SCIENCE FOR DEMOCRATIC ACTION

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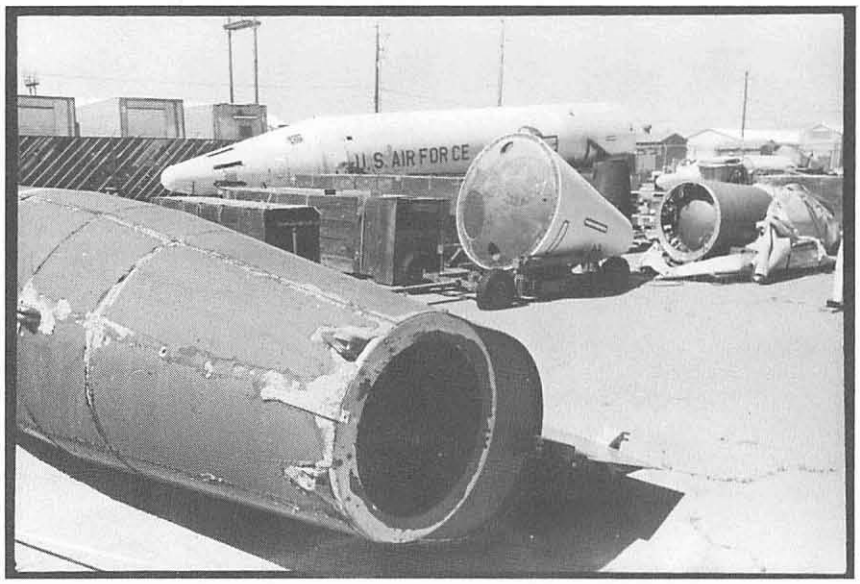

PHOTOGRAPH BY ROBERT DEL TREDICI

Obsolescent dismantled nuclear forces in the backyard of the National Atomic Museum in Albuquerque, NM (1986)

Biological Damage from Plutonium

Howard Hu*

Plutonium is among the most dangerous of substances. Plutonium-239, the isotope of plutonium used in nuclear weapons, decays to uranium-235 by emitting an alpha particle, which consists of 2 protons and 2 neutrons. Besides emitting an alpha particle during its decay, the plutonium isotope also releases some gamma radiation. It takes about 24,000 years for half of a given amount of plutonium-239 to decay to uranium-235. Plutonium-239 is difficult to detect since its gamma radiation is weak and alpha radiation is hard to detect due to its short range.

When in contact with living tissue at high enough levels of exposure, plutonium causes direct tissue death. Animals experimentally exposed to high concentrations of plutonium by inhalation or injection incur acute damage to the lungs, liver and the hematopoietic (blood-forming) system and show other

See "Biological Damage"– p. 2

* Howard Hu, M.D., is an Assistant Professor of Medicine at Harvard Medical School. This article is based on the IPPNW–IEER book *Plutonium: Deadly Gold of the Nuclear Age*, of which Dr. Hu is a co-author.

Editorial

Plutonium— Deadly Waste of the Nuclear Age

In the U.S., plutonium has been regarded by its proponents with the same reverent awe that Columbus regarded gold. It would provide military security and be an endless source of cheap energy. Yet, today, "civilian" plutonium is an expensive burden, far more costly than uranium. Civilian plutonium also poses threats of nuclear weapons proliferation. Moreover, it can be used to make radiological terror weapons, which would disperse it into the environment. Even plutonium in nuclear weapons has become a security headache, since most weapons are already slated for dismantlement.

Plutonium is an especially pressing security threat in Russia—30 tons of it sit in Chelyabinsk alone, a ready temptation for sales for hard currency. And

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NEW IN THIS ISSUE:

THE IEER CENTERFOLD FOR TECHNO-WEENIES

It Pays to Increase Your Jargon Power

by Dr. Egghead

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manifestations of acute tissue injury. Surviving animals are scarred and develop a number of chronic conditions. Such high-level exposure, however, is unlikely to occur to the general public. Of greatest concern are the radiobiological effects of plutonium, including its ability to cause cancer at low levels of internal body burden.

Carcinogenic Mechanisms

As a carcinogen, plutonium is dangerous principally because of its alpha (rather than gamma) radiation, and primarily when it is inside the body rather than when outside. When plutonium is in the body, even in small quantities, its alpha radiation causes biological damage.

Alpha particles, being heavy, ionize atoms more effectively than electrons and therefore lose their energy and are stopped in a much shorter distance. Because of the relatively many ionizations per unit distance (and per unit of energy lost), alpha radiation is called "high linear energy transfer" radiation ("high LET radiation"), as distinct from the relatively low energy transfer per unit length of photons and electrons ("low LET radiation"). The range of alpha radiation in soft tissue is about 50 micrometers (about two-thousandths of an inch). When plutonium is deposited inside the body, the short range of alpha particles results in far more biological damage than gamma or beta radiation for the same amount of energy deposited in living tissue. For the same reason, plutonium outside the body, on or near the skin deposits essentially all of its energy in the outer, non-living layer of the skin, where it does not cause biological damage.

Recent research suggests that the true damage caused by alpha radiation, as emitted by plutonium, may be even higher than previously estimated.

Recent research suggests that the true damage caused by alpha radiation, as emitted by plutonium, may even be higher. Findings in two recent studies indicate that even at very low levels of exposure genetic damage occurs.[1,2] One study found that alpha radiation could produce a type of genetic instability that makes people more prone to the development of early cancers. If confirmed, these studies have implications for both the setting of standards for allowable exposure to plutonium as well as the design and interpretation of epidemiological studies of populations exposed to plutonium.

Routes of Exposure

In addition to level of dose, the toxicity of plutonium depends

See "Biological Damage"– p. 3

[1] Kadhim, M.A., et. al 1992. Transmission of chromosomal instability after plutonium [alpha]-particle irradiation. *Nature*, vol. 355, no 6362, pp. 738-740.

[2] Nagasawa, J. and Little, J.B. 1992. Induction of sister chromatid exchanges by extremely low doses of alpha particles. *Cancer Research*, vol. 52 pp. 6394-6396.

SCIENCE FOR DEMOCRATIC ACTION

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PHOTOGRAPH BY ROBERT DEL TREDICI

On May 19, designated "radiation day," school children in Chelyabinsk, Russia, practice protection against accidental releases from the nearby Chelyabinsk-65 nuclear weapons complex.

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on route of exposure, particle size, chemical form and isotope. The route of exposure of greatest concern is inhalation. Once inhaled, plutonium can become lodged in the sensitive tissues of the lung. Studies in humans and beagle dogs have indicated that such deposits of plutonium remain for years, with gradual absorption into the circulation.

Wounds render skin more vulnerable. Studies of beagles indicate that a significant amount of plutonium can be absorbed from a skin wound and enter the general circulatory system.

Ingestion of plutonium is a possible route of exposure, through hand-to-mouth transfer of plutonium-contaminated soil or the consumption of contaminated food or water. However, the gastrointestinal absorption of plutonium oxide is less than 0.1 percent of that ingested, and the great majority of ingested plutonium is rapidly excreted.

Given the same total amount, plutonium is more dangerous in the form of fine particles than in large ones. When large particles (greater than 5-10 microns) are inhaled, they tend to be trapped in nasal hair or deposited on the surfaces of the bronchial airways, where they can be disposed of by normal respiratory clearance mechanisms such as coughing or spitting. These particles are then either ingested, which leads to little, if any, absorption. Smaller particles (less than 1 micron), however, gain entry into alveoli (the small terminal air sacs of the lung), where they can become lodged, irradiating the surrounding tissue.

Biokinetics

Retained plutonium is gradually absorbed, distributed throughout the body, and excreted via urine. Beagle studies have demonstrated that most plutonium retained in the lung is transferred to pulmonary lymph nodes within months to years. Plutonium is

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also distributed to hepatic and splenic lymph nodes, ovaries, testes, kidney, other soft tissues, bone, and teeth.

Much of plutonium biokinetics (that is, rates of absorption and excretion, proportion of tissue distribution, etc.) depends on the chemical form of plutonium. Soluble forms of plutonium—for example, plutonium nitrate—are absorbed from the lungs relatively rapidly and are deposited heavily in bone and liver, whereas most of the relatively insoluble plutonium oxide is retained in the lung for years, with gradual internal translocation to pulmonary lymph nodes. Half of deposited plutonium oxide is distributed out of the lung within 4 years, with 75 percent of extrapulmonary deposits found in the liver and 21 percent in bone.

Unlike radium, another bone-seeking element, which tends to be incorporated exclusively into the calcified mineral matrix of bone, plutonium has an affinity for the non-calcified, non-cartilaginous areas of bone including the epiphyseum (bone growth plate), the periosteum (outer bone skin), and the endosteum (inner bone in contact with marrow). Deposition is predominately in trabecular bone (spongy bones in vertebrae and at ends of long bones) rather than in cortical bone.

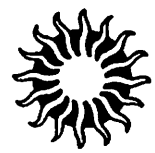
Species and age are additional factors determining the biological effects of plutonium. For example, in younger animals a proportionately larger amount of absorbed plutonium is deposited in bone. Studies of monkeys have demonstrated that plutonium deposits in bone concentrate on the endosteal surface (the surface of the bone in contact with marrow).

Some data are available on the biokinetics of plutonium in humans. In workers who accidentally inhaled plutonium-238 oxide in an insoluble matrix, plutonium was observed to appear in urine withins six weeks of exposure and then remain measurable in urine for years. Whole body counting cannot be used to estimate small body burdens accurately because internal alpha radiation does not penetrate far enough to be detected. Attempts have been made to estimate total plutonium body burden from urinary concentrations and in-vivo chest counts of plutonium's weak 17 kV x-rays or gamma rays; great variability seems to exist in the relatively sparse data, however, making accurate extrapolation difficult.

Few published studies exist from which one can directly estimate the carcinogenic risk of plutonium in humans. Most relevant published studies have been on cohorts of workers involved in nuclear weapons production who were exposed to multiple sources of radiation in addition to plutonium. Studies on beagle dogs indicate that a lung burden of 27 micrograms (about one millionth of an ounce) would ***produce cancer in humans with near 100 percent probability.***

The paucity of available data on the effects of human exposure to plutonium is both unfortunate and inexcusable. It is unfortunate because it forces plutonium risk estimates to rely on animal studies, which means that the sensitivity of the study is low and the uncertainty of the results large. And it is inexcusable given the large number of plutonium workers employed over the past five decades in the U.S. alone, on whom exposure data in fact exist.

The paucity of available data on the effects of human exposure is unfortunate because it forces risk estimates to rely on animal studies. It is also inexcusable, given the large number of plutonium workers on whom exposure data in fact exist.



Deadly Gold

continued from p. 1

Russia is still extracting ("reprocessing") two-and-a-half tons of it each year from irradiated nuclear fuel. There have already been many arrests in Germany of smugglers attempting to sell radioactive materials from the former Soviet Union. There are indications of involvement of organized crime as well.

All further plutonium reprocessing, civilian and or military, should be stopped. Since the United States has essentially halted military plutonium production and has no active program to use plutonium in civilian reactors, it could easily take the initiative towards an international agreement for a total ban on plutonium production.

Plutonium from nuclear weapons slated to be dismantled also poses security and environmental risks. Yet, neither the U.S. nor Russia has squarely confronted verification issues or decided what they will do with the plutonium from dismantled weapons. That is because the nuclear establishment still seeks to hang on to it, viewing it as a precious resource. The underlying premise of U.S. policy appears to be to store much or most of the plutonium from dismantled weapons for a long period for possible use again in weapons or to give a boost to the moribund program to use it as a fuel for civilian electricity production. It is time to cut our losses and see both

See "Deadly Gold"– p. 6

LETTERS

I enjoy your publication very much and only wish our high school students could read and become more exposed to some of your thinking.

James P. Marquart
Shepardsville, KY

If you will send us the name of the school, we'd be happy to send a copy of each issue to the library and to all interested teachers and students.

Arjun Makhijani

✉ ✉ ✉

I was recently introduced to your organization by a member of my staff, who passed me a copy of *Science for Democratic Action.* I applaud your effort to improve the practical knowledge and skills of non-technical citizens in the area of nuclear technology; this is also an objective of the American Nuclear Society. I also found the light and humorous tone of the newsletter refreshing.

You are obviously critical of the DOE "establishment" and its policies, and point out some problems that certainly deserve some criticism. Perhaps some of your frustration about our current state of affairs stems from the growth, institutionalization, and bureaucratization of activities that were once driven, guided, and executed by the principles of scientific inquiry . . .

James G. Toscas
Executive Director,
American Nuclear Society

Thank you for your kind note. The problem that IEER has found is that the work of the nuclear establishment (both governmental and private) on health and environmental issues *has never been consistently guided by principles of sound science. Rather, public relations and an underlying agenda to push nuclear power and nuclear weapons production have dominated and often overwhelmed science.*

Arjun Makhijani

✉ ✉ ✉

I have just read Volume #3 of *Science for Democratic Action.* I compliment and cheer you for your caring and passion and understanding and effort to educate. I love your statement 'it is part of hoary mythology that passion does not have a role in science.' I'm not sure how the current issue came into my mail box but I certainly wish to continue my subscription and enclose a check. Thank you and all of your staff.

Eleanor Faithorn
Annapolis, MD

Deadly Gold
continued from p. 5

civilian and military plutonium for what it is—a deadly waste.

Treating plutonium as a waste necessarily means mixing it with other materials and putting it into a form that would make it very expensive and difficult to re-extract the plutonium for any use. A technology to do that is already available in the U.S., Russia, Britain, France and other countries: vitrification. In this process, radioactive materials, such as plutonium and/or fission products, are mixed with molten glass and solidified into large blocks.

Like all other options for dealing with plutonium, vitrification will increase the waste disposal problem. There simply is no "good" way to deal with plutonium, a deadly material with a half-life of about 24,000 years. There are almost 400 tons of separated plutonium in the world today, including that in all nuclear weapons. This is far smaller than the unseparated plutonium that would accumulate in spent fuel from existing civilian reactors worldwide by the time they are retired (which is projected to amount to roughly 2,000 tons). Since vitrification can, in principle, be implemented far more quickly than other options, it appears to be a way to minimize the security and environmental hazards of dismantling large numbers of nuclear weapons.

The environmental impacts of the dismantlement of nuclear weapons and of plutonium vitrification should be evaluated urgently, but also carefully. Heretofore, in matters that have affected nuclear weapons, the federal government has ridden roughshod over the concerns of the local residents and workers who have had to bear the health and environmental costs. Indeed, the nuclear weapons complex has been a web of deceit and lawbreaking, the extent of which has become apparent only over the last few years.

With the end of the Cold War, most people want nuclear weapons to be dismantled. But this time, the needs of this country and the world must be carried out with the fully informed, democratic participation and consent of people living in the areas affected by vitrification and dismantlement. And implementation must be done in conformity with all laws and regulations that would apply to a comparable civilian industry. People all over the country must work to see that local residents have the power to enforce these elementary norms of decency and democracy on the nuclear establishment. As Beverly Gattis of Serious Texans Against Nuclear Dumping (Amarillo) has put it:

> If there is a moral obligation that a site undertake work that will benefit others, then there is a reciprocal obligation on the part of the rest of the country to commit to such a site the legal, regulatory, and technical investment necessary for it to protect itself.

Arjun Makhijani

SELECTED IEER WORK

- Project to support grassroots groups working on nuclear weapons production, testing and clean-up issues.
- Portsmouth Residents lawsuit, for neighbors of this DOE uranium enrichment facility.
- Outreach on protection of the ozone layer.
- Rongelap Rehabilitation Project to assess the habitability of Rongelap Atoll.
- Mound lawsuit for neighbors of the DOE's Mound Plant, near Dayton, Ohio.
- Production of *The Nuclear Power Deception: Military and Civilian Nuclear Mythology from Electricity "Too Cheap to Meter" to "Inherently Safe" Reactors.*
- 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 PIN-UP FOR TECHNO-WEENIES

Table of Radioactive Materials

The 2-page table that follows contains a list of many of the radioactive materials (called "radionuclides") found in nuclear weapons, nuclear power plants, and/or radioactive waste. Beside the radionuclides are listed some of the properties of interest to persons concerned about their health and environmental effects. To conserve space, we have omitted very short-lived radionuclides (half-lives of several hours or less), although some of these may be relatively important in short-term doses, for instance from nuclear power plant accidents (as was the case with Three Mile Island).

The half-lives shown in this table are from the 1988 edition of the *CRC Handbook of Chemistry and Physics*. Different sources often give somewhat different values for half-lives. The *CRC Handbook* contains a comprehensive list of radionuclides; it can be found in most college or university libraries and many public libraries. Half-lives are important because they indicate how fast the radioactivity in the element dissipates. Specific activities in this table are calculated from the following expression:

Specific activity = (361,600)/(half-life in years*atomic weight)

(See *Science for Democratic Action*, volume 1, number 2 for an explanation.)

Specific activity measures the amount of radioactivity per unit weight. It is a very handy number to have. Often discharges of radioactive materials are given in terms of weight—so many pounds of uranium, or so many grams of tritium, but standards and guidelines for contamination of air, water and soil are usually expressed in terms of radioactivity—so many curies per liter or gram. The values for specific activity in this table allow you to convert weight figures into amounts of radioactivity. Conversely, you can get a feel for the quantities of materials involved if you know the amount of radioactive contamination, and want to calculate the weight. See the **Arithmetic for Activists** column in this issue for further explanation.

The energy of the radiation emitted is shown in kilo-electron-volts (keV), also from the *CRC Handbook*. This figure is the average amount of energy released per radioactive decay, averaged over all the different decay modes of the element. The main carriers of the energy are shown in parentheses. An electron volt is the amount of energy gained by an electron accelerated through a voltage drop of one volt. (Common batteries are a few volts.) The amount of energy per decay is important to the bioloigcal effect of the material: the greater the energy per decay, the greater the damage it can do *per radioactive disintegration.*

Finally, note that some radioactive elements decay into other radioactive elements. The full decay chains are not shown in this table. Information is only for the specific radionuclide listed. In assessing the effects of radionuclides, it is important to consider the effects of all radionuclides in their decay chains that are present.

IEER TECHNO-WEENIE CENTERFOLD

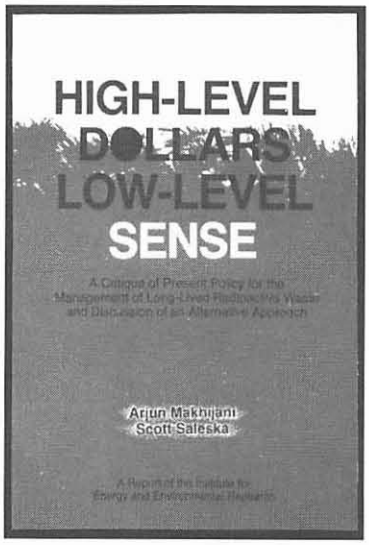
Abbreviations: a = alpha radiation; b = beta radiation; g = gamma radiation, mil = million; bil = billion, Ci = curies; chemical names shown in parentheses

radionuclide	half-life	specific activity curies/gram	decay energy keV	comments
hydrogen-3 (H-3) (tritium)	12.26 yrs	9,800	18.61 (b)	combines with oxygen to form water
carbon-14 (C-14)	5,730 yrs	4.5	156.48 (b)	present in air as carbon dioxide
sodium-24 (Na-24)	14.97 hrs	8.8 mil	5,514 (b, g)	created by neutron activation of sodium-23
phosphorous-32 (P-32)	14.28 days	290,000	1,710 (b)	used in medicine
potassium-40 (K-40)	1.25 bil yrs	7.2 microCi/gm	1,320 (b, g)	occurs in nature; present in human body
cobalt-60 (Co-60)	5.272 yrs	1,143	2,824 (b, g)	gamma source in medicine
nickel-59 (Ni-59)	76,000 yrs	0.081	see note	decays by electron capture; activation product
nickel-63 (Ni-63)	100 yrs	57.4	65 (b)	activation product
krypton-85 (Kr-85)	10.72 yrs	397	687 (b, g)	a main gaseous gamma emitter fission product
strontium-90 (Sr-90)	29 yrs	139	546 (b)	
zirconium-95 (Zr-95)	64.03 days	21,700	1,124 (b, g)	
niobium-94 (Nb-94)	24,000 yrs	0.16	2,040 (b, g)	
technetium-99 (Tc-99)	213,000 yrs	0.017	293 (b)	fission product
ruthenium-106 (Ru-106)	372.6 days	3,342	39.4 (b)	fission product
iodine-129 (I-129)	16 mil yrs	175 microCi/gm	193 (b, g)	fission product
iodine-131 (I-131)	8.04 days	125,000	971 (b, g)	fission product; thyroid disorders
xenon-133 (Xe-133)	5.25 days	189,000	427 (b, g)	fission product

IEER TECHNO-WEENIE CENTERFOLD

radionuclide	half-life	specific activity curies/gram	decay energy keV	comments
cesium-135 (Cs-135)	3 mil yrs	893 microCi/gm	205 (b)	fission product
cesium-137 (Cs-137)	30.17 yrs	87.5	1,170 (b, g)	fission product
cerium-144 (Ce-144)	284.4 days	3,200	318 (b, g)	fission product
samarium-151 (Sm-151)	90 yrs	26.6	76 (b)	
lead-210 (Pb-210)	22.3 yrs	77.2	63 (b, g)	U-238 decay chain
bismuth-210 (Bi-210)	5.01 days	125,000	1,160 (b)	U-238 decay chain
polonium-210 (Po-210)	138.4 days	4,540	5,407 (a, g)	U-238 decay chain
radon-222 (Rn-222)	3.82 days	156,000	5,590 (a, g)	U-238 decay chain
radium-226 (Ra-226)	1,600 yrs	1.0	4,870 (a, g)	U-238 decay chain
radium-228 (Ra-228)	5.75 yrs	276	45 (b, g)	Th-232 decay chain
thorium-230 (Th-230)	75,400 yrs	0.021	4,771 (a, g)	U-238 decay chain
thorium-232 (Th-232)	14 bil yrs	0.11 microCi/gm	4,081 (a, g)	
uranium-234 (U-234)	245,000 yrs	0.0063	4,856 (a, g)	U-238 decay chain
uranium-235 (U-235)	704 mil yrs	2.2 microCi/gm	4,679 (a, g)	
uranium-238 (U-238)	4.46 bil yrs	0.34 microCi/gm	4,180 (a)	weak gamma also
neptunium-237 (Np-237)	2.14 mil yrs	713 microCi/gm	4,957 (a, g)	
plutonium-238 (Pu-238)	87.74 yrs	17.3	5,593 (a, g)	transuranic element
plutonium-239 (Pu-239)	24,110 yrs	0.063	5,244 (a, g)	transuranic element
plutonium-240 (Pu-240)	6,537 yrs	0.23	5,255 (a, g)	transuranic element
plutonium-241 (Pu-241)	14.4 yrs	104	21 (b)	transuranic element
americium-241 (Am-241)	432.2 yrs	3.47	5,637 (a, g)	decay product of Pu-241; transuranic
americium-243 (Am-243)	7,370 yrs	0.202	5,438 (a, g)	transuranic element

RECENT PUBLICATIONS



High-Level Dollars, Low-Level Sense

A Critique of Present Policy for the Management of Long-Lived Radioactive Waste and Discussion of an Alternative Approach

by Arjun Makhijani and Scott Saleska

Radioactive wastes contain materials that remain hazardous for up to millions of years. The authors explain inconsistencies in the waste regulations, expose the industry's tactics, and propose an alternate unified approach to the problem.

High Level Dollars, Low-Level Sense *is a devastating analysis of the attempt to manage radioactive wastes generated by the production of nuclear power and nuclear weapons . . . . Makhijani and Saleska have written what might well stand as the epitaph of nuclear technology.*

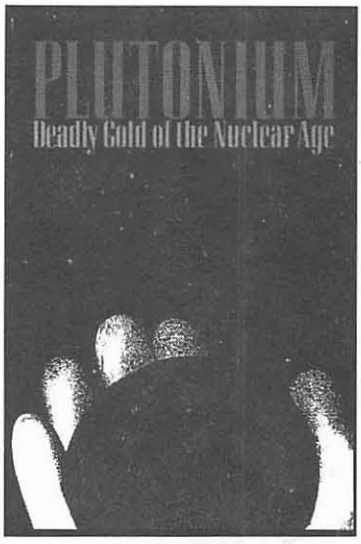
—Barry Commoner, Center for Biology of Natural Systems, Queens College

PRICE: $15.00 including postage and handling

Plutonium

Deadly Gold of the Nuclear Age

by International Physicians for the Prevention of Nuclear War and IEER

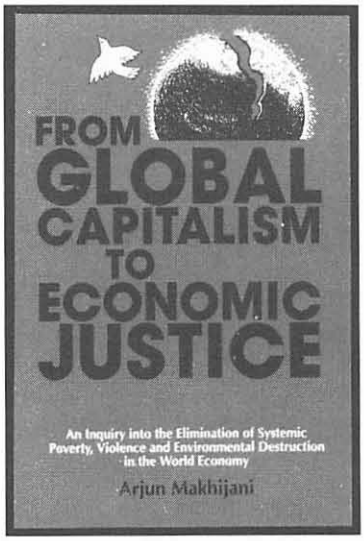


The Cold War is over, yet production of plutonium continues in many countries, including Russia. While much of it is allegedly for nuclear power, all plutonium can be used for nuclear weapons. This book examines the huge security, health and environmental risks posed by plutonium globally and spells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

—Daniel Ellsberg

PRICE: $17 including postage and handling



From Global Capitalism to Economic Justice

An Inquiry into the Elimination of Systemic Poverty, Violence and Environmental Destruction in the World Economy

by Arjun Makhijani

In capitalism, not only workers and communities everywhere, but also the well-off pay a heavy price. Everyone is dispossessed by militarized borders and global environmental destruction. This book presents a vision that unites local and private initiative with distributive justice.

This is a book of hope—that working people everywhere, by joining hands at the grassroots, can yet achieve real economic democracy. Everyone committed to building a more just and sustainable future should read this book—and then act on its message.

—Anthony Mazzocchi, Assistant to the President and former Secretary-Treasurer, Chemical and Atomic Workers International Union

PRICE: $ 17.00 including postage and handling

Arithmetic for Activists #4

Fifteen people sent in replies to the *Science Challenge* in the last issue, up from 10 for the previous challenge. There were six correct answers. Congratulations! We drew lots for the $25 prize from among the correct answers, and the winner is Robin Caiola, of 20/20 Vision of Washington, D.C. All other respondents will get a $10 prize.

The number of prizes offered (20) was greater than the number of replies received. Don't let these surplus prizes go unclaimed. If you are one of the first 25 to responed to this issue's challenge, you're guaranteed a $10 prize. You get a prize just for trying to answer all the parts, even if your answer is incorrect.

Solution to the Problem in *SDA* volume 1 number 3

Last issue's Science Challenge was as follows:

Here is a diagram of a contaminated parking lot. Assume that each sector has a uniform gamma radiation rate. Not knowing the lot is contaminated, you have spent a total of 2 hours in sector 1; 3 hours in sector 2; 2 hours in sector 3; and 1 hour in sector 4. Please refer to the "Arithmetic for Activists" column and the table of units for useful information.

SECTOR 1 20 millirem per hour	**SECTOR 2** 50 millirem per hour
SECTOR 3 15 millirem per hour	**SECTOR 4** 3 millirem per hour

1. Calculate the total dose you received in millirems.

2. Find out the average (or mean) dose rate per hour which *you experienced* over the time you spent in the parking lot.

3. Express your answers to questions 1 and 2 in sieverts.

4. Assuming that each sector of the parking lot has an equal area, find the average (or mean) radiation rate in millirems in the whole lot.

Answer: 1. The total dose to the person is the sum of the doses received in the four sectors and therefore equals

20*2 + 50*3 + 15*2 + 3*1 = 223 millirem

2. The mean dose rate that you experienced is the total dose divided by the total number of hours you spent in the parking lot. This equals 223/8 = 27.9 millirem per hour, approximately.

3. Since 1 sievert = 100 rem, 1 millisievert = 100 millirem. So 223 millirem = 2.23 millisieverts and 27.9 millirem = 0.279 millisieverts.

4. The average dose rate in the parking lot is (20 + 50 + 15 + 3)/4 = 88/4 = 22 millirem per hour.

From Weight to Radioactivity

Measurements of radioactive materials in the environment are sometimes given in units of weight of the material per unit volume of water or air, or as weight of the material per unit weight of soil. For instance, the uranium-238 content of soil may be given as **x** milligrams (or micrograms) of uranium-238 per gram of soil (written as **x** mg/gm or µgm/gm). Standards for uranium and other radioactive materials are generally set in terms of radioactivity content per unit

See "Arithmetic"– p. 12

Arithmetic
continued from p. 11

volume or weight. It is therefore necessary to convert the limits from the weight of the radioactive material to the amount of radioactivity.

To do this, it is necessary to know the specific activity of the material—that is the number of radioactive disintegrations that the particular isotope of the element undergoes in a unit time. If the material is a mixture of isotopes of an element, then it is necessary to know the proportion in which the various isotopes are present, because equal weights of different isotopes contribute different amounts to the radioactivity.

You can look up specific activities of many radionuclides in the table published in this issue, and larger lists are found in many standard reference books. Let us do an example with uranium in soil.

Consider a soil sample of one thousand grams containing 10 grams of uranium-238, 0.07 grams of uranium-235, and 0.0005 grams of uranium-234. We know from the isotopic composition of natural uranium that these measurements are approximately the proportions of uranium isotopes found in natural uranium.

The specific activities of the three uranium isotopes are approximately:

uranium-238:
0.34 microcuries per gram

uranium-235:
2.2 microcuries per gram

uranium-234:
6,300 microcuries per gram

Thus:

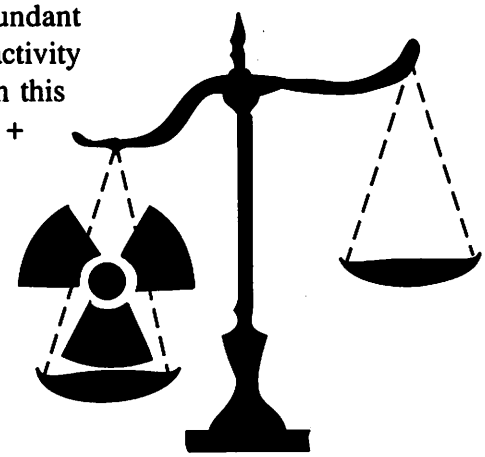
10 grams of uranium-238 has a radioactivity = 10*.34 = 3.4 microcuries

.07 grams of uranium-235 has a radioactivity = 0.07*2.2 = 0.154 microcuries

.0005 grams of uranium-234 has a radioactivity = 0.0005*6,300 = 3.15 microcuries

The isotope of interest in producing nuclear weapons and power, uranium-235, contributes very little to the overall radioactivity, but uranium-234, which is present in trace quantities, contributes about as much as uranium-238, the most abundant isotope. The total radioactivity of all uranium isotopes in this soil sample is 3.4 +0.154 + 3.15 = 6.7 microcuries in the 1,000 gram sample, which is 0.0067 microcuries per gram (written as 0.0067 μCi/gm).

It turns out that uranium-235 does not contribute much to the radioactivty of uranium mixtures at any level of enrichment. In enriched uranium, the uranium-235 content is increased, but the proportion of uranium-234 goes up faster since the lighter the isotope, the more of it goes along in the enriched stream. Since uranium-234 is far more radioactive than uranium-235, it contributes most of the radioactivity even in highly enriched uranium (more than 90 percent uranium-235), even though it is less than one percent of the total weight. Depleted uranium contains almost no uranium-234, and therefore uranium-238 dominates its radioactivity. Here, also, uranium-235 makes only a small contribution to the total radioactivity.



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It Pays To Increase Your Jargon Power

by Dr. Egghead

Dear Arjun,

I'm sick of technical terms and jargon. Do something.

Sick in Secaucus.

Dear Sick,

I have consulted with Dr. Egghead, who is IEER's leading authority on jargon. He offered to write a new column, *It Pays to Increase Your Jargon Power*, as the cure for your ills. I am giving over this space to Dr. Egghead's new column in this issue. If you study these columns diligently, they will not only get rid of your sickness, but produce a positive exhilaration.

* * *

Choose the correct definition. Answers are given below.

1. **Hex**

a. a witch's spell

b. a new six-sided building the Pentagon wants to build

c. a department store chain

d. a colloquial expression referring to uranium hexafluoride (chemical formula, UF_6), a form used in uranium enrichment plants

2. **green salt**

a. organically produced table salt

b. sea salt mixed with kelp, highly recommended for use in California hot tubs

c. a kind of currency in the days when salt and spices were used as money

d. a colloquial term for uranium tetrafluoride (chemical formula UF_4), deriving from its appearance, used as a raw material to make either uranium metal or uranium hexafluoride

3. **MTHM**

a. a medieval acronym for "meet him," used for arranging trysts, as in MTHM at 6 o' clock

b. "Medieval Torture and Hanging Machine"

c. a polite way of referring to eMpTy-headed royalty

d. "Metric Tons of Heavy Metal"—the uranium content of fresh nuclear fuel rods; in irradiated fuel, the content of uranium still left, and newly created plutonium and other radioactive heavy metals

4. **MWd burnup**

a. a measure in months, weeks or days of how long a jealous fit lasts

b. a physician's estimate of how many antacid pills to prescribe

c. a space-flight term for how much rocket fuel is left to reach the moon

d. "megawatt days burnup"—referring to the thermal energy that has been generated (average megawatts of thermal power generated multiplied by the number of days) from a specifed quantity of nuclear fuel, usually a metric ton, in which case it is measured in MWd/MTHM. Also written as MWthd/MTHM, to indicate that thermal (as distinct from electrical) nuclear energy is being measured. This measure provides an indication of the fission product content of irradiated (or spent) nuclear fuel.

See "Egghead"– p. 14

Egghead
continued from p. 13

5. **MOx**

a. the Los Alamos National Laboratory baseball team

b. courage or guts

c. imitates and jeers

d. an acronym for "mixed oxide," a mixture of plutonium oxide and uranium oxide that can be used as a fuel in some nuclear power plants

6. **Isotope**

a. a polite way of saying "I told you so, you dope"

b. lines that indicate the contours of baldness and the size of the toupee

c. boring night on bald mountain

d. a variant of an element, distinguished from other isotopes of the same element by the number of neutrons in its nucleus. All isotopes of the same element have the same number of protons in their nuclei and the same chemical properties. The nuclei of one or more isotopes of an element may be stable (non-radioactive), while others may be radioactive.

Answers: 1 d; 2 d; 3 d; 4 d; 5 d; 6 d.

Some Facts about Spent Fuel from Nuclear Power Plants*

There are 109 operating nuclear power reactors in the U.S. About 24,000 tons of irradiated or spent fuel have accumulated as a result of their operation. There are two types of reactors in operation in the U.S.—pressurized water reactors (PWRs) and boiling water reactors (BWRs).

The fuel in nuclear reactors consists of uranium dioxide (UO_2) in the form of pellets, which are thin, long tubes of zircalloy, called fuel pins. These pins are bundled together in a fuel assembly. BWR fuel assemblies are about 5.5 inches square, 14 feet, 8 inches long and 606 pounds. The corresponding figures for a PWR are 8.4 inches square, 13 feet, 4 inches long and 1,450 pounds. About 70 percent of the weight of the fuel bundles is uranium (the initial charge of heavy metal).

Uranium is enriched to about 3 percent uranium-235 (the rest being almost all uranium-238) upon loading. When most uranium-235 has been fissioned and converted to fission products, the fuel is discharged. The burn-up of the fuel upon discharge is typically about 30,000 megawatt-days thermal per metric ton of heavy metal. (See Dr. Egghead's column in this issue for an explanation of the terms.) The total amount of fuel discharged by a typical 1,000 megawatt (electrical) reactor is about 48 metric tons per year for a BWR and about 40 metric tons per year for a PWR (about two-thirds is heavy metal).

The spent fuel is highly radioactive. There are nine kilograms (20 pounds) of plutonium per metric ton of initial uranium charged into the reactor. Typically, there are over half-a-million curies per ton of heavy metal ten years after discharge from a PWR, including strontium-90, cesium-137, cesium-135, iodine-129, americium-241 and neptunium-237. The total quantity of radioactivity decreases with time, but the amounts of some radionuclides grow, since they are the decay products of other radionuclides.

* The information on fuel characteristics is based on National Academy of Sciences National Research Council, *A Study of the Isolation System for Geologic Disposal of Radioactive Waste*, Waste Isolation Systems Panel, Washington, D.C., 1983.

SCIENCE CHALLENGE

This problem will give you experience in converting weight measurements into radioactivity. Please refer to the table of radionuclides and the **Arithmetic for Activists** column in the newsletter for useful information in solving it.

1. Suppose a soil sample contains 2 milligrams of uranium-238 per gram of soil. Express this in microcuries per gram of soil. Also find the answer in bequerels per gram of soil. Bequerels (Bq) are another way of measuring radioactivity. One curie = 37 billion bequerels.

2. If the tritium content of water is 4 picograms per liter, how much is it in picocuries per liter? (pico- = one-trillionth)

3. If the plutonium-239 content of a soil sample is 5 nanograms, and the plutonium-240 content is 0.3 nanograms, calculate the total radioactivity of plutonium in the sample. (nano- = one-billionth)

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 Arjun Makhijani, 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 March 15, 1993. People with science, math, or engineering degrees are not eligible.

The Institute for Energy and Environmental Research (IEER) provides citizens 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 safer and healthier environment.

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