be granted eternal life, a single extension for a fixed period, or a rolling extension with periodic reviews. Though the treaty is a relatively weak one, the outcome of the extension conference could have a lasting effect on nuclear geopolitics as well as on domestic nuclear policy. The NPT is the only treaty in which all declared nuclear weapons states have committed themselves to pursue complete nuclear disarmament.

Treaty Background

The NPT is a collection of eleven articles designed to prevent new countries from obtaining nuclear weapons, to promote disarmament, and to establish a system for safeguards and verification (see

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box "Articles of the NPT"). The treaty codifies a bargain struck between two types of states—the nuclear weapon "haves" and "have-nots" (see box "The Nuclear Weapon Haves and Have-nots"). In return for forgoing nuclear weapons development and possession, non-nuclear countries were offered access to civilian nuclear technology. The transfer of that technology was to be closely controlled and monitored. The treaty formally limits possession of nuclear weapons to the five states that possessed them by 1964, and thus legitimizes that possession.

Some of the strengths and weaknesses of the treaty are reflected in the history of its formation. In the 1960s, wary of what seemed like an inevitable spread of nuclear weapons, the U.S. and the Soviet Union started the treaty process from a position of power and a legacy of secrecy. The main motivations of the three nuclear weapons states who signed the NPT (the U.S., Soviet Union, and U.K.) were to retain close control of nuclear weapons and to profit from the sale of civilian nuclear technology. These ideas were based on President Eisenhower's 1953 "Atoms for Peace" program in which the U.S. offered civilian technology to those states that would refrain from nuclear weapons development.

The NPT thus emphasized a program of non-proliferation based on denial, limiting the *supply* of nuclear weapons and technologies, rather than on the *demand*. In other words, instead of decreasing their own nuclear forces in order to lessen the desire for nuclear weapons on the part of other states, the haves decided to hold on to their weapons and try to prevent other states from obtaining or building them. They concentrated on *horizontal* proliferation, which refers to the spread of arms or technology from country to country, as opposed to *vertical* proliferation, in which a given country increases the number or sophistication of its weapons.[1] In this way, the haves could continue to research and develop their own nuclear weapons without violating the letter of the treaty.

It seemed reasonable to ask the have-nots to forgo nuclear weapons production in return for "peaceful" nuclear energy technology, liberally granted from the haves (under Article IV). "You can have all the reactors you want," the treaty said in effect, "but you should not acquire nuclear weapons." Non-nuclear weapon states, concerned that the treaty divested them of potential military power in the face of five nuclear-armed nations, were determined to balance the treaty with some checks upon the nuclear weapons states. The have-nots, with strength in numbers, were able to add Article VI to the treaty, requiring the haves to:

> pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms

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[1] Peter Gray, *Briefing Book on the Nonproliferation of Nuclear Weapons*, Council for a Livable World Education Fund: Washington, D.C., 1993, p. 3.

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race at an early date and to nuclear disarmament, and on treaty on general and complete disarmament.

The meaning of an "early date" is undefined. The treaty's preamble also calls for a conclusion of a Comprehensive Test Ban Treaty (CTBT), but again, no time-frame is given. Even with its weaknesses, Article VI is extremely important. It is the only time that all five declared nuclear weapon states have formally agreed to work toward complete nuclear disarmament. It is also important because, if these states live up to their obligations under Article VI, de-facto nuclear states that have not signed the NPT would be much more likely to disarm and join the treaty. India and Pakistan, for example, may agree to join a global disarmament treaty if China does so. Article VI thus points the way to complete and total global disarmament, not just among the five declared nuclear states.

Articles of the NPT: Description and Analysis

Articles I and II

Text summary: The nuclear weapon "haves" agree not to transfer nuclear weapons to the "have-nots," nor will they assist the have-nots in producing nuclear weapons. By the same token, the have-nots agree not to receive nuclear weapons or to build them.

Analysis: This article perpetuates the division of countries into nuclear weapon states and non-weapon states and as such is inherently discriminatory. By direct or indirect assistance, these articles have been breached. For example, Iraq developed its nuclear weapons program while it was still a signatory to the NPT. Moreover, nuclear weapon states may abet the manufacture of nuclear weapons, either unwittingly or intentionally, since some peaceful technologies may be applied for military purposes (see Article IV). Finally, a nuclear weapon is not clearly defined in the treaty. States can obtain all necessary components to build a weapon but not violate the treaty unless they assemble the parts.[2]

Article III

Text summary: This article empowers the International Atomic Energy Agency (IAEA) both to promote nuclear energy and to monitor nuclear exports and activities by way of inspections and accounting of nuclear materials ("safeguards").

Analysis: The IAEA cannot impose sanctions and is limited in the scope of investigations it can conduct. Unlike the have-not signatories, the nuclear weapon states are not required to undergo IAEA inspection, though recently four of the five have begun a very limited voluntary program to do so.

Article IV

Text summary: This article sanctions and encourages the international transfer of civilian nuclear technology (e.g. for nuclear energy).

Analysis: Article IV is designed as the carrot to prevent the build-up of military nuclear programs by promoting civilian ones. The problem with Article IV is that civilian nuclear technology can be diverted to military nuclear technology. Many types of civilian technology, especially reprocessing plants to extract plutonium from irradiated reactor fuel, are identical to those needed in a nuclear weapons program.

Article V

Text summary: This article asserts the right of non-nuclear weapon states to conduct "peaceful nuclear explosions," or PNEs. These explosions are intended for civil purposes such as building canals or harbors, or exploring for natural gas.

Analysis: Included as a perk for the have-nots, Article V backfired in 1974 when India (a non-signatory) tested a nuclear explosive, claiming it was a PNE. The article is widely regarded as outdated and against the spirit of a hoped-for Comprehensive Test Ban Treaty.

Article VI

Text summary: This article charges all signatories to the treaty with ending the nuclear arms race and moving toward disarmament. It also calls for a future treaty

See **Nuclear** *on page 4.*

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[2] Frank Barnaby and Shaun Burnie, "The Non-Proliferation Treaty: A Critical Assessment," Greenpeace International: Amsterdam, July 1994, p. 6.

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on "general and complete" disarmament.

Analysis: This is the article that requires progress on disarmament. However, there is no time frame given in the article for disarmament or a future treaty; there are no milestones to mark progress; and there are no sanctions for failure to achieve disarmament.

Article VII

Text summary: The NPT will not bar signatories from entering into regional treaties.

Analysis: This article recognizes the importance of regional treaties for strengthening the NPT. The treaty of Tlatelolco, for example, is well on the way to establishing a nuclear-weapon-free zone for Latin America and the Caribbean.

Article VIII

Text summary: This article outlines the amendment process. In order to amend the NPT, one third of treaty signatories must request a special conference. The amendment will pass if it receives a majority of votes. Those allowed to vote are NPT signatories and the Board of Governors of the IAEA. If the majority ratifies the amendment then it will enter into force, but only for those parties that ratified it.

Analysis: An amendment conference would most likely be called by non-weapon states. Since the nuclear weapon states would be unlikely to ratify an amendment that they did not support, and since the amendment would only be binding on those signatories that ratified it, then a given amendment would either have to be watered down for the nuclear weapon states to ratify it, or it would remain a strong amendment but not binding on the nuclear weapon states. The treaty is widely seen an practically impossible to amend.

Article X

Text summary: This article allows a signatory to withdraw from the treaty with three months advance notice when "supreme interests" are threatened. It also calls for a 25 year extension conference.

Analysis: There is no definition of "supreme interests." As a result, a signatory can obtain all the materials necessary to make nuclear weapons, then withdraw, claiming that "supreme interests" are involved, without violating the treaty.

Options for extending the NPT[3]

The extension conference of the NPT in 1995 comes at a crucial political juncture, when the Cold War arrangements of political and military influence in the world have broken down but new ones have not yet been established. Whether we achieve an historic new course to disarmament or not depends in part on extending the NPT in a manner that encourages both disarmament and non-proliferation.

There are three options facing NPT signatories for the extension conference: extending the treaty indefinitely, for one fixed period, or for rolling fixed periods. A decision will be reached by consensus or by a majority vote of NPT signatories. At least 86 votes will be required to choose an option.

Option 1: Indefinite Extension

Under this option, the NPT would remain in force indefinitely or until another treaty could take its place. Such unlimited duration is advocated by the U.S., NATO, the Conference on Security and Cooperation in Europe, the Group of Seven, the European Union, the South Pacific Forum, and the Secretary General of the United Nations. It is opposed by many non-nuclear weapon states and the "non-aligned movement," which consists mainly of countries in the Third World that did not want (or proclaimed they did not want) to align their foreign policies with either the U.S. or the Soviet Union.

The Clinton administration has expressed strong support for indefinite extension. Thomas Graham, Jr., acting deputy director of the Arms Control and Disarmament Agency (ACDA) and a key player in negotiations for indefinite extension at the upcoming conference, firmly supports this option. In an interview with *Arms Control Today* (July/August 1994), he explained his position.

> The NPT . . . is the only international arms control agreement of significance that does not have

See **Nuclear** *on page 5.*

[3] For a summary of the advantages and disadvantages of extension options, *see* Richard Guthrie, "Trust and Verify," The Bulletin of the Verification Technology Information Centre, No. 49, VERTIC: London, August, 1994. Many of the advantages and disadvantages below are drawn from this analysis.

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unlimited duration . . . . It is important to make this treaty permanent so as to eliminate the tendency for countries to do worst-case planning and, as a result, possibly pursue nuclear weapons programs because they assume that the treaty might someday end.

Though Graham's argument is a strong one, it fails to give the entire picture. While the NPT may lessen the need for worst case planning, it currently does not altogether eliminate this need since a country could withdraw with three months notice. Moreover, the disadvantages of indefinite extension, especially the lack of pressure on nuclear weapon states to disarm, far outweigh the advantage that Graham cited.

There are a number of obstacles to achieving an indefinite extension. For example, Arab nations may not vote for indefinite extension if Israel (a non-signatory) continues to be able to make and possess nuclear weapons unchallenged. The key obstacle to indefinite extension, however, will be the skepticism of non-nuclear weapon states that the nuclear weapon powers have actually changed their ways.

While the five declared nuclear weapon states have taken some positive steps to reduce nuclear weapons, they have neither developed a plan for disarmament nor a timetable for it. Currently, there is little likelihood for achieveing total and complete disarmament, because none of the military postures of the five nuclear states contemplates a strategy in which they themselves would not have these weapons.

The U.S. still does not support Geneva negotiations for a treaty to outlaw the first use of nuclear weapons against states that have no nuclear weapons. Russia recently retreated from its 1978 no-first-use pledge. Moreover, the U.S. did not seriously consider a Comprehensive Test Ban Treaty (CTBT) until recently, under pressure expressed clearly in the 1990 NPT review conference by the non-nuclear states.[4] Four of the big five nuclear weapon states adopted a testing moratorium, but China continues to test and the U.S. wants to continue laboratory scale testing (hydronuclear testing).

Indefinite extension could postpone universal disarmament indefinitely, defeating the treaty's long-term goal.

In sum, the non-nuclear weapon states have ample reason to think that indefinite extension could mean a corresponding indefinite postponement of universal nuclear disarmament. This would defeat one central purpose of the treaty, and in our view, the most important long-term goal.

Option 2: A Single Extension of the Treaty

This option would define a limited time period during which the treaty would remain in effect. At the end of that period the treaty would end with no opportunity for extension. There are two potential purposes of this type of extension. Either a new treaty could be negotiated to replace the NPT, or the treaty would be allowed to expire. Periods ranging from five to twenty five years have been proposed.

One of the most serious disadvantages to this option is that if no new treaty were put into place during the extension, then at the end of the period the world would be left with no legal instrument for either horizontal non-proliferation or disarmament. On the other hand, this possibility might provide the means to pressure the nuclear weapon states to work effectively toward a meaningful disarmament and safeguards treaty.

Option 3: Rolling Extension

This third option would allow the have-nots to try to reduce the more contentious, discriminatory elements of the treaty by insisting on meaningful progress towards disarmament. It would also create a process for moving toward a new treaty, without running the risk of losing a non-proliferation/disarmament regime altogether. Although there is not yet agreement on the mechanics of this option, most analysts agree that it would automatically extend the treaty at the end of each extension period until signatories decided the treaty should expire (see box on p. 6).

Beyond the 1995 Extension Conference

In the unlikely event that signatories do not achieve a majority

See **Nuclear** *on page 6.*

[4] *See* George Bunn, "The NPT and Options for its Extension in 1995," *The Nonproliferation Review*, Monterey Institute of International Studies: Monterey, CA, Winter 1994, p. 56.

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vote for one of the three options outlined above, then no outcome is immediately clear from the language of the treaty since there is no provision for plurality. According to one analyst, "at least some scholars. . . have argued that the treaty would technically continue to remain in force until an agreement is reached. The treaty would obviously not carry much weight without [majority] support."[5]

If the treaty were to expire, it would mean that all obligations under the treaty for non-proliferation, CTBT, disarmament, and inspections, as well as for promotion of nuclear technology, would lapse. The safeguards and inspection role of the IAEA, for example, would be brought into question.

As the extension conference approaches, proponents of indefinite extension recount the accomplishments of the treaty with an almost awed reverence. The NPT *has* served the vital purpose of curbing new weapons programs and has complemented arms reduction treaties such as START I and START II. It has also created a means by which the international community can come together and discuss difficult security issues. And review and extension

See **Nuclear** *on page 7.*

[5] Lennon, 1994, p. 208.

Why Opt for Rolling Extension?

Signatories of the Non-Proliferation Treaty will decide how to extend the treaty at the upcoming conference. This important decision will have lasting effects on the treaty itself, how various signatories perceive the treaty, and on international efforts to control proliferation in general. Many signatories are lobbying for indefinite extension, while others favor long rolling extension, for instance every 25 years. Others advocate a far shorter rolling extension of various periods, some as short as 2 to 3 years (see pp. 4 and 5 for a description of extension options).

The NPT rests on complex and dynamic political footings. When it entered into force in 1970, few signatories could have imagined how rapidly and deeply world politics would change before the extension conference twenty-five years later. To accommodate the swiftness of global change, the NPT should require short rolling periods. *A rolling extension of ten years, with two or three review conferences within each extension period, would give the treaty the flexibility it needs without compromising international trust in the continuity of disarmament and non-proliferation goals.*

The main advantage of a rolling extension when compared to indefinite extension of the NPT is that it would safeguard the principal form of power within the NPT wielded by non-nuclear weapon states: the ability to vote for or against extension of the treaty in the future. By agreeing to rolling extension, the nuclear weapon states would send a message that the power and voice of the have-nots and the non-aligned movement are taken seriously. Indefinite extension on the other hand, would cement the existing NPT, complete with all of its shortcomings. While this is true of all extension options, rolling extension would at least provide frequent review and extension conferences to assess the treaty's progress and narrow the gap between the haves and have nots. Another problem with indefinite extension is that the impetus to move toward and achieve disarmament would be compromised. The NPT was intended to be a transitional document to curb proliferation until disarmament could be achieved. Rolling extension would leave open the possibility of a new, more effective treaty.

A twenty-five year rolling extension, though a theoretical improvement over indefinite extension, is still a weak option. The grave crisis in the former Soviet Union has given rise to fundamental political and military changes there every year or two. The situation continues to be highly unstable and unpredictable. Recent events point to a time-scale for serious political changes in that region on the order of months, or years. This pace of change is fundamentally different from 1970, when NPT signatories decided on a 25-year period for the treaty to remain in force, under the presumption, evidently false, that the two superpowers would continue to exist as such into the indefinite future.

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conferences provide the political opportunities for universal nuclear disarmament even though the NPT itself cannot be amended in any meaningful way.

But the NPT has had its share of weaknesses. Iraq was able to develop a nuclear weapons program while it was a signatory to the NPT and while under IAEA inspections. North Korea highlighted the possibility of a country obtaining "civilian" nuclear technology under the NPT—technology that can be used for nuclear weapons—and then withdrawing from the treaty. North Korea has used threats of withdrawal from the treaty to extract concessions from other countries.

In addition, countries such as India, Pakistan, Israel, and South Africa were not convinced that the NPT could provide for their security and developed nuclear weapons outside the treaty. The U.S.-Soviet arms race and the high value that the five declared states placed on their nuclear weapons exacerbated the worries of these countries. India apparently felt that it could not abstain from developing nuclear weapons with a nuclear-armed China at its border. Delegitimizing nuclear weapons and negotiating a global disarmament treaty as required under Article VI would do much to allay the security concerns of these and other countries.

Finally, the NPT is not the only way to achieve non-proliferation of nuclear weapons. Brazil and Argentina, for example, decided to forego nuclear weapons and set up an inspection regime outside the NPT framework.

The indefinite extension that the five declared haves seek would tend to cement existing power relationships, weaken the treaty, and damage international trust and relations. According to George Bunn of the Center for International Security and Arms Control at Stanford University:

> achieving a bare majority for an indefinite extension might be counterproductive: the losers might go home mad and even withdraw from the treaty. Since the NPT's effectiveness depends so much on the widest possible consensus, a narrow victory leaving many angry losers should be avoided.[6]

Moreover, indefinitely extending the treaty would remove direct pressure on nuclear weapon

See **Nuclear** *on page 8.*

[6] Bunn, 1994, p. 55.

The Nuclear Weapon Haves and the Have-Nots

DECLARED NUCLEAR WEAPONS STATES		
	(The "Big Five")	
United States	France	Russia
Britain	China	
HEIRS OF THE SOVIET BREAKUP		
Ukraine*	Belarus	Kazakhstan
DE-FACTO NUCLEAR WEAPONS STATES		
(states that possess or have tested nuclear weapons)		
India*	Israel*	Pakistan*
SUSPECTED SECRET BOMB PROGRAMS		
Iraq	North Korea	
BELIEVED TO HAVE ABANDONED BOMB PROGRAMS		
South Africa	Brazil*	Argentina*
WEAPONS CAPABLE STATES		
(technological capability regardless of intent)		
Canada	Germany†	Italy†
Japan†	South Korea	Sweden
Taiwan	Switzerland†	Belgium†
Netherlands†	Finland	

* States that are *not* NPT signatories as of August 1994.

† Weapons capable states that possess separated plutonium.

Note: Many U.S. analysts believe the list of countries attempting to acquire weapons may be larger. See Gray 1994 as an example.

Sources: "Factfile." *Arms Control Today*, July/August 1994, p. 28; Gray, P. *Briefing Book on the Nonproliferation of Nuclear Weapons.* Council for a Livable World, December 1993 , pp. 7-10; Posey, C. "Nuclear World Order." *Omni*, February 1993, p. 43.

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states to move toward disarmament.

A better course would extend the NPT with an eye to developing a new treaty enforcing full disarmament. The road to such a treaty is not an easy one; the have-nots will expect the nuclear weapon states to accomplish several important measures to level the playing field. These include extending the moratorium on nuclear weapons testing and successfully negotiating the CTBT, adopting the no-first-use policy, fully complying with START arms reduction treaties, and adopting a ban on weapons-usable fissile materials (plutonium and highly enriched uranium that are used in nuclear warheads). The pressure also exists for creating a definite timetable and commitments for nuclear disarmament.

LETTERS

Last issue's article on the DOE's plutonium inventory elicited support for IEER's effort to educate the public on technical issues.

The description of the plutonium packaging and disposal problem was presented clearly and objectively. A very complex problem was made understandable. We in the nuclear business often have difficulty communicating effectively with our non-technical colleagues on such an issue.

— Garland Proco,
Chief Materials Control and Accountability Branch, U.S. Department of Energy, Oak Ridge, TN

The humor in our last issue provoked several comments from readers.

Thanks for your newsletter, especially the jokes . . . a welcome relief!

— Adele Kushner,
Action for a Clean Environment, Alto, GA

The attached page [Dr. Egghead: "Increase Your Jargon Power"] degrades your publication. Seldom do I write any fellow editor with such a criticism, but I mean to be constructive

— Andrew Rudin,
Interfaith Coalition on Energy, Philadelphia, PA

Thank you for your thoughtful, witty and fact-filled magazine . . . Technoweenies unite!

— Edward Passarini,
New College, University of Alabama, Tuscaloosa,

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accepted by an independent oversight panel of scientists. Project reports are available from IEER.

Workers' Doses at the Fernald, Ohio Plant

In July, IEER completed several years of study on doses received by workers at the DOE-owned uranium plant near Cincinnati, commonly called the Fernald plant. This work was submitted to the court as expert testimony in a class action lawsuit filed by Fernald workers against the former contractor, National Lead of Ohio (NLO). Project reports are available from IEER.

The DOE and NLO claimed that overexposure occurred rarely, if ever. IEER concluded that, in almost every year in from 1952 to the early 1960s, more than half of the workers were exposed to uranium in excess of then-prevailing legal limits (15 rem dose to the lung), mainly due to inhalation of uranium. The DOE and NLO had actually never calculated internal radiation doses due to uranium, even though NLO's records on lung burdens of uranium and uranium content in workers' urine samples allowed approximate estimation. Workers' dose records only contained external dose estimates (of questionable accuracy in many cases).

The DOE settled the lawsuit on behalf its contractor, who was immune from all liability. The settlement provides for medical monitoring to all workers who worked at the Fernald plant for more than two weeks. The DOE also has promised not to fight workers compensation claims in

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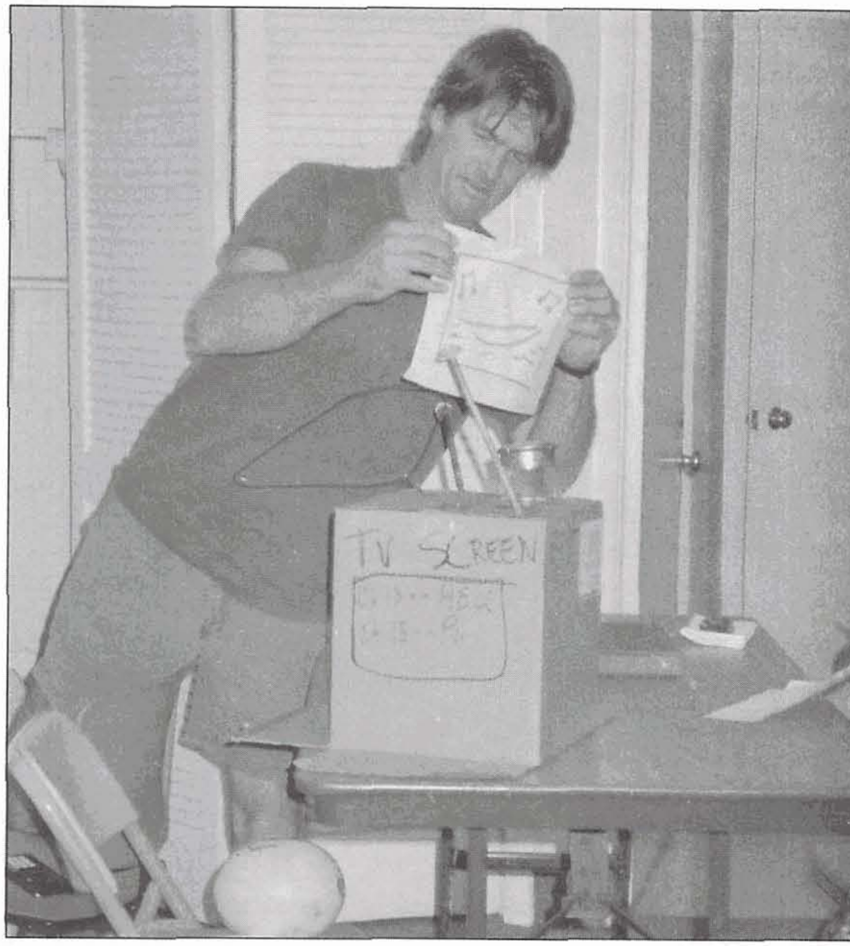
court, but to submit them to a panel of three doctors for a decision. And there is also a compensation fund of $15 million to be distributed among workers. The staff and consultants who worked on this project at various times were: Bernd Franke, Kevin Gurney, Mike Thorne, Milton Hoenig, and myself.

IEER staff and consultants created a new technique for dose reconstruction for workers that provides an approximate indication of population dose. In the Fernald case though, the records are too poor to give reliable estimates of individual doses in most cases. This case may have historic implications for present and former workers across the DOE weapons complex.

Nuclear Wastelands

IEER's six-year collaborative project with the International Physicians for Prevention of Nuclear War (IPPNW) to research the health and environmental effects of nuclear weapons production also came to a close this year, with the acceptance by MIT Press of our joint manuscript, *Nuclear Wastelands: A Global Guidebook to Nuclear Weapons Production and Its Health and Environmental Effects*. This book is scheduled to appear next July; it has 17 authors and was edited by Howard Hu, Katherine Yih, and myself.

IPPNW and IEER have jointly published two other books. The first in 1991, *Radioactive Heaven and Earth*, published by Apex Press, was on nuclear weapons testing. It has been translated into German and a summary has appeared in Japanese. The second, *Plutonium: Deadly Gold of the Nuclear Age*, was the first global assessment of the health and environmental effects of plutonium production; it also addressed many security aspects of the problem of plutonium after the Cold War. It has been translated into Japanese and German.



Jay Coughlan of Concerned Citizens for Nuclear Safety demonstrates an option for plutonium disposition at IEER's June technical training workshop on plutonium issues. His option would cook a TV dinner while transmuting plutonium.

Mending the Ozone Hole

In its August meeting, the MIT Press editorial board also accepted another IEER manuscript for publication. This book is on ozone depletion. Entitled *Mending the Ozone Hole: Science, Technology and Policy*, it will appear next spring.

This manuscript is the culmination of seven years of effort by IEER staff. We made many contributions to the protection of the ozone layer along the way. In 1988 we produced our first report on the subject for the Environmental Policy Institute. The report became a guidebook for activists trying to persuade corporations to phase out the use of ozone-depleting chemicals more rapidly.

In 1989, we persuaded the Environmental Protection Agency that

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A SPECIAL CENTERFOLD FOR TECHNO-WEENIES

Types of Nuclear Reactors

Nuclear reactors serve three general purposes. **Civilian reactors** are used to generate energy for electricity and sometimes also steam for district heating; **military reactors** create materials that can be used in nuclear weapons; and **research reactors** are used to develop weapons or energy production technology, for training purposes, for nuclear physics experimentation, and for producing radioisotopes for medicine and research. The chemical composition of the fuel, the type of coolant, and other details important to reactor operation depend on reactor design. Most designs have some flexibility as to the type of fuel that can be used (see Dear Arjun). Some reactors are dual-purpose in that they are used for civilian power and military materials production. The technoweenie centerfold below gives information about civilian and military reactors.

A nuclear reactor is a vessel designed to contain and harness the large amount of energy generated when the nuclei of heavy elements are fissioned (split). In the fission process, a small amount of the mass of the nucleus of the heavy elements (like uranium and plutonium) is converted into energy. This conversion is described

Reactor Type	**Light Water Reactor (LWR)**		**Heavy Water Reactor (HWR)**
	a. Boiling Water Reactor (BWR)	b.Pressurized Water Reactor (PWR)	
Purpose[1]	electricity	electricity; nuclear powered ships (U.S.)	electricity; plutonium production
Coolant Type	water (H_2O)	water	heavy water (deuterium oxide, D_2O)
Moderator Type	water	water	heavy water
Fuel—Chemical Composition[2]	uranium dioxide (UO_2)	uranium dioxide	uranium dioxide or metal
Fuel—Enrichment Level[3]	low-enriched	low-enriched	natural uranium (not enriched)
Comments	steam generated inside the reactor goes directly to the turbine	steam is generated outside the reactor in a secondary heat transfer loop	used in Canada: called "CANDU"—**Can**adian **D**euterium **U**ranium;" also used in Savannah River Site reactors (metal fuel at SRS)

[1] The purpose of the reactor does not depend on the choice of coolant or moderator, but rather on reactor size and on how the reactor is operated, and on what ancilliary materials are put into fuel rods besides fuel. The same reactors can, in principle, be used for electricity production, military plutonium production, and production of other radioactive materials such as tritium for military and civilian applications. The purposes listed in this column are the common ones to which such reactors are or have been put.

[2] Not all fuel types necessarily included.

by Einstein's famous expression $E=mc^2$, where E is the energy released, m is the mass converted to energy, and c is the speed of light. The expression c^2, (pronounced "c squared"), means the speed of light multiplied by itself. Since the speed of light is a very large number (300 million meters per second), a small mass is converted into a large amount of energy.

Nuclear reactors fission heavy nuclei by bombarding them with neutrons. Fission of some isotopes of heavy elements such as uranium and plutonium produces enough free neutrons to enable reactors to be designed so that each fission produces exactly one additional fission. In this way, once a nuclear reaction starts, it can go on without an additional external source of neutrons, a process called a chain reaction.

Reactors differ from each other mainly based on three criteria: 1) the types of coolant used, 2) the type of moderator employed, and 3) whether the reactor is "thermal" or "fast".

The energy produced by nuclear fissions is carried away from the reactor vessel by a **coolant**. This transport of heat out of the reactor vessel is necessary both for converting the energy into usable heat and/or electricity, and to keep the reactor cool. A failure to carry away a sufficient amount of the heat generated by the fission reactions in a reactor will result in overheating the reactor and, in extreme cases, a melt-down of the fuel. A considerable amount of heat is also generated by the radioactive decay of the fission products. This heat must also be transported out of the reactor vessel by the coolant.

The neutrons generated by fission reactions are energetic, or "fast" neutrons. Since they tend to escape from a container too rapidly to be able to sustain a chain reaction, most reactors are designed to slow down or "moderate" neutrons in order to increase the probability of fission reactions. The process of slowing down neutrons is accomplished by a **moderator**, which causes fission neutrons to collide with atoms of another material, such as hydrogen or carbon. The slowing down of the neutrons in such collisions occurs much in the same way that a billiard ball slows down when it

See **Techno-Weenie** *on page 12.*

Reactor Type	**Graphite Moderated Reactor**		**Fast Breeder Reactor (FBR)**
	a. Gas Cooled	b. Water Cooled	Liquid Metal (LMFBR) (most common type of breeder)
Purpose[1]	electricity; plutonium production	electricity; plutonium production	electricity; plutonium production
Coolant Type	gas (carbon dioxide or helium)	water	molten, liquid sodium
Moderator Type	graphite	graphite	not required
Fuel—Chemical Composition	uranium dicarbide (UC_2) or uranium metal	uranium dioxide (RBMK) or metal (N-reactor)	plutonium dioxide and uranium dioxide in various arrangements
Fuel—Enrichment Level[3]	slightly-enriched, natural uranium	slightly-enriched	various mixtures of plutonium-239 and uranium-235
Comments	used in Britain, and France (e.g.: AGR, MAGNOX)	used in former Soviet Union, e.g. Chernobyl (RBMK); N-reactor at Hanford.	breeder reactors are designed to produce more fissile material than they consume.

[3] The enrichment of fuel refers to the percentage of the isotope of uranium-235 compared to uranium-238 present in fuel. It is defined here as follows: slightly enriched uranium = about 0.8 to 3%; low enriched uranium = 3 to 5 %.

Source: Lamarsh, John, *Introduction to Nuclear Engineering*, (Reading, MA: Addison-Wesley Publishing Co., 1983), 120-143.

Techno-Weenie, *from page 11*

strikes another billiard ball. Since the weight of a neutron is about the same as that of a hydrogen atom, only light elements like hydrogen can be used to moderate neutrons, for the same reason that a billiard ball can be slowed down significantly by another ball of comparable weight. If the other ball is far heavier, the lighter ball will tend to bounce off without slowing down very much. Reactors that use slow neutrons to sustain chain reactions are called thermal reactors because the distribution of energy of the neutron is about the same as that of the atoms or molecules of the surrounding medium.

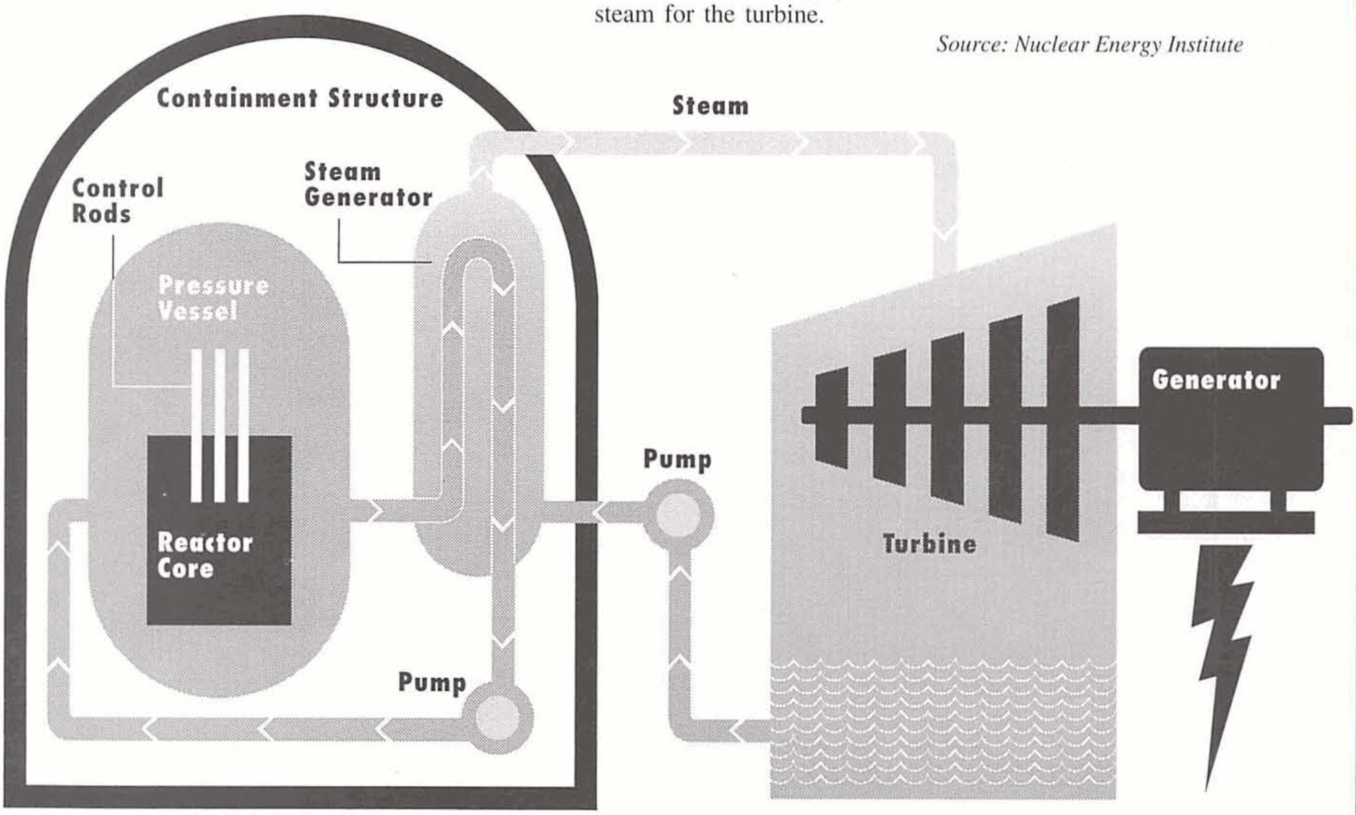
Some reactors are designed to use fast neutrons for sustaining chain reactions, and so operate without moderators. Such reactors, called **fast reactors** generally use liquid metal coolants, usually liquid sodium. Fast reactors are usually designed to convert non-fissile isotopes of elements into fissile elements in such a way that the amount of fissile material produced in the reactors is larger than the amount of fissile material loaded as initial fuel. Therefore, they are also called breeder reactors. The most common design involves converting non-fissile uranium-238 into fissile plutonium-239 (see Dear Arjun on page 15). Another design, which has not yet been made into a large-scale power reactor, converts non-fissile thorium-232, found in nature, into fissile uranium-233, which does not occur naturally in significant quantities.

Pressurized water reactors that use regular water as both moderator and coolant are by far the most common reactors used for electricity generation (see diagram below).

Pressurized Water Reactor (PWR)

In this reactor, water is heated by the nuclear fuel but kept under pressure so it will not boil. The water is piped from [reactor] vessel to a steam generator. There it transfers its heat to a second supply of water, which boils to make steam for the turbine.

Source: Nuclear Energy Institute



1994, *from page 9*

its initial analysis regarding carbon tetrachloride—a toxic, highly ozone-depleting chemical—was incorrect. The EPA originally believed that emissions of this chemical would soon decline to zero and not appreciably contribute to ozone depletion, but an IEER analysis led EPA to conclude that carbon tetrachloride should be phased out along with chlorofluorocarbons (CFCs). Carbon tetrachloride was included in the 1990 London revision of the Montreal Protocol as one of the ozone-depleting chemicals to be phased out by the year 2000; the date has since been brought forward to 1996.

IEER was the first (1990) to point out the role of anthropogenic biomass burning in the build up of ozone-depleting chlorine in the stratosphere. This analysis was subsequently accepted by other scientists in 1992, at an international meeting sponsored by NASA.

In 1992, we pointed out that so-called "low-ozone-depleting" compounds were several times more damaging to the ozone layer than conventional analytical techniques indicated, since those conventional techniques were based on the outdated assumption that the use of CFCs would go on indefinitely. Since this conventional analysis was the basis of EPA regulation of these chemicals, we filed a petition with the EPA to change its assessment. A similar analysis was first published in the peer-reviewed literature about three months after IEER published its report for use by activists. The EPA has agreed to take the new analysis into account in its regulation of these chemicals. IEER's ozone layer project was initiated by Annie Makhijani. Other current and former staff members who have worked on the project are Kevin Gurney, Amanda Bickel, David Kershner, and myself. *Mending the Ozone Hole* is authored by Kevin Gurney and me.

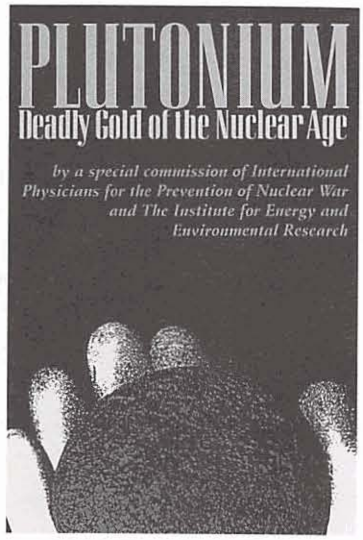
See **1994** *on page 14.*

RECENT PUBLICATIONS

Plutonium

Deadly Gold of the Nuclear Age

by International Physicians for the Prevention of Nuclear War and IEER



The Cold War is over, yet production of plutonium continues in many countries, including Russia. While much of it is allegedly for nuclear power, all plutonium can be used for nuclear weapons. This book examines the huge security, health and environmental risks posed by plutonium globally and spells out policies to end the plutonium era.

Plutonium, with its dangers, is, in human terms, forever. Deadly Gold is the first truly comprehensive account of the legacy of threats that production of plutonium—still continuing—bequeaths to the next one hundred thousand years. Its specific short- and long-term policy recommendations provide an immediate agenda for the . . . Clinton administration.

—Daniel Ellsberg

PRICE: $17 including postage and handling

FREE FACT SHEETS NOW AVAILABLE

IEER has two new fact sheets available. Each fact sheet is four pages long and written in clear, understandable language, with tables and a glossary. To order your free fact sheet, simply write to IEER, attention FACT SHEET, 6935 Laurel Ave., Takoma Park, MD 20912.

Physical, Nuclear, and Chemical Properties of Plutonium

This fact sheet describes the different isotopes and properties of plutonium. The fact sheet also explains how some important plutonium compounds are used and what some of the hazards of plutonium are.

Uranium: Its Uses and Hazards

A fact sheet on the physical and chemical characteristics of uranium and uranium fabrication.

1994, *from page 13*

Plutonium as a liability

We also began a new project in 1994 focused on plutonium. It is our first major national and international outreach effort. Our aim is get the U.S. and other plutonium-producing and plutonium-owning countries to declare plutonium an economic, security and environmental liability, and to decide on its disposition on that basis. For a description of the program, see below.

Dozens of Organizations Send a Letter to Clinton

IEER's plutonium project is moving into high gear with our recent submission to President Clinton of a letter urging him to declare plutonium a security, economic, and environmental liability. The draft declaration, printed below, was enclosed with the letter. IEER believes that a strong public declaration by the President would be a first step toward the vital goal of ending all production and use of plutonium world-wide.

The United States is in a good position to take the lead on this issue. It stopped producing plutonium in 1988 and is currently deciding how to dispose of plutonium from dismantled warheads. In addition, Secretary of Energy Hazel O'Leary has already said that surplus military plutonium "is a global security risk and an economic liability." Because the U.S. has little interest in plutonium, we believe that the President would agree to IEER's recommendation that he declare plutonium a liability. This would then prompt other countries that are more wedded to plutonium, such as Britain, France, and Japan, to rethink their plutonium plans.

Over three dozen groups from around the country have signed on to the letter to the President. We will keep you posted on its progress and continue our work to keep plutonium issues high on the Administration's agenda. *For more information about the Plutonium Project, contact Noah Sachs at IEER.*

U.S. Government Declaration: Excess Plutonium is a Liability

A Declaration that plutonium is a liability

It is U.S. government policy, based on extensive evidence and analysis, including the January 1994 study by the National Academy of Sciences, that all excess plutonium is a security, economic, and environmental liability. Excess plutonium is defined as all plutonium, of military or civilian origin, in any chemical form, that is not a physical component of the weapons designated as part of the U.S. arsenal in the Nuclear Stockpile Memorandum. It has the following operational meaning for policy:

- Excess plutonium will not be used to make nuclear weapons.
- Excess plutonium will not be regarded as part of an energy program. This does not *a priori* preclude using nuclear reactors as part of the disposition decision, but it does exclude any plutonium separation from spent fuel. The choice of a plutonium disposition option would be made on the basis of security and environmental criteria, and not on the energy value of plutonium.
- The U.S. government will make it a priority to persuade other countries to join in a similar declaration, even if their current position is that plutonium is a valuable energy resource. Cooperative exploration of energy policy issues will be an important part of U.S. diplomacy on plutonium and highly enriched uranium, the other fissile material of great concern to our security.

"Dear Arjun"

Dear Arjun,

What is MOX fuel and why is it so costly?

Mystified in Mystic, CT

Dear Mystified,

Once upon an ancient time, there was a knight who always tricked his fellow knights into taking the wrong path in their search for the Holy Grail, so that he could find it first. But since he never actually did, he came to be known as the "foxy fool." The court jester soon began to mock him, making all the other knights laugh, thus giving them the heart to continue their quest. Soon the jester's energetic performance came to be called "MOX fuel."

After the modern nuclear knights discovered plutonium, they thought they had found the Holy Grail and gave MOX fuel a new meaning: "**M**ixed **OX**ide fuel." MOX fuel is a mixture of uranium dioxide and plutonium dioxide. It can be used in nuclear reactors as a substitute for the more commonly used pure uranium dioxide fuel.

Power Reactors

Most power-production reactors in the world are light water reactors and use low enriched uranium dioxide as fuel (see Centerfold for reactor types). Nuclear power relies on energy released during the fissioning (or splitting apart) of two important isotopes: **uranium-235 and plutonium-239**.

Natural uranium contains three isotopes (or forms) of uranium, namely uranium-238, uranium-235, and uranium-234. Of these, only uranium 235 is fissile and can sustain a chain reaction. "Enriched" fuel has a higher percentage of uranium-235 than does natural uranium, which contains only 0.711 percent uranium-235. "Low enriched uranium" (LEU) used in light water reactors contains about 3 to 5 percent uranium-235. Such fuel also contains very small amounts of uranium-234, which is far more radioactive than the other two isotopes, and hence important from a health and safety point of view.

Almost all the rest of uranium in reactor fuel is uranium-238. Since uranium-238 can be split only by fast neutrons, it provides essentially no energy in light water reactors or other reactors that use slow neutrons to sustain the energy-producing chain reaction However, when slow neutrons are absorbed by uranium-238, the resulting nuclear reactions convert the uranium-238 into plutonium-239, which *can* be split by slow neutrons. Such fissions result in a release of energy (and two lighter elements called fission products). In this way some of the energy produced in nuclear reactors containing natural uranium or low-enriched uranium as fuel comes from the plutonium-239 made during reactor operation itself. Other isotopes of plutonium, notably plutonium-240, -241 and -242, are also created in reactors. (This mixture of plutonium isotopes is simply referred to as plutonium below.) Plutonium is also produced in other reactors that contain significant amounts of uranium-238, which includes almost all civilian power reactors.

The MOX Mix

In order to operate efficiently and maintain chain reactions, old fuel rods (containing "spent fuel") must be removed from reactors before all the uranium and plutonium are used up. At this point, the fuel rods can be stored as waste or "reprocessed" to recover usable fissile materials. In reprocessing, the residual plutonium, consisting mostly of plutonium-239, can be separated from fission products and from residual uranium in the

See **Dear Arjun** *on page 16.*

Dear Arjun, *from page 15*

spent fuel. However, plutonium cannot be used by itself as a fuel in reactors designed to use natural or low enriched uranium; these uranium fuels contain only a small proportion of fissile material (in the form of uranium-235). Using only plutonium as a fuel would result in far too many fission reactions, and the accompanying release of energy would overheat the reactor and damage it. Therefore, to be used as a fuel, plutonium must either be used in specially designed reactors, or it must be mixed with far larger amounts of natural or slightly enriched uranium. This limits fissile material loading in light water reactors to about 5 percent or less. The plutonium loading could be increased to 6 to 7 percent if special neutron-absorbing materials are added. According to a 1994 National Academy of Science study on plutonium, the use of such materials "would require safety review."[1] MOX fuel can also be used as a fuel in other reactor types.

To make MOX fuel, plutonium is converted into the chemical form of plutonium dioxide (PuO_2) and mixed with uranium dioxide (UO_2). These are both powders. The mixture is then formed into ceramic fuel pellets. This is the final form of MOX fuel.

[1] National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium* (Washington, DC: National Academy Press, 1994), p. 159.

We have not received any mail lately from Dr. Egghead in the Galapagos. We hope he will return soon to increase our jargon power and show us slides from his travels.

The Price of MOX

MOX fuel is both costly and a security risk. It is far more expensive to fabricate MOX fuel than LEU fuel because plutonium is thousands of times more radioactive per unit weight than low enriched uranium. Such high levels of radioactivity require special handling and safety procedures, which in turn raise the cost of MOX fuel. Moreover, unlike natural uranium or LEU, plutonium from civilian power plants can be used to make nuclear weapons. This makes security requirements at plants that handle plutonium far more complicated and expensive. For both these reasons, it is far more expensive to make MOX fuel than pure uranium fuel. In fact, given the low price of uranium that currently prevails, and that is forecast to prevail in the foreseeable future, MOX fuel is more costly than uranium fuel, even if the plutonium itself is free.

MOX fuel is far more costly than uranium fuel, even if the plutonium itself is free.

The end of the Cold War has accelerated the dismantling of nuclear warheads that contain weapon-grade plutonium (which contains 93 percent or more of plutonium-239). There is no consensus as yet in the U.S. on what to do with this dangerous material. There is some interest in converting plutonium into MOX fuel, as a way of making it more resistant to proliferation. Since burning MOX fuel in reactors mixes plutonium with highly radioactive fission products, it is difficult to re-extract and use the plutonium in weapons. On the other hand, burning MOX fuel in the U.S. would encourage other countries to continue reprocessing their spent fuel, and would tend to perpetuate the plutonium problem. Further, the liquid, high-level radioactive waste stream associated with reprocessing is more dangerous from an environmental and health perspective than standard low enriched uranium fuel for the time that such liquids must be storied in tanks (prior to vitrification).

Credits for this Issue

Production: Sally James of Cutting Edge Graphics, Washington, D.C.

Photographs: Arms Control and Disarmament Agency, Ellen Kennedy

Diagram: Nuclear Energy Institute

Dr. Polly C. Wonk's Federal Forum

IEER is pleased to announce that we have retained a new consultant, Dr. Polly C. Wonk, to write a column of advice to Washington officialdom. The aim of the column is to improve the return that taxpayers get for the dollars from government and raise the level of quality of environmental science and protection. Dr. Wonk not only likes to point to areas that need improvement and correction; she also likes to point out the positive things that are going on. She believes that it is time that liberals heeded Spiro Agnew's advice to stop being "nattering nabobs of negativism."

If any of our readers know of executive branch officials and Congressional staff they believe should be getting advice from Dr. Wonk, please send along their names, and we will add them to our mailing list.

Dr. Wonk welcomes short letters from those in the government concerned with nuclear-weapons related issues. Letters should discuss good, bad, or ugly aspects of current policy and what out to be done to improve the latter two. Dr. Wonk may publish some of these letters, in abbreviated form.

New Mission Possible at DOE

The Department of Energy, under Hazel O'Leary's leadership, has recently changed its mission statement for the better. The new statement reflects greater openness (working "in partnership with our customers") and a commitment to energy efficiency, providing the "leadership necessary to achieve efficiency in energy use, diversity in energy resources, [and] . . . improved environmental quality . . . . "

Hanford

Kudos to the DOE for at last trying to see in practice whether cement mixed with radionuclides, nitrates, and organic chemicals would actually set. It didn't. Armed with this experimental evidence, it rightly concluded that its program to mix millions of curies of radioactive wastes with cement and pour it into "grout vaults" at the Hanford site would not work. Too bad it did this simple experiment only after spending more than $100 million of taxpayer money, much of it digging huge holes into the ground in which to pour the cement.

The $100 million lesson for the DOE is: When doing something new, please try it out on a small scale first so that we know if the idea is workable.

It's a lesson that DOE does not seem to be applying to its proposed vitrification plant at Hanford. Discussions are underway about a large plant that would use a French design. I like French designs too, but in this case, the wastes that the French are vitrifying at home have a very different chemical composition from those in stored in 177 tanks at Hanford. DOE officials are aware of that.

Vitrification technology is not the main problem; we know how to make glass. The glass in question here is just like the Pyrex in your kitchen. What DOE urgently needs, and does not have, are methods to get the high-level wastes out of the tanks safely, and process them for one of two ends. Either they would be put in a dry, non-explosive form for later processing with glass or other waste form, or the treated wastes would be fed directly into a glass melter.

DOE has a long way to go to designing such treatment processes (called "pretreatment" because they would come before vitrification). Many different processes may be necessary, because wastes in various tanks have different chemical compositions. Further,

See **Polly C. Wonk** *on page 18.*

Polly C. Wonk, *from page 17*

independent of the number of pretreatment processes, the processing should be done in small-scale modules. That would assure that accidents, if they occur, will not produce large scale contamination. Since much of the waste is explosive, pretreatment will be more than normally dangerous. The risk of accidents is heightened by the fact that we do not know the exact composition of wastes; moreover, considerable uncertainties are likely to persist. Another advantage of small-scale treatment modules is that they can be coupled to small melters, which are relatively inexpensive, are advanced in design, have high capacity per unit melter volume, and are available in the United States.

Uranium

At many sites within the nuclear weapons complex as well as civilian sites regulated by the Nuclear Regulatory Commission, there are large quantities of waste contaminated with high concentrations of uranium. These uranium concentrations often exceed those of commercially-mined ore (which typically contains about 0.2 percent uranium). For example, two of the waste pits at the Fernald plant contain large concentrations of uranium — considerably more than ten times that found in commercial ore. Another example is some uranium-containing soils that are designated as wastes at the Sequoyah Fuels Plant near Gore, Oklahoma.

Given the high costs of clean-up, it may well be worthwhile to extract uranium not only from materials with mine-able levels of uranium, but also from materials with far lower concentrations than the 0.2 percent that is processed as commercial ore. Yet, the DOE has never made a thorough study of the economic and environmental costs and benefits of using these wastes to displace some domestic uranium production from ore (or uranium imports). Is it because uranium mining interests might not like such a study?

It is possible that this approach may have environmental costs higher than under current processing and disposal plans; but that needs to demonstrated in a careful study. But it is at least as likely that the current DOE approaches may result in far higher clean-up costs and greater waste disposal problems.

For instance, DOE's plan at Fernald is to make wastes in uranium pits and other wastes into glass marbles. The number of marbles will be far larger than the number of children in the world, and I presume that the DOE won't want to be handing them out. Where is the DOE going to put these billions of marbles?

Results of Last Issue's Naming Contest: "The Atomic Puzzler"

In the last issue of *Science for Democratic Action*, we asked our readers to help us dream up a new name for "Science Challenge"—our regular brain teaser on math and science problems related to nuclear issues. We received many fine entries. The winner is Adele Kushner, who suggested "The Puzzler." We have adapted her suggestion to "The Atomic Puzzler." Ms. Kushner also suggested "Beat the Egghead," but that suggestion was less popular with eggheads at IEER. Ms. Kushner will receive $25.00 for her creative contribution. Thanks to all readers who sent in entries.

Answers to the Last Atomic Puzzler (Science Challenge)

Last issue's Puzzler introduced readers to some basic properties of plutonium and the concept of half-lives of radionuclides like plutonium. The answers were as follows: 1) the volume of a 5 kilogram plutonium pit is about 312.5 cubic centimeters; 2) there are 315 curies in 5 kilograms of plutonium-239; 3) 2.5 kilograms (or half) of the original plutonium-239 remains after one half-life of 24,110 years.

For a detailed explanation of the answers, please write to IEER.

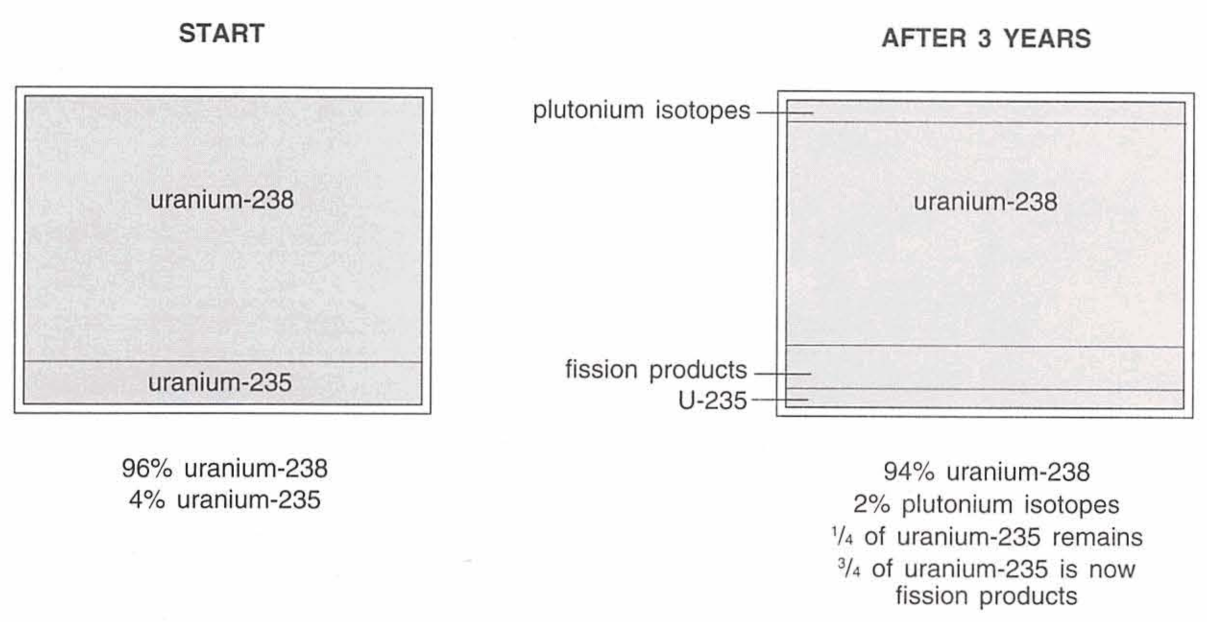
ATOMIC PUZZLER

A nuclear reactor is loaded at the start of the year with 40 tons of fuel containing 4 percent uranium-235 and 96 percent uranium-238. During power production over the course of three years (a typical fuel burn-up period), three-fourths of the uranium-235 is fissioned; further, 2% of the fuel is converted from uranium-238 to various plutonium isotopes. Find:

1) The percentage of fission products and uranium-235 remaining in the reactor's spent fuel at the end of three years.

2) The weight of fission products, uranium-235, uranium-238, and plutonium isotopes remaining in the reactor's spent fuel at the end of three years.

Note: In an actual reactor, some of the plutonium produced from uranium-238 would fission and produce energy. For simplicity, we have not included this aspect in the numerical calculations suggested above.



The **Atomic Puzzler** is a regular *Science for Democratic Action* feature. There is no way to learn arithmetic except to do it! We offer 25 prizes of $10 to people who send in solutions to all parts of the problem, right or wrong. There is one $25 prize for a correct entry. Work the problem and submit the answer to Ellen Kennedy, IEER, 6935 Laurel Avenue, Takoma Park, MD 20912. If more than 25 people enter and there is more than one correct entry, the winners will be chosen at random. The deadline for submission of entries is **December 31, 1994**. People with science, math, or engineering degrees are not eligible.

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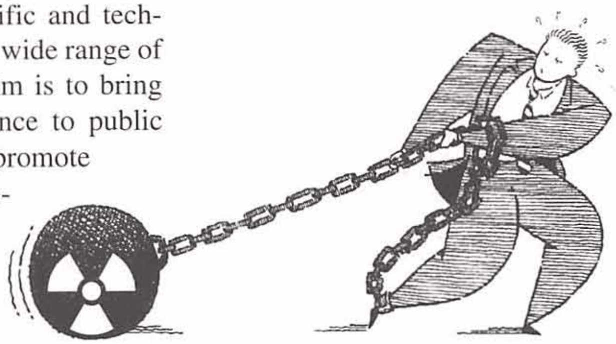

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