SCIENCE FOR DEMOCRATIC ACTION

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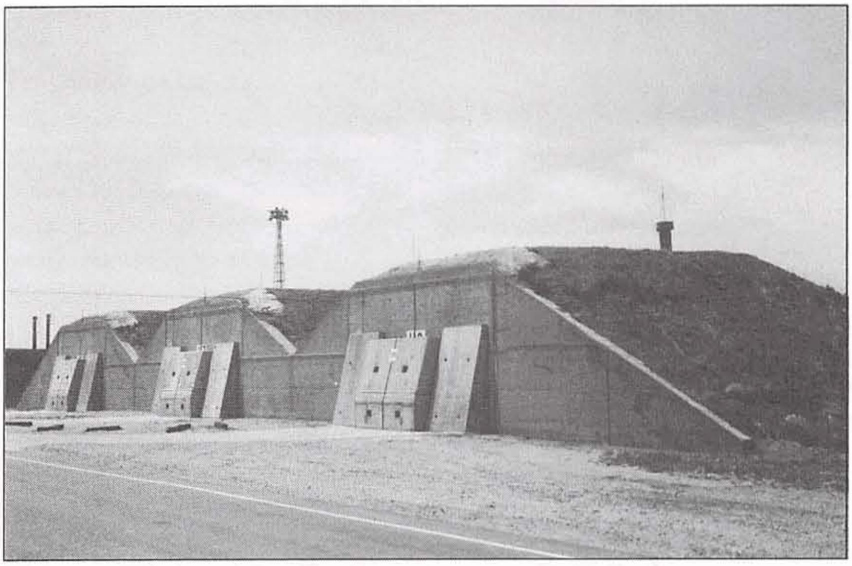

PHOTO COURTESY OF U.S. DEPARTMENT OF ENERGY

Staging bunkers at US DOE's Pantex Plant in Texas. Sixteen such "igloos" are used for interim storage of plutonium pits removed from disassembled weapons.

DOE Assesses Dangers from its Plutonium Inventory

by Bret Leslie

With the end of the Cold War, the Department of Energy (DOE) weapons complex has shifted from plutonium and warhead production to weapons dismantlement. This change in program direction has forced the United States government to address how it can manage and dispose of excess weapons plutonium. In response, the DOE has launched a project to recommend measures for the control, storage, and ultimate disposition of surplus plutonium and highly enriched uranium present or stored in the various DOE facilities.[1]

Plutonium in the DOE complex consists largely of plutonium metal pits (the spherical core of a nuclear warhead). But there are also over 33 tons of plutonium in other forms, including processing residues and pieces of metal scrap. Residues and scraps are stored in different chemical and physical forms and a variety of containers, many of which are unsuitable for long-term storage. Some plutonium remains in "process hold-up," (e.g., plutonium in ventilation systems and process vessels).

See "Assessment"—p. 2

[1] H. O'Leary, Memorandum for Secretarial Officers and Managers, Operations Offices Managers, "Department-wide Initiative for Control and Disposition of Surplus Fissile Materials" (Washington, DC: US DOE, January 24, 1994).

Editorial

Plutonium is a Liability

*A Commentary on a National Academy of Sciences Study**

by Arjun Makhijani

The National Academy of Sciences (NAS) issued an historic report in January 1994, entitled *Management and Disposition of Excess Weapons Plutonium.*** Prepared under the direction of the NAS Committee on International Security and Arms Control (CISAC), the report examines the problem of the management and disposition (long-term management) of plutonium from unwanted nuclear weapons at the end of the Cold War.

The report warns that excess military plutonium poses high security risks and at the same time

See "Liability"—p. 5

*This article is largely derived from an article in the May/June 1994 issue of The *Bulletin of Atomic Scientists*.

**Committee on International Security and Arms Control, *Management and Disposition of Excess Weapons Plutonium*, prepublication copy, National Academy Press, Washington, DC., 1994. *See* "Resources on Plutonium" to order a copy.

INSIDE... POSTCARDS FROM THE EGG (SEE PAGE 12)

Assessment
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A number of potential problems, or "vulnerabilities" (see box), could arise from extended storage of excess plutonium in unsuitable containers or forms. The DOE is currently examining how to include excess plutonium[2] in its long-term plans for managing plutonium (known as "final disposition"). Since final disposition will likely take decades to complete, excess plutonium will require some Band-Aid measures in the meantime, such as processing or interim storage.

The term "vulnerability" has acquired a specific definition in the context of this DOE inquiry. Vulnerabilities in nuclear facilities are "conditions of weakness that may lead to unnecessary or increased radiation exposure of the workers, release of radioactive materials to the environment, or radiation exposure of the public."[3]

The Assessment

As the first step in deciding what to do in the short-term with plutonium residues and pits, the Office of Environment Safety & Health (ES&H) of the DOE is currently performing a vulnerability assessment. This assessment will provide the DOE with an understanding of ES&H issues surrounding the plutonium inventory. The assessment results will serve as the foundation for determining immediate, interim and final disposition actions.

Immediate corrective actions are needed to remedy pressing safety concerns. For instance, the solutions in degraded containers could be transferred to new containers to prevent leakage. **Interim** actions may be required to address vulnerabilities during the next 1 to 20 years. For example, the DOE has suggested converting plutonium nitrate solutions and plutonium oxide into metal "buttons" (disks of plutonium that are roughly the size of hockey pucks) at Savannah River Site (SRS) and Hanford. Some interim actions, however, are controversial. For example, the DOE has suggested that, from a technical perspective, pits are the ideal form for storage. But this option would contradict the nonproliferation objective of the project, since plutonium metal in pit form is essentially ready to fashion into a weapon. Finally, though the assessment project will not recommend actions for **final disposition**, the results of the study will help shape disposition policy in the future.

Some vulnerabilities are already known to exist. One of these relates to containers known as "cans" in which plutonium is deteriorating (see figure, page 3). A survey

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Science for Democratic Action Managing Editor: Ellen Kennedy

[2] "Excess plutonium," sometimes called "surplus" plutonium, refers to all plutonium in the complex that is not considered strategically necessary. Since DOE has not clarified what plutonium is considered strategic, the amount of excess plutonium is also unclear.

[3] US Department of Energy, "Plutonium ES&H Vulnerability Assessment Project Plan" (Washington, DC: US DOE, April 25, 1994).

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of 30 representative cans at the Los Alamos National Laboratory, in New Mexico, indicated that while none of the packages examined had yet failed, a third of the 30 containers showed various degrees of deterioration that could lead to failure if not properly stabilized and repackaged. There are thousands of storage containers.[4] The ES&H study will also try to uncover vulnerabilities not yet identified.

The vulnerability assessment study will address several categories of plutonium, including process hold-up; plutonium metal; oxide; unirradiated reactor fuel and targets; weapons components and pits in DOE custody; scrap, residues, and compounds; and product solutions and laboratory samples. However, the study excludes plutonium in spent fuel. DOE has identified a total of 42 sites as possessing plutonium.

We urge DOE to address how their interim actions will affect long-term plutonium disposition options.

Initial assessment of all these sites will rely on a set of written questions. In addition, 14 of the 42 sites will be visited.

The assessment will try to find out how much plutonium in its various forms is present at each of the 42 sites, and to analyze the physical barriers and administrative controls that would restrict the release of plutonium from the site ("barrier analysis"). It will identify adverse conditions both inside and outside of the facility that could aggravate environment, safety and health or security problems. Examples of such adverse conditions inside facilities include fire, equipment failure, and inadequate preventive maintenance. External adverse conditions could include aircraft crash, earthquake, and power failure.

The Hazards of Plutonium Storage

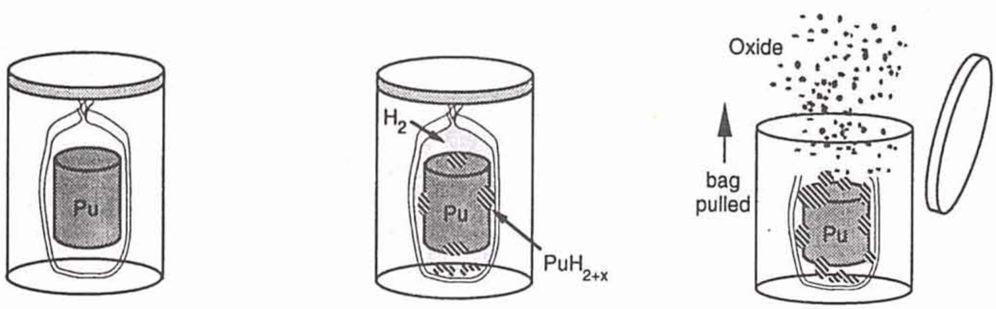
The principal hazard to human health from plutonium arises when it is inside the body. Plutonium emits almost all its energy as alpha radiation, which does not penetrate the outer, dead layer of the skin. But once inside the body, the alpha radiation from plutonium is able to damage cells. Even very
See "Assessment"—p. 4

[4] This information was provided by a Los Alamos National Laboratory (LANL) employee in a presentation at the Working Group Meeting of the Plutonium Vulnerability Assessment Study March 29, 1994.

PLUTONIUM STORAGE—CASE STUDY

Incident: Energetic release of material on opening.

- initial configuration - | - early processes - | - catastrophic release -



Polyethylene bagging, probably two layers
Lead-lined outer can, tape sealed
5 kg Pu metal
Packaged in 1984

Radiolytic decay of bagging creates hydrogen
Hydrogen reacts with Pu to form PuH_{2+x}
Bag embrittles

Opened in hood (air)
Pulling embrittled bag causes massive breach
Hydride spontaneously reacts with oxygen
Hood, operator contaminated

No physical failure mechanism, intrinsic errors in packaging.

Direct cause: Exposure of pyrophoric hydride to air.

Underlying factors: Many. Use of organic material, 'first surface' of organic material, handling in oxidizing environment, short-term storage extended to long-term with no repackaging, inadequate documentation, others.

Source: Haschke and Martz, Vulnerability Working Group meeting, March 28, 1994.

Assessment
continued from p. 3

small quantities of plutonium inside the body increase cancer risk substantially. When storing plutonium then, it is crucial to ensure that no plutonium can escape its storage container. The dangers to worker and public health from plutonium storage depend on the risk that plutonium may not be contained. That risk in turn depends on the physical and chemical properties of the various forms of plutonium (see Centerfold) and on their interaction with storage conditions and containers. See the box below, "Plutonium Storage: Why is it Hazardous?"

Evaluating the Results

When the survey stage of the assessment is complete, the problems at each site (materials, barriers, and adverse conditions) will be weighed against the compensatory measures (safety precautions such as alarm systems). The net result, or the "consequence analysis" will determine if and where

PLUTONIUM STORAGE: Why is it Hazardous?

In the nuclear weapons complex, plutonium is primarily found in three forms: plutonium metal, plutonium oxide, and plutonium nitrate solutions. Each form poses its own set of potential problems that may result in the release of plutonium from storage containers or create difficulty in handling. Plutonium metal reacts with oxygen in air (or corrodes) to form plutonium oxides. Of these oxides, plutonium dioxide (PuO_2) is the most prevalent. The formation of plutonium dioxide from plutonium metal is accompanied by release of heat and a large expansion in volume, which may breach the primary storage container.[1]

Plutonium oxide normally consists of small particles. If not contained, such particles can be easily dispersed and inhaled. Plutonium oxide has the ability to **adsorb** (to stick: see Dr. Egghead) water and organic molecules on its surface. If the container (and thus the plutonium inside it) is heated, or if chemical reactions within the container raise the temperature, any adsorbed water on the plutonium may be released, building up the pressure in the container. Pressurization can also occur when the adsorbed materials are slowly released over time. In addition, the adsorbed molecules are subject to radiation from the plutonium, which can chemically break them up (the process of **radiolysis**; see Dr. Egghead). Radiolysis can also cause problems in packaging materials; any plastic in the packaging, for example, may disintegrate. Unfortunately, the DOE wrapped and sealed many containers in plastic bags in an effort to minimize the spread of contamination. A breach of the primary containment would therefore put plutonium in contact with the plastic. Radiolysis of some types of plastic bags releases hydrogen and gaseous hydrochloric acid, both of which react with the container material and the plutonium metal. These reactions increase the risk of fires; some of them also release heat within the container. Such reactions in turn increase the risk that the plutonium will not be contained.

Other material properties of plutonium may result in hazards in the DOE weapons complex. First, plutonium in some cases is **pyrophoric** (spontaneously igniting in air: see Dr. Egghead). Clean plutonium metal does not burn at room temperature, but the higher temperatures associated with machining plutonium metal have caused numerous fires in the finely-divided plutonium metal machine scraps. Second, the decay of short-lived plutonium-241 in plutonium metal yields americium-241, which emits penetrating gamma radiation. Thus, worker exposure from gamma radiation during direct handling of some material may be a concern. Hazards associated with forms of plutonium other than metal or oxides are also likely to create environment, safety and health vulnerabilities. For instance, spills or accidental criticality are important concerns for plutonium nitrate solutions, such as those stored at the Savannah River Site, near Aiken, South Carolina.

[1] US Department of Energy, "Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities," DOE/DP-0123T (Washington, DC: US DOE,, January 1994).

Assessment
continued from p. 4

there are vulnerabilities relating to contamination, exposure, and direct injury to workers and the public. It will also assess vulnerabilities in terms of environmental insult to the air, water, and ground. For instance, a vulnerability might consist of the potential contamination and exposure of workers (e.g., rupture of container in storage).[5]

Several actions can be taken to reduce risks from known vulnerabilities. For instance, preparation and certification of materials for storage are generally likely to reduce risks. The risks associated with storage of metal and oxide can be reduced by excluding all organic materials from the storage package. Finally, using leak-tested, hermetically-sealed, storage containers could also decrease risks.

This DOE initiative of determining environment, safety and health vulnerabilities and corrective actions for plutonium in the complex is vital. But, as with many past DOE efforts on ES&H matters, it has one crucial flaw. The scope of the effort excludes all consideration of what impact interim actions will have on the final disposition options for plutonium. Since interim processing could complicate final disposition and increase its costs, this is a serious omission. We urge DOE to address how their interim actions will affect each of the disposition options discussed in the accompanying editorial.

> *Much plutonium is stored in deteriorating containers. One sampling showed that a third of the containers had deteriorated.*

[5] US. Department of Energy, "Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities," DOE/DP-0123T (Washington, DC: US DOE, January 1994).

Thanks to Joseph Martz of the Los Alamos National Laboratory for his review of the preliminary draft of this article.

LETTERS

I appreciate your newsletter a lot. For example, your last issue gave me the most detailed info. I've found concerning the human subject tests....I'm a Carleton physics professor and science and soc[iety] activist.

J. Weisberg
Northfield, MN

Your publication has given me some hope [that] I can be decisive and courageous on this committee and understand radioactivity well enough not to be silenced....

Z Krippke, M.D., M.P.H,
La Jolla, CA
serving on a citizen oversight committee for cleanup of a naval base

I appreciate the information [in *Science for Democratic Action*] as I am... working to bring a stop to the planned MRS storage dump here on the Mescalero Apache Reservation. Keep us in your thoughts and prayers as others in the group fight along with me.

Rufina Laws,
Mescalero Apache Tribe member, Ruidoso, NM

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affords no economic advantage for the foreseeable future. It states that "exploiting the energy value of plutonium should not be a central criterion for decision-making, both because the cost of fabricating and safeguarding plutonium fuels makes them currently uncompetitive with cheap and widely available low-enriched uranium fuels, and because whatever economic value this plutonium might represent now or in the future is small by comparison to the security stakes."

The NAS analysis shows that even when the plutonium itself is assumed to be "free," it costs more as an energy source than uranium because plutonium processing and the fabrication of fuel containing plutonium is so expensive. (In most cases, plutonium is used in a reactor fuel known as MOX—a mixture of oxides of plutonium and uranium).

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The report also discusses the issue of "civilian plutonium," or plutonium recovered from reprocessing spent fuel from civilian power plants. Recognizing the security risks from all separated plutonium, including that in civilian nuclear power programs, it recommends that the US and Russia "pursue a reciprocal regime of secure, internationally monitored storage of fissile material, with the aim of ensuring that the inventory in storage can be withdrawn only for non-weapons purposes." As Russia continues to experience severe economic problems and political uncertainty, this is a crucial and very urgent recommendation.

The report also implies that civilian plutonium is a liability, comparing it with producing oil from oil shale rock, which will remain uneconomic for decades, but which poses no comparable security risk. In taking on the subject of civilian plutonium, albeit gingerly, the NAS report has contributed to progress on resolving plutonium disposition issues across the board.

Recommendations

The NAS report recommended the possible use of MOX as one long-term plutonium disposition option. If MOX were used in existing nuclear reactors, the plutonium remaining in the waste would be sufficiently mixed with radioactive fission products that it could not be used in weapons without costly and dangerous processing. Alternatively, the report suggested mixing excess plutonium with radioactive wastes and molten glass—a process known as vitrification.

Both of these options would make it difficult, costly, and dangerous to re-extract the plutonium for use in weapons. The criterion by which these options were adjudged suitable was the "spent fuel standard"—that is, it should be at least as difficult to make nuclear weapons from the end product as it would be to make weapons from unreprocessed spent fuel from civilian nuclear power plants.

The report also recommended considering deep boreholes (two to four kilometers deep) for evaluation as a disposal option, but recognized that retrievability from such boreholes could pose problems because, in that case, the plutonium could be re-used to make nuclear warheads. On the other hand, the report notes that retrievability might be an advantage in negotiations with the Russian government, which views plutonium as an economic resource.

> *"...the world is condemned to having to baby-sit this material for at least another decade..."*

But plutonium would continue to pose a threat even in these hard-to-handle radioactive forms. The report notes that most fission products, which make spent fuel or radioactive glass logs difficult and expensive to handle, decay well before plutonium does. It therefore recommended research into a variety of transmutation options using critical and sub-critical reactors that, in the very long-term, could fission essentially all existing plutonium. The NAS panel recommended this approach as a supplement to, and not a substitute for, the two main options.

None of these disposal options can be accomplished quickly—it will be well into the next century before they are completed. As Wolfgang Panofsky, Chair of the NAS plutonium panel, told the *Washington Post*, "the world is condemned to having to baby-sit this material for at least another decade," (January 25, 1994). As part of that atomic baby-sitting exercise, the NAS report recommends, all inventories of fissile materials must be declared, and put into international or bilateral verified storage.

Another Option

One possibility for relatively quick processing of plutonium (within the next decade) is to vitrify it alone, without mixing it with radioactive waste. Because plutonium emits mainly alpha radiation, which is dangerous only when inside the body, it can be vitrified without massive shielding. A far more complex plant would be needed if radioactive wastes—emitting far more penetrating radiation—were mixed in.

The NAS report considered such an option, but did not recommend it, since the plutonium could be recovered after processing at far lower levels of effort than with spent fuel from reactors, a disadvantage from the point of view of potential re-use in weapons.

However, the report does note that "experience with separating materials from glass is far less widely disseminated than experience with spent fuel reprocessing."

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For this reason, IEER advocates vitrification of plutonium alone, provided the technical aspects are properly worked out in a pilot plant. This measure would provide a considerable barrier to re-use. Moreover, as with deep boreholes, a potential for re-extraction could be an advantage in the near future, if the U.S. were to arrive at an agreement with Russia on disposition. Finally, the glass could be re-melted and mixed with radioactive waste at a future date.

Given the collapse of the economy in the former Soviet Union and the accompanying political and military instability, time is the most important factor in coping with excess plutonium. Added to the problem is the Russian government's attachment to plutonium as a resource. The NAS report should have put the vitrification of plutonium alone at least on a par with disposal in deep boreholes. We recommend that DOE build a pilot plant to test the process with plutonium metal and with various chemical residues present in the DOE complex (see the article on Plutonium Vulnerabilities). This would provide much of the environmental, health, and safety data needed for a sound decision on the vitrification of plutonium.

Finally, the NAS report does not mention the use of photons as a possible transmutation option. This may be worthy of some theoretical consideration at this stage along with other long-term possibilities, though the engineering challenges will probably be great. Photons in a narrow spectrum (about 10 to 15 MeV for plutonium-239), called the "giant resonance region," can induce fission with a high probability relative to other parts of the electromagnetic spectrum. Such photons can be generated using electron accelerators.

No Nuclear Nirvana

Its makers had hoped that plutonium would lead the world to a nirvana created by a boundless source of energy. Glen Seaborg, who led the team that first isolated it, felt that plutonium would provide the energy to make deserts bloom and enable "planetary engineering"; there would be earth to moon shuttles; sea water would be made potable. "My only fear is that I may be underestimating the possibilities," he said in 1968.

These were fond hopes, not engineering conclusions. The high cost of deriving energy from plutonium has to do with the enormous precautions that must be taken in processing it (it is highly carcinogenic), with the large capital investment needed for building nuclear reactors, and with the difficulty and expense of decommissioning reactors and disposing of their radioactive wastes. Other burdens stem from safeguarding it, since all grades of plutonium are usable for making nuclear weapons, another important fact that the NAS report highlights.

Plutonium was regarded in most of the post-World-War-II era as the gold of a glorious nuclear age to come. It was not to be. Rather, it has become a terrible liability. Today, knowledge of nuclear weapons technology is so widespread that getting access to it is not a substantial barrier to proliferation. Rather, as the NAS report notes, "access to fissile material is the principal technical barrier to proliferation in today's world...." That is why complete elimination of nuclear-weapons-usable materials is a necessary condition for achieving both nuclear non-proliferation and nuclear disarmament goals.

SELECTED IEER WORK

- Project to support grassroots groups working on nuclear weapons production, testing and clean-up issues.
- Outreach on ozone layer protection.
- Project to declare plutonium a liability.
- Rongelap Rehabilitation Project to assess the habitability of Rongelap Atoll.
- Environmental evaluation of proposed uranium enrichment plant in Louisiana.
- Production of *The Nuclear Power Deception,* a book on nuclear power issues.
- Production of source-book on global environmental and health effects of nuclear weapons production for IPPNW.
- Work on clean-up and decommissioning issues for Native Americans for a Clean Environment.

A SPECIAL CENTERFOLD FOR TECHNO-WEENIES

Properties of Plutonium Metal

(Plutonium metal is used in nuclear weapons)

Compiled by Annie Makhijani

Physical characteristics	
Color	silver
Melting point	641 centigrade
Boiling point	3,232 centigrade
Density	16 to 20 grams/cubic centimeter

How plutonium metal reacts in air	
FORMS AND AMBIENT CONDITIONS	REACTION
Non-divided metal at room temperature	relatively inert, slowly oxidizes (corrodes)
Divided metal at room temperature	readily reacts to form plutonium dioxide (PuO_2)
Finely divided	
particles under about 1 millimeter diameter	pyrophoric (spontaneously ignites) at about 150 degrees C[1]
particles over about 1 millimeter diameter	pyrophoric at about 500 degrees C
Humid, elevated temperatures	readily reacts to form plutonium dioxide (PuO_2)

Solubility of plutonium metal in acids	
Hydrochloric acid (HCI)	soluble
Perchloric acid ($HCIO_4$)	soluble
Phosphoric acid ($H3PO_4$)	soluble
Nitric acid (HNO_3)	insoluble[2]

[1] US Department of Energy, "Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities," DOE/DP-0123T (Washington, DC: US DOE, January 1994).

[2] Plutonium metal is insoluble in nitric acid. Plutonium dioxide (PuO2) is slightly soluble in hot, concentrated nitric acid. But when plutonium dioxide and uranium dioxide (UO2) form a solid mixture, as in spent fuel for example, then the solubilitiy of plutonium dioxide in nitric acid is enhanced due to the fact that uranium dioxide is soluble in nitric acid.

Important Plutonium Compounds and their Uses

COMPOUND	USE
Oxides	
Plutonium Dioxide (PuO_2)	can be mixed with uranium dioxide (UO_2) for use as reactor fuel
Carbides	
Plutonium Carbide (PuC) Plutonium Dicarbide (PuC_2) Diplutonium Tricarbide (Pu_2C_3)	all three carbides can potentially be used as fuel in breeder reactors
Fluorides	
Plutonium Trifluoride (PuF_3) Plutonium Hexafluoride (PuF_4)	both fluorides are intermediate compounds in the production of plutonium metal
Nitrates	
Plutonium Nitrate ($PuNO_3$)	no use, but it is a product of reprocessing (extraction of plutonium from used nuclear fuel)

Important Plutonium Isotopes Radiological Properties

The plutonium isotopes listed below are "fissionable", which means that the nuclei can be split into two fragments, called fission products. In addition to being fissionable, plutonium-239 and plutonium-241 are "fissile" — that is, they can be split by neutrons of very low (ideally zero) energy. This means that they can be assembled into a critical mass, and hence can sustain a chain reaction without an external source of neutrons.

	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
Half-life (in years)	87.74	24,110	6,537	14.4	376,000
Specific activity (curies/gram)	17.3	0.063	0.23	104	0.004
Principal decay mode	alpha	alpha	alpha some spontaneous fission[3]	beta	alpha
Decay energy (MeV)	5.593	5.244	5.255	0.021	4.983
Radiological hazards	alpha, weak gamma	alpha, weak gamma	alpha, weak gamma	beta, weak gamma[4]	alpha weak gamma
How isotope is produced	nuclear reactors	nuclear reactors	nuclear reactors	nuclear reactors	nuclear reactors
Main Uses	Production of thermoelectric power used in nuclear weapons, satellites, and heart pacemakers	Fissile material for nuclear weapons, and for the production of energy	None	None	None

Source: CRC Handbook of Chemistry and Physics, 1990-1991. Various sources give slightly different figures for half-lives and energies.

[3] Source of neutrons causing added radiation dose to workers in nuclear facilities.

[4] Plutonium-241 decays into Americium-241, which is an intense gamma-emitter.

Resources on Plutonium and Non-Proliferation

Council on the Department of Energy's Nuclear Weapons Complex, Tides Foundation. *Beyond the Bomb: Dismantling Nuclear Weapons and Disposing of their Radioactive Wastes* (San Francisco, CA: Tides Foundation, 1994). Softcover, 26 pages, $2.00 or discount for bulk orders. Write to: Nuclear Safety Campaign, 1914 North 34th St., Suite 407, Seattle, WA 98103. *A clear, succinct guide for citizens.*

Chow, B. and Solomon, K. *Limiting the Spread of Weapon-Usable Fissile Materials* (Santa Monica, CA: RAND, 1993). Softcover, 102 pages, $18.00 including handling: to order call (310) 451-7002. *Discusses quantities of fissile materials, costs of civilian nuclear fuel cycles, and disposition options.*

Leventhal, P. and Alexander, Y., editors. *Preventing Nuclear Terrorism*, Nuclear Control Institute, International Task Force on Prevention of Nuclear Terrorism (Lexington, MA: Lexington Books, 1987). Softcover, 472 pages, $24.95. *A summary of recommendations and a presentation of nuclear terrorism issues by members of the Task Force. The book is both national and international in scope.*

IPPNW and IEER. *Plutonium: Deadly Gold of the Nuclear Age* (Cambridge, MA: International Physicians Press, 1992). Softcover, 178 pages, $17 including shipping and handling: to order send $17 to IEER, 6935 Laurel Avenue, Takoma Park, MD 20912. *An overview of plutonium characteristics, production and resulting wastes, and a history of accidents associated with plutonium production and use. Includes recommendations for management of wastes and materials.*

IEER. *The Yellow Pages: A Technical Reference Guide for Activists, Citizens and Policy Makers on Nuclear Waste and Cleanup Issues* (Takoma Park, MD: IEER, 1994). Unpublished photocopy, 21 pages, $3.00: to order send $3 to IEER, 6935 Laurel Avenue, Takoma Park, MD 20912. *A handy reference guide to the science and math necessary for reading documents on nuclear issues. Includes information on radionuclides, half-lives, units of radiation, etc.*

National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, Executive Summary (Washington, DC: National Academy Press, 1994). Softcover, 31 pages, free: call (202) 334-2811. *Summary of recommendations by Committee on Security and Arms Control. Provides clear summary of the issues, including long-term disposition.*

U.S. Congress, Office of Technology Assessment, *Dismantling the Bomb and Managing the Nuclear Materials*, OTA-O-572 (Washington, DC: U.S. Government Printing Office, Septermber 1993). Softcopy, 202 pages, $12.00: to order call OTA at (202) 783-3238. *An important report on the dismantlement of nuclear warheads and the disposition of the remaining nuclear materials.*

U.S. Congress, Office of Technology Assessment, *Proliferation of Weapons of Mass Destruction: Assessing the Risks*, OTA-ISC-559 (Washington, DC: U.S. Government Printing Office, August 1993). Softcopy, 123 pages, $7.00: to order call OTA at (202) 783-3238. *This report gives a good overview of proliferation risks and policy implications of weapons of mass destruction, including nuclear, biological and chemical weapons.*

BOOK REVIEW

Albright, Berkhout and Walker. ***World Inventory of Plutonium and Highly Enriched Uranium, 1992.*** Oxford University Press, SIPRI: New York, 1993. Hardcover, 246 pages, $39.95.

The international community is gearing up for the 1995 Extension Conference of the Non-Proliferation Treaty, which will in part determine the fate of materials used in nuclear weapons. Inventories of these "fissile materials"—plutonium and highly enriched uranium—are described at length in The *World Inventory of Plutonium and Highly Enriched Uranium, 1992.* The *World Inventory* contains clear presentations of technical details that are important for understanding nuclear weapons development and proliferation issues. Readers should note that since publication, new data on plutonium and highly enriched uranium have become public.

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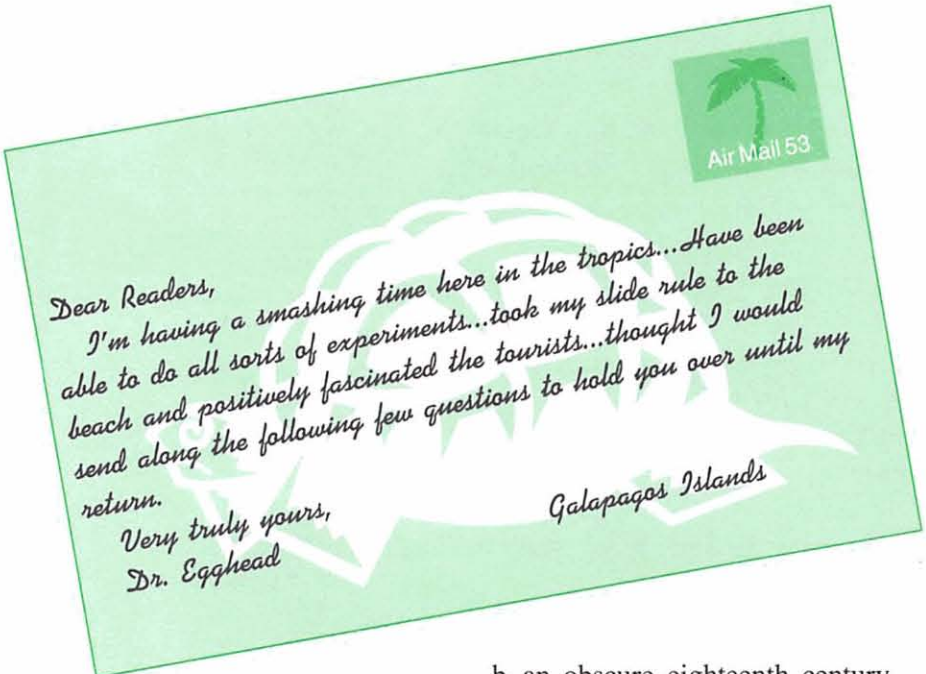
by Dr. Egghead

Reactors and Pu Disposal Options



1. **pits**
a. a sassy cologne for the manly man; let her know how base you can be
b. the depth of despair felt by bomb makers in the post Cold War period
c. a hollow sphere of plutonium-239 or uranium-235 metal. It is the trigger of nuclear weapons—the first part of a nuclear explosion in the primary stage of a nuclear weapon.

2. **pyrophoric**
a. having a phobia of spontaneously catching on fire
b. an obscure eighteenth century term that referred to pirates who had successfully found treasure. It eventually was used by royalty to express a feeling of euphoria (as in "totally pyrophoric, Duke")
c. the ability to ignite spontaneously in air. Several metals used in the nuclear fuel cycle, such as liquid sodium, plutonium, and uranium, are pyrophoric to varying degrees. The latter two metals have an increasing likelihood to spontaneously ignite with rising temperatures or decreasing particle size. However, they are not pyrophoric at room temperature.

3. **vitrification**
a. an especially cruel form of medieval torture involving the force feeding of vitamin supplements
b. the transformation of a sincere and sweet child into a vitriolic teenager
c. to convert into glass. In the nuclear arena, vitrification refers to the glassification of radioactive waste, mixed waste, or materials such as plutonium.

4. **adsorption**
a. the manner in which humans have long-term memory of television commercials
b. the rate at which various billboard materials succumb to the ravages of birds
c. the sticking of molecules to the surface of a liquid or solid. Adsorption is different from absorption, which involves taking molecules in through pores, or soaking up.

5. **radiolysis**
a. the process by which listening to the radio turns you into a couch potato
b. a special hair treatment for bald people
c. the change in chemical form of a substance caused by the action of radiation.

ANSWERS:1-c, 2-c, 3-c, 4-c, 5-c

"Dear Arjun"

Dear Arjun,

What is HEU and is it used in all reactors?

At Sea in Seattle

Dear At Sea,

Back in the fifteenth century, the Castillian court was cursed with a king who could not talk. So desperate were his courtesans to hear the king speak, that every time he sneezed they would intone "His Eminence Utters!" and throw a party. This got boring. As the king aged, they began to just say "HEU" when he sneezed, and finally, just "aych ee ooo!"

In the nuclear arena, HEU refers to **highly enriched uranium**. Natural uranium contains three isotopes (or forms) of uranium, namely uranium-238, uranium-235 and uranium-234. Of these only uranium-235 is fissile, thereby making it an essential ingredient for creating nuclear chain reactions, necessary for nuclear weapons and capable of generating power. (The only practical substitute for uranium-235 in this role is plutonium-239.)

Summary of Select Uranium Isotopes (Nuclides)

Nuclide	Percent found in nature	Half Life (in years)[3]	Specific Activity
Uranium-238	99.284	4.46 billion	0.34 microcuries/gram
Uranium-235	0.711	704 million	2.2 microcuries/gram
Uranium-234	0.005	245,000	0.0063 curies/gram

HEU refers to uranium that has been enriched to greater than 20 percent uranium-235. Above this level, it can be used to make nuclear weapons. However weapons grade HEU generally contains more than 90 percent uranium-235. HEU is also used in naval reactors because it allows the same mass of fuel to generate a given level of power for a longer period of time. In other words, a smaller mass of fuel is needed to generate the same amount of energy.

Most reactors do not use HEU because it is expensive fuel. Civilian power reactors use **"Low Enriched Uranium"** (LEU), which contains up to about 5 percent uranium-235. Other civilian reactors use natural uranium, which has just over 0.7 percent uranium-235. Besides nuclear weapons, HEU is most commonly used in naval reactors and in some research reactors. Research reactors are those used for basic and applied research, as well for training. Research reactors are also used to produce medical isotopes, though there are other ways to produce such isotopes. World-wide, about 200 test and research reactors use HEU as fuel.[1] Of these reactors, about 66 may send their spent nuclear fuel to the US, according to a list supplied to IEER by the DOE.[2] Most research reactors can be converted from HEU to LEU use.

Since HEU can be used to make a nuclear weapon, many countries are concerned about the possible diversion of HEU from research reactors to weapons use. In 1978 the U.S., which has been the largest supplier of HEU to the world,

See "Dear Arjun"—p. 14

[1] Albright, D., Berkhout, F., and Walker, W. 1993. *World Inventory of Plutonium and Highly Enriched Uranium 1992*, p. 144. (See book review.)

[2] Charles Head, Office of Spent Fuel Management, Department of Energy, letter to Lois Chalmers, IEER, May 17, 1994, with enclosure.

[3] The "half-life" of a nuclide refers to the period of time it takes for the nuclide to lose half of its radioactivity. Note that uranium-238, which is less radioactive than uranium-235, has a longer half-life.

SHHH...

CLASSIFIED

IEER is secretly developing a new column on environmental policy for our next issue, upon the advice of [redacted]. We are looking over the literature to select [redacted] material for our readers. Here are some thoughts on the subject of openness and [redacted]

From Glenn Seaborg:

One conclusion I have reached is that the security classification of information became in the 1980s an arbitrary, capricious, and frivolous process, almost devoid of objective criteria.... Furthermore, some of the individual classification actions seem utterly ludicrous. These include my description of one of the occassions when I accompanied my children on a "trick or treat" outing on a Halloween evening....

Glenn T. Seaborg first isolated plutonium in 1941 and is now at the Lawrence Berkeley Laboratory. The above quotation relates to the classification of personal diaries kept during his tenure as chairman of the Atomic Energy Commission (1961 to 1971). This excerpt is from an article in the June 3, 1994 issue of Science.

From Secretary of Energy Hazel O'Leary:

[During the Cold War], we were shrouded and clouded in an atmosphere of secrecy. I would even take it one step further. I would call it repression.

[Now] we are declassifying the largest amount of information in the history of the Department of Energy.... There are some 32 million pages of information documents being archived in the Department of Energy or at the National Archives or at other sites which are now subject to...review as we move through declassifications. To put that in some perspective, it is 32 Washington Monuments and it is three miles worth of data.

From the "Openness" press conference, December 7, 1993.

From IEER:

Secretary O'Leary, will you please help out Dr. Seaborg?

Credits for this Issue

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

ANSWERS TO THE LAST CHALLENGE

Last issue's Science Challenge introduced readers to radiation clean-up standards for soil, water, and surfaces. The answers were as follows: a) lake water exceeds MCL by 5 picocuries per liter, and b) lake water is less than the MCL by 10 picocuries per liter.

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

Ask Arjun

continued from p. 13

initiated the Reduced Enrichment for Research and Test Reactors (RERTR) program. Under this program, the U.S. is converting most of its own research reactors to LEU use and has stopped exporting HEU for research reactors abroad. The program also encouraged foreign countries to use low-enriched uranium (LEU) instead. The U.S. has proposed accepting foreign spent research reactor fuel. The DOE is preparing a programmatic environmental impact statement on spent fuel management, and one on foreign research reactor spent fuel, as well.

SCIENCE CHALLENGE

CASH CONTEST

Think up a new name for "Science Challenge," and you may **win $25.00!**

We want a new name for "Science Challenge," our regular math and science contest. Send us a letter with your name, address, and as many entries as you want by August 15, 1994. If we select a name you sent us, we will send you $25.00.

These problems illustrate some important aspects of plutonium isotopes and plutonium metal pits (the core of a nuclear weapon).

1) It takes 5 kilograms of plutonium-239 to make a nuclear weapon. What is the volume (or the size) of the plutonium? Express your answer in cubic centimeters. [As you can see in the Centerfold on pages 8–9, the density of plutonium is 16 to 20 grams per cubic centimeter. For this problem, assume a density of 16 grams/cubic centimeter].

2) How many curies are there in 5 kilograms of plutonium-239 [see the Centerfold for specific activity. Remember that curies are a unit of radioactivity].

3) Based on the half-life given for plutonium isotopes in the Centerfold, how much of the initial 5 kilograms of plutonium-239 is left after 24,110 years? [Note the half-life is the time in which half the atoms of a radioactive substance will have decayed and formed atoms of a new element. Half of the original radioactive substance will decay after another half-life. Thus one-fourth the original amount is left after two half-lives, one-eighth is left after three half-lives, and so on. For instance, plutonium-239 decays into uranium-235. See diagram below.]

The Half-life of Plutonium-239

The amount of Plutonium-239 (Pu-239) is represented by the grey shading.
The amount of Uranium-235 (U-235) is represented by the black shading.

The **Science Challenge** 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 **September 15, 1994**. People with science, math, or engineering degrees are not eligible.

The Institute for Energy and Environmental Research (IEER) provides the public and policy-makers with thoughtful, clear, and sound scientific and technical studies on a wide range of issues. IEER's aim is to bring scientific excellence to public policy issues to promote the democratization of science and a healthier environment.

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Address correction requested.

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