SCIENCE FOR DEMOCRATIC ACTION

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Truth and Caring: The DOE's Problems with Environmental Science

Arjun Makhijani

Whether the DOE can do environmental science or not is a two hundred billion dollar question confronting us today. The DOE often fails to pose the right questions, especially those which may have answers inconvenient for programs already decided upon. We may therefore be on a course to spending large sums of money without commensurate results necessary to protect future generations from the deadly radioactive and other wastes and contamination from five decades of nuclear weapons production and testing. The DOE's problems with the environment begin at the level of basic science.

It is a part of hoary mythology that passion does not have a role in science. While a scientist must have a detachment from a particular answer or hypothesis, good science has its foundation in passion. Actually, it needs two kinds of passion.

The first has to do with love and caring about the subject of

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Meeting in Muslyumovo, on the radioactive Techa River.

Chelyabinsk: Report on a Trip to a Russian Nuclear Weapons Site[1]

Scott Saleska

During May 20th-22nd, 1992, an international conference on the "Ecological Consequences of Nuclear Weapons Development in the Southern Urals" was held in Chelyabinsk, Russia, a city near the site of a principal nuclear weapons production facility of the former Soviet Union. For many years, this facility, now known as Chelyabinsk-65, was the principal producer of plutonium for the nuclear weapons of the Soviet Union. Chelyabinsk-65 is in many respects analogous to the Hanford Nuclear Reservation in the United States (which produced plutonium during World War II for the bomb which was dropped on Nagasaki).

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IEER is producing a book jointly with the International Physicians for Prevention of Nuclear War on worldwide plutonium production and the problems arising from it. It will be released in December 1992. This trip was made as part of that project.

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the enquiry. Great physicists care as deeply about physics as great composers about music or great painters about painting. Entomologists love ants and other bugs that give many people the creeps. Like plants in a lovely garden or like a fine painting of them, good science needs a lot of tender, loving care.

The second kind of passion in good science is a passionate commitment to the truth (with a small "t"). This distinguishes zealotry and dogmatism from science. Science begins with a question and with a hypothesis, which is proposed as a tentative answer to the question. The less one knows at the start, the more tentative the hypothesis. Even if the hypothesis appears to be strong at the start, a good scientist is always ready to discard a hypothesis in the face of evidence, or even simply declare "I don't know." (Henri Poincaré, a great mathematician who was a contemporary of Einstein, wrote two wonderful books about discovery in science: a non-mathematical one, entitled *Science and Method*, and another, with mathematical illustrations, entitled *Science and Hypothesis*.)

The DOE's history on environmental questions shows it often cannot get even the minimal facts and analyses right.

For instance, a hundred years ago, it was confidently hypothesized that a medium called ether was essential for the propagation of light. Yet, a careful experiment set up to find it (the Michelson-Morley experiment) showed the contrary: ether, with the postulated properties, did not exist. This rejection of a long-cherished notion was shortly to be one of the founding inspirations of Einstein's theory of relativity and the famous equivalence between energy and mass $E = mc^2$, which led to the nuclear age. ("E" is for energy, "m" is for mass, and "c" is the speed of light. The superscripted "2" means "c" is multiplied to "m" twice.)

Good science needs no inspectors. The passion for truth plays that role. Yet, the DOE's history on environmental questions shows that even with outside prodding, inspections and publicity, it often cannot get even the minimal facts and analyses right.

The environmental results, and the contrasts with weapons production, are plain to see. Let us consider two examples. First, bomb-making. The first nuclear weapon designed at Lawrence Livermore Laboratory turned out to be a dud. The weapons scientists knew that some hypothesis, some assumption, some defect somewhere had produced the still-born bomb. With the passionate commitment that is still evident among the bomb-makers who succeeded them,[1] they set

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[1] Hugh Gusterson, an anthropologist, has described how the rituals of the bomb-designers of Lawrence Livermore Laboratory closely resemble tribal rituals. See his "Rituals of Renewal Among Nuclear Weapons Scientists," Center for International Studies, Massachusetts Institute of Technology, Cambridge, February 16, 1991.

SCIENCE FOR DEMOCRATIC ACTION

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Phone: (301) 270-5500 FAX: (301) 270-3029

President *Arjun Makhijani, Ph. D.*
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Scott Saleska and Stacy Stubbs have moved on to new things, but will remain as consultants to IEER.

EDITORIAL

To Get Clean-up, Stop Weapons Production

It has been many years since we were promised a clean-up of the weapons complex. But even after the Cold War, DOE's heart is still in weapons production and a spanking new weapons complex. Hundreds of millions are still being spent on research on new tritium production. Old projects for plutonium production keep showing up as new projects for "Waste Management."

On the environmental side, the vitrification plant at Savannah River Site, built to glassify dangerous liquid high-level wastes, continues to be seriously mismanaged, and is burdened with huge cost escalations and delays. Poorly conceived plans, such as those to mix huge quantities of radioactive materials in cement, are proceeding at Hanford—the trenches are already being dug, though it is not yet known how the explosive waste will be processed to mix it with cement!

Consideration of the programmatic environmental impacts from new production and from clean-up continue to be fundamentally deficient. Most importantly, DOE shows no fundamental change in the way it deals with suggestions and criticisms which might imply an abandonment of ill-conceived projects.

A good environmental restoration and waste management program appears to be incompatible with nuclear weapons production. We have neither time nor money to waste. To get a clean-up it is necessary to stop all testing, production and design of nuclear weapons and suspend current plans for a new nuclear weapons complex.

It is necessary to investigate why the DOE cannot take the sound scientific suggestions that are often made by non-government institutions and individuals, especially in areas such as waste management where its own track record is appalling. Perhaps DOE's environmental science should be routinely subjected to peer review, in addition to other present scrutiny.

We also need to scrap the current flawed plans for long-term management of high-level and transuranic waste, and put together a new institution whose mission it is to deal with long-term management of these wastes (military and civilian). These steps would provide a big start in the direction of a real clean-up program in place of the present sorry state of affairs.

Arjun Makhijani

I want to thank Stacy Stubbs, who, as first editor of the newsletter, designed it and produced the first two issues. Stacy is moving on to other things, but will remain a consulting engineer to IEER.

LETTERS

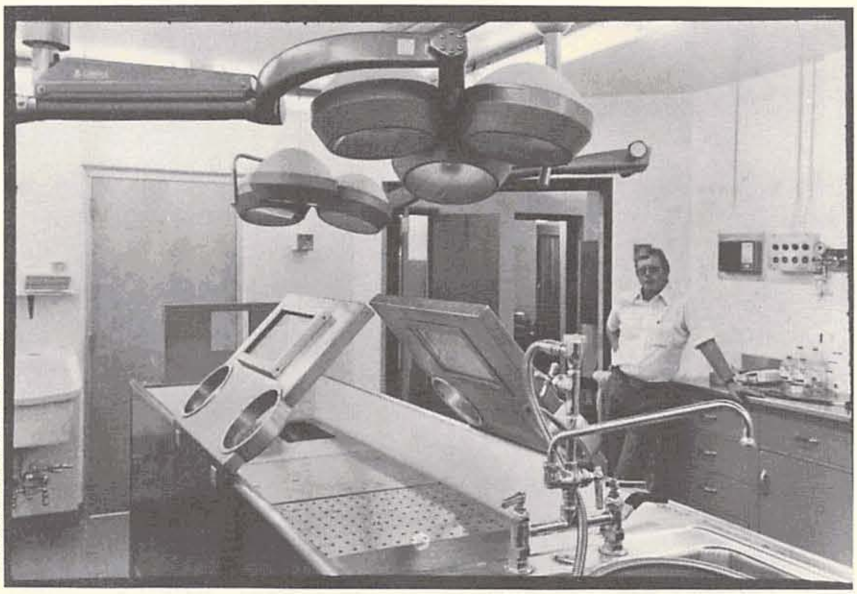
Dear Stacy,

. . . Thanks for the useful information in the "Dear Arjun" column . . . . My present hobby of [is to] try . . . to pry open the technical smoke-screens contained in obscure AEC documents . . . .

Our democracy requires a well–educated and highly informed populace for its continued functioning in this highly technical world. The enormous gap that exists between a tiny minority that possess some understanding of nuclear physics and the vast majority who exhibit little understanding to highly distorted views, has led to a breakdown in our democratic processes. I believe IEER can help heal the deep wounds in the fabric of our democratic system.

Sincerely,
Vernon Brechin
Mountain View, CA

PHOTOGRAPH BY ROBERT DEL TREDICI



Medical emergency room, Oak Ridge National Laboratory, with shielded operating table for severely contaminated workers.

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out to find and eliminate the problems. The light of science searched eagerly for the physical truths that led to atomic explosions; it needed no inspectors-general or FBI agents crawling all over the lab.

In stark contrast, consider the calculations of emissions of uranium from the DOE plant near Fernald, Ohio. Plant records made public (as a result of a 1985 lawsuit) showed that one of the formulas used to estimate uranium emissions from scrubbers was essentially backwards: it gave estimates of emissions that got smaller as the performance of the scrubber got poorer.

The error was at the level of high school algebra: there were two unknowns in the equation (the amount of uranium trapped in the scrubber and the efficiency of the scrubber) and only one quantity was being routinely measured, a situation which allows for an infinity of solutions. The management of the plant resolved the problem by assuming that the scrubbers were always operating properly at high efficiency, which they knew to be false. (At least, some measurements and observations to that effect existed in the plant.) One plant engineer, with an eye for the truth, called it an "inherently deceptive" formula as far back as 1971.

His observation was brushed aside. Almost two decades later, in 1989, the problem was pointed out in an independent analysis (by IEER) done in connection with the lawsuit, and made public in federal court and by the media. The DOE settled the lawsuit for $78 million, but neither the DOE, nor its contractor, Westinghouse, nor its former contractor, National Lead of Ohio, acknowledged the problem, much less fixed it. Indeed, at one point, in 1990, National Lead of Ohio stated that an investigation had been done and nothing was found wrong with the estimating formula. I publicly challenged National Lead to make the results of the investigation public, so that at least we could settle a simple mathematical matter. It refused.

In late 1991, a study sponsored by the Centers for Disease Control (CDC) analyzed the issue, but without making a direct criticism of previous emissions' estimates made by the DOE and its contractors. The CDC uranium release estimates (like IEER's earlier ones) were far higher than DOE's. At that point, the DOE admitted that its estimates and those of its contractors had been very wrong. But the problem with the errant formula remains unacknowledged and unfixed. Clearly, when it comes to environmental science, even the passion needed to fix a problem at the level of basic math is still absent.

Part of the problem arises from a conflict of interest. If the main mission is to produce bombs, and the bomb-making produces deadly wastes and pollution, then grave environmental problems are not so much scientific questions to be addressed, but risks or inconvenient facts to be hidden and suppressed, or public relations problems to be managed.

Scientific truth must necessarily be a frequent casualty of this attitude. Potential conflict of interest can be overcome, but that

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requires a passion for the subject and a commitment to the truth *far greater* than the source of the conflict. But in the dark shadows of bomb-making secrecy, covered with a noble public mantle of "national security," leavened by ample money, the commitments to environmental science were not just weak; the truth was often deliberately subverted.

For instance, a 1948 Joint Chiefs of Staff document perceived the need for a "reeducation campaign" to alleviate the fears about radiation among the public so that a nuclear weapons test site could be located in the continental United States without much protest. Later, agents of the Atomic Energy Commission lied in court when they said that thousands of sheep sick or dead from radioactive fallout in 1954 in Utah had not been affected by radiation. In this way, *the subversion of democracy and of environmental science became a part of the same process.*

The attitude of the DOE towards the public became a sort of "ignorance-is-bliss" formula: "What they don't know can't hurt us." With that as the starting point, the next logical step was to try to *not pose* difficult questions and to *not investigate* inconvenient hypotheses: "if we don't know, they can't know." As a result, all too often, inconvenient facts were buried and difficult questions were shunted aside. Partly by this process, a considerable environmental ignorance became a feature of the agency that tried to perpetrate it amongst the public. (That, at least, is my hypothesis.)

Propaganda and public relations in place of science and truth are now such an entrenched habit that today, with billions of dollars to clean up the mess, the DOE still has problems with simple algebra when it comes to environmental issues (but not yet with nuclear testing). It would appear that it is too difficult to create a commitment to scientific truth on environmental questions, an area where nurture and sustenance are fundamental, when there is still a basic commitment to building bombs.

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Chelyabinsk
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Three major radiation disasters at Chelyabinsk-65 have so far been acknowledged by the Russian authorities. The first was the result of the dumping of high-level waste from plutonium production activities there directly into the nearby Techa River. This occurred primarily from 1949 to 1951, though some dumping went on until 1956. Many residents of towns downstream were exposed to high levels of radiation, and eventually many of these towns were evacuated. People used the water then, and there are lots of anecdotal reports that many people died of acute illnesses. The area is still contaminated; yet children play in the waters of the river.

The second disaster was the chemical explosion in a high-level radioactive waste storage tank which occurred in September 1957. This accident (sometimes referred to in the west as the "Kyshtym disaster," after a nearby town) was kept secret at the time and was not officially admitted by the Soviet government until June 1989. This explosion dumped 18 million curies of radioactivity into the soil nearby and sent 2 million curies into a high fallout plume that scattered radioactivity over 15,000 square kilometers (about 5,900 square miles). More than 10,000 people were evacuated.

The third disaster was in 1967 when a drought resulted in the partial drying up of a lake (Lake Karachay) which had been used

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as a dump for high-level liquid radioactive wastes. Portions of the contaminated lake-bed were thus exposed and as a result radioactive dust was scattered around the region by the wind.

Muslyumovo

Muslyumovo is a farming village along the Techa river (78 kilometers from Mayak). Its residents experienced substantial exposures (estimated at an average of 24 rem effective dose equivalent to about 3,200 residents) due to the Techa River dumping. Despite being at considerable risk from the river contamination, the town was never evacuated. In some respects, my visit to Muslyumuvo was the most moving part of my trip to Russia.

Radiation levels in the village proper—including the local cafeteria—were in the range of natural background, maybe 6 to 15 microrads per hour, if anything slightly lower than in Chelyabinsk city. After lunch at the cafeteria, we went to the town square, where we were met by a crowd of 200 to 300 townspeople (including lots of kids) who had

Despite being at considerable risk from the river contamination, the town was never evacuated.


PHOTOGRAPH BY ROBERT DEL TREDICI

Sveta, a girl with leukemia, a chemotherapy patient who lives in the contaminated area.

apparently been told about this visiting delegation of Americans, evidently a very exciting event for them. We were led onto the back of a flatbed truck, whereupon local officials began to make speeches. What followed was about as close to the classic New England town meeting as you might imagine.

First, a politician began a speech enumerating achievements such as grain production, but he was quickly cut off by shouts from the crowd. He responded by moving quickly on to the problems they have experienced, the many people who died, the compensation they or their relatives never got. He confirmed that the situation near the river itself is terrible.

A teacher recounted school children's problems; she does not believe the readings from the official dosimeters they have been given. At one point she asked heatedly: "Where are the cottages that we are supposed to have?" This ignited a response from the crowd, which started shouting, "Yes, where are our cottages?"

Apparently, there had been some government promise to provide new cottages to mo people who currently live close to the contaminated Techa to points further back from the river. But they have not yet been provided and it is a sore point. Then a politician spoke of the importance of the conference to the villagers' problems and proceeded to detail how he would present their plight to the conference.

At this point, I started to get a little bit of a sinking feeling. It struck me that these people, who have been lied to and hurt time and again, were really excited about the mere presence of so many Americans. They seemed to think that because we had come to the conference, somehow things would be fixed. It was symbolic, in a more poignant way, of the general attitude I encountered in Russia, which was that Americans would help them out of their mess, and that if they could only have a system like that in the U.S., things would be better. I found this a sad attitude for the people of a great country to have about themselves. In this particular instance, though, I felt personally a little guilty, because these people were being set up yet again for another disappointment, and we were the ones giving them false hopes just by being there.

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After the speeches, members of our delegation went down to the river. There I measured radioactivity levels, all the while with children running about me. It is clearly a play area they are familiar with. They wanted to know how much the meter was reading. It consistently read about 300 to 500 microrads per hour (about 30-50 times natural background).

Russian officials want to complete the plutonium breeder reactor. I asked how much more radioactivity they would have to dump as a result. The guide did not know.

The Breeder Reactor Site

On Sunday, we went to a partially completed plutonium breeder reactor site at Chelyabinsk-65. Along the way, we stopped at a bridge over the Techa River. I went under the bridge, and took readings on the silty area of the riverbank which ranged up to about 8,000 microrads per hour (about 800 times natural background). Though this is an area along the main highway north out of Chelyabinsk, the only indications of the radioactivity were warning signs along the side of the bridge. Russian Ministry of Atomic Energy (Minatom) officials want to complete the breeder reactor. I asked how much *more* radioactivity they would have to dump into the reservoirs as a consequence of the extra reprocessing entailed by the breeder operation. Our guide said he did not know the figure on that.

The Conference

There were about 550 people at the conference, mostly Russians and Americans, with some people from Britain, France, Germany and Japan as well. One main issue of the conference was plutonium production, stimulated by the continued desire of Minatom to construct a plutonium breeder reactor (the Southern Urals Atomic Power Station) at Chelyabinsk-65. The general theme was that the U.S. needed to halt testing and the Russians needed to halt plutonium production and reprocessing.

Representatives of citizens' groups from Russia and the United States decided to establish direct links with each other to help both countries change from nuclear weapons production to taking care of the victims of that production and to cleaning up of the mess.

SELECTED IEER WORK

- Report for IPPNW entitled *Plutonium—Deadly Gold of the Nuclear Age.*
- Outreach on protection of the Ozone Layer.
- 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.
- Rongelap Rehabilitation Project to assess the habitability of Rongelap Atoll.
- Mound residents lawsuit for neighbors of the Mound Plant, near Dayton, Ohio.
- Publication 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 effects of nuclear weapons production for IPPNW.

"Dear Arjun"

Dear Arjun,

Can a parking lot be hot, and if so, how hot?

Hot Rodder in Houston

Dear Hot Rodder,

Even in the 1950s, the nuclear establishment was doing unusual things in parking lots to make them hot, especially at the Knolls Atomic Power Laboratory, near Albany, New York. The Knolls Atomic Power Laboratory tests reactors for the nuclear Navy and is the main site for the training of navy reactor operators.

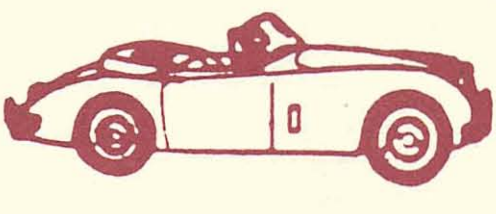
There, after the demise of drive-in movies, you will still find a hot parking lot. The radiation levels vary over the lot, but the entire area is radioactive. The general gamma radioactivity is 200 microrads per hour, or about 20 times natural background. There are many hot spots, with the hottest one having a gamma reading of 25,000 microrads per hour, or about 2,500 times natural background. In addition, there is considerable beta radiation also.

The main contaminant is cesium-137, which emits both gamma and beta radiation. (If it gets inside the body, it mimics the chemical action of potassium.)

When the General Electric Company, which operates the Laboratory for DOE, and which owned the land at the time, discovered that its parking lot was radioactive, it examined two "options": either G.E. could continue to own the land and wait for over a hundred years for the cesium-137 to decay (half-life about 30 years), or the DOE could acquire the land and the radioactivity at once.

After pondering the problem carefully, G.E. recommended that the DOE should acquire the land and radioactivity at once. It looked into the real estate listings and found that the "fair market value" of the 1.33 acres, "without private access and utility services," was about $8,000 to $10,000. Presumably, this value was for a lot also without cesium-137 from Knolls, but the document delicately neglects to mention that. (The G.E. document, number LSS-6161-192, is available form Knolls Action Project, Albany, New York, or from IEER.)

DOE bought the lot for $1.



What a steal! A hot 1.33 acres, with a view and at least a thousand cubic meters of soil contaminated with cesium-137. Finally, DOE delivers value for your tax dollars.

Dear Arjun

What are SWUs and why are they so costly?

Pennywise in Pennsylvania

Dear Pennywise,

The word SWUs is pronounced "swooze." It was the first acronym (more or less), invented in ancient Roman times, and referred collectively to "swillers of booze." The well-lubricated conversations of SWUs led to new words later, such as "schmooze" (see your Yiddish dictionary). In the nuclear establishment, it has quite another meaning.

SWUs is the plural of SWU (pronounced "swoo"). SWU is an acronym for Separative Work Unit. It measures the amount of work needed to enrich uranium. Natural uranium consists of 99.284 percent uranium-238, which cannot sustain a chain reaction (it is non-fissile), and 0.711 percent uranium-235, which is the isotope of interest for nuclear

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power and nuclear weapons. (Natural uranium also contains 0.005 percent of uranium-234, which is far more radioactive than the other two isotopes, and accounts for about half of the radioactivity in natural uranium.)

For nuclear weapons and many types of nuclear power plants in use, uranium must contain a higher proportion of uranium-235 than is found in natural uranium—that is it must be "enriched" in uranium-235. This is done in a uranium enrichment plant by spinning a gaseous form of uranium in a centrifuge or by diffusing uranium through a barrier which helps separate the isotopes. (There is also a technology under development called laser isotope separation; the DOE wants to operate a demonstration plant called AVLIS at the Lawrence Livermore Laboratory.)

Since the weight of uranium-235 is very close to that of uranium-238, it takes a lot of energy and thousands of enrichment stages to enrich uranium to the degree required (a few percent for U.S. nuclear power plants, 93 percent for weapons and 97-plus percent for naval reactors). The amount of work that needs to be done to separate uranium-235 from uranium-238 is measured in separative work units, or SWUs. The usual unit used to measure SWUs is kilograms.

Enrichment leaves behind "depleted uranium" as a waste material which contains about 0.2

percent uranium-235; the rest is uranium-238. Some of this is used to make tank armor, artillery shells, armor piercing bullets, etc.

In the United States, enrichment is carried out by the most energy intensive method—gaseous diffusion. It takes about 2,400 kilowatt-hours per SWU, which is five to twenty times the energy needed for a SWU using gaseous centrifuge technology. The uranium enrichment plant near Portsmouth, Ohio has the equivalent of about three nuclear power plants (2,700 megawatts) of power connected to it. If operated at 70 percent capacity for 11 months of the year, this would be enough to supply the residential electricity requirements of about 4 million people at typical U.S. levels of consumption.

There are three uranium enrichment plants in the United States: Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. The Portsmouth plant is the only one that can produce highly enriched uranium for bombs and naval reactors. That part of it is shut due to a surplus of highly enriched uranium. The Oak Ridge plant is also closed.

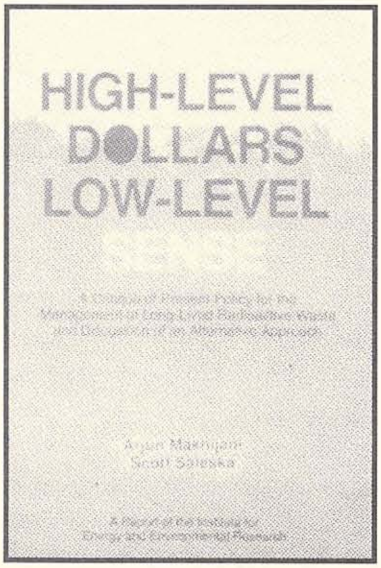
Uranium enrichment has left a considerable amount of contamination at the plant sites. Further, processing uranium to prepare it for enrichment also has created problems. For instance, the Sequoyah Fuels Corporation plant near Gore, Oklahoma, converts uranium into a chemical form suitable for use in gaseous diffusion plants (uranium hexafluoride); it is highly contaminated.

Since enrichment plants are huge, operate with radioactive material, and consume lots of energy, SWUs are very costly. There is currently a glut of enriched uranium on the world market, so it is difficult to assess the price of a SWU. DOE has two prices—a "base price" of $121.50 per kilogram-SWU and an "incentive price" of $104.75 per kilogram-SWU (quoted to me on August 26, 1992 by the DOE Office of Enrichment Services). The Russians are selling SWUs in Europe for considerably less.

It takes over four SWUs to convert about five-and-a-half kilograms of natural uranium to one kilogram of 3 percent enriched uranium suitable for a civilian light water reactor.

Despite the worldwide surplus of enriched uranium, an international consortium is planning to build a new uranium enrichment plant in Homer, Louisiana, a poor African-American community. Perhaps it is more a case of nuclear religion than market economics. The residents are resisting.

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

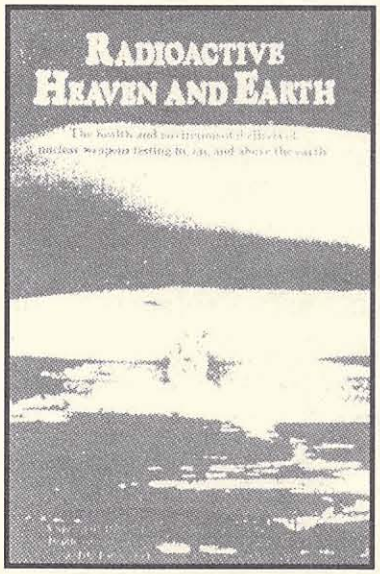
by Arjun Makhijani and Scott Saleska

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



Radioactive Heaven and Earth

The Health and Environmental Effects of Nuclear Weapons Testing in, on, and above the Earth

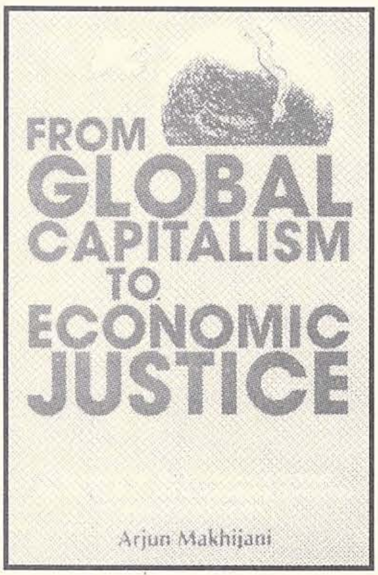
by International Physicians for the Prevention of Nuclear War and IEER

Radioactive Heaven and Earth is the first global analysis of the health and environmental effects of nuclear weapons testing, both atmospheric and underground, since testing began at Alamogordo, New Mexico in 1945.

Radioactive Heaven and Earth *is in the great tradition of physicists and scientists as they continue to document the dangers of nuclear testing. This authoritative book exposes the human costs and environmental damage wreaked on the earth as the United States and other nuclear powers continue to develop new, more destructive nuclear weapons.*

—Rear Admiral Eugene Carroll (Ret. US Navy)
Deputy Director, Center for Defense Information

PRICE: $17.00 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 #3

by Arjun

Progress

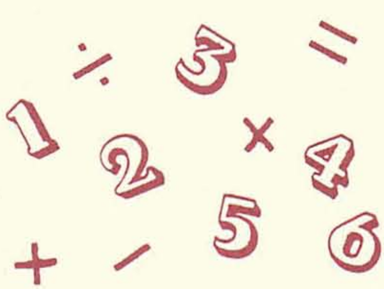
Good news! We had a fine response to the last Science Challenge. Eleven people sent in answers (as opposed to none the first time). Six of them were completely correct and four were partly correct. Congratulations all! It inspires me to go on. One respondent with a correct answer had a technical college degree. We drew lots from among the other fully correct answers. And so the winner of the grand $25 prize is—**Mary Diedrich**! We also sent $10 to the ten other respondents. In view of the number of responses, we will offer prizes of $10 each to the twenty respondents (up from ten) and continue with one $25 prize. So keep them rolling in.

By a strange coincidence, one of the respondents, Alex Medler, found himself sitting next to the DOE San Francisco field officer for nuclear programs and space reactors, while he was solving the problem on a plane. The man from the DOE looked over the answers and found them to be right, but, Alex wrote: "I don't know if that disqualifies me, or only makes the likelihood of my answers being correct much smaller. He claimed not to have designed any reactors for 20 years, so he wasn't sure of my math." Well, given the state of affairs at DOE, we kept you in the running. Moreover, I'm sure of my math and yours Alex. You were right! Maybe we ought to make **Science for Democratic Action** required reading, and the **Science Challenge** a required routine test for all DOE technical personnel! Here is the correct answer:

Solution to Science Challenge Number 2.

The problem had three parts, all of which related to units. In brief, the questions were as follows:

1. Convert a tritium concentration of 0.028 microcuries per liter to units of picocuries per liter.



There are one million picocuries per microcurie, since a picocurie is one trillionth of a curie and microcurie is one-millionth of a curie. So to get picocuries from microcuries we multiply by one million. Thus 0.028 microcuries = 28,000 picocuries (six decimal places to the right of 0.028). The denominator is liters in both cases so no adjustment is required on that account. Thus, 0.028 microcuries per liter equals 28,000 picocuries per liter.

2. Convert 5 gallons of gasoline into units of acre-feet.

There are about 325,000 gallons in an acre-foot. Thus 5 gallons = 5/325,000 acre-feet = 1/65,000 acre-feet = 0.00001538 acre-feet.

3. Convert 400 centisieverts into sieverts and rems.

A centisievert is one-hundredth of a sievert. Thus 400 centisieverts = 4 sieverts. Since one centisievert is the same as a rem (1 rem = 0.01 sievert = 1 centisievert), 400 centisieverts =

See "Arithmetic"– p. 12

Arithmetic
continued from p. 11

400 rem. If a cat got this dose, it would be, as Daniel Mackay of the Knolls Action Project put it, "one zapped cat." This dose, suddenly delivered, is about equal to an LD50 dose in humans. "LD" stands for "lethal dose" and 50 means 50 percent. Half the human beings exposed to an LD50 dose die within a few days.

Means and Medians

Measurements of physical quantities differ from one another for two reasons: first, the things being measured have different amounts of the property being measured; second, there is the question of measurement error. A considerable portion of the discipline of statistics is devoted to the understanding and interpretation of measurements.

Let us consider the first aspect: the variation of the thing being measured. If one took a number of samples of water from the Savannah River downstream of the Savannah River Site at various times in the days just before Christmas 1991, one would get different readings, since the tritium content of the water reached a peak and then declined in the days following the leak on December 22. For people who drank this water over those days, the total dose could be estimated from the average tritium content of the various samples of water (assuming they were representative of drinking water).

For example, if the measurements on successive days were 50,000 picocuries per liter (pCi/l), 40,000pCi/l, 30,000 pCi/l, 20,000 pCi/l, and 1,000 pCi/l, then the average concentration would be 28,200 pCi/l (please check it out for yourself). This average is also called the *mean* in statistical jargon. The *median* is something different. The median is one particular measurement from the entire set. Half the measurements are below the median, the rest above. In this case, the median is 30,000 pCi/l. Note that we cannot derive medians from means, nor means from medians.

Incidentally, income statistics are often reported as medians. For instance, the median household income in the U.S. in 1988 was $27,225, which means that half the households in the U.S. had incomes lower than this. (Look it up in the U.S. Statistical Abstract. This is a wonderful book if you want to get to know and love socially important numbers. I know someone who sleeps with a copy next to him. I don't go that far.)

Back to tritium. We could also take a number of samples at the same time from (nearly) the same spot to check on the accuracy of the measurements. Alternatively, one could take one sample and "split" it. This is what is normally done if one wants to verify a measurement. Even if the lab work is done very well, there will normally be some difference between the readings derived from the two portions of a split sample. In the case of tritium oxide in water it will be thoroughly mixed (since it is chemically identical to water), so that this will not be a source of error.

The differences between readings will then depend on the accuracy of the instruments and on the care of the operator. If the tritium content is below the detection limit of the equipment, then it would normally be reported as less than that figure. For instance, if the detection limit is 10 pCi/l, and the tritium content is below that, we could not detect it, and would report it as less than 10 pCi/l (written as < 10 pCi/l). DOE often reports such readings as zero.

CREDITS FOR THIS ISSUE

1. Photographs: Robert del Tredici
2. Stats of books : Tama Jackson and Howard Kohn
3. Production: Sally James of Cutting Edge Graphics, Washington, D.C.

Table of Units

In reading environmental literature (or DOE documents), one comes across a large variety of units. Here are some common units with conversion factors in tabular form. Conversion factors have been rounded off, so conversions back and forth between British and metric units will not be exact.

(Common Abbreviations are shown within the parentheses)

Physical quantity	Unit of Measure	Equivalence	Comments
Length	millimeter (mm)		metric
	centimeter (cm)	10 mm; 0.39 in	metric
	meter (m)	100 cm; 1.09 yd	metric
	kilometer (km)	1,000 m; 0.62 mile	metric
	inch (in; ")	2.54 cm	British
	foot (ft; ')	12"; 30.5 cm	British
	yard (yd)	3'; 0.91 m	British
	mile (mi)	1,760 yd; 1.61 km	British
Area	square centimeter (sq cm; cm^2)	0.155 sq in	
	square meter (sq m; m^2)	1.20 sq yd	1 m on a side
	hectare (ha)	10,000 sq m; 2.48 acres	100 m on a side
	square km (sq km; km^2)	100 ha; 0.39 sq mi	1 km on a side
	square foot (sq ft; ft^2)	144 sq in; 929 cm^2	
	square yard (sq yd)	9 sq ft; 0.84 sq m	
	acre	4,840 sq yd; 0.4 ha	
	square mile (sq mi)	640 acres; 2.59 sq km	
Volume	milliliter (ml) or cubic centimeter (cc)		cc and ml are equal
	liter (l)	1,000 cc or ml	
	cubic meter (cu m; m^3)	1,000 liters; 35.3 cu ft	
	quart (qt)	0.95 liter	U.S. quart
	gallon (gal)	4 qt; 3.79 liters	U.S. gallon
	cubic foot (cu ft; ft^3)	7.48 gal; 28.3 liters	
	acre-foot (ac-ft)	43,560 cu ft; 1 acre 1 ft deep	
Mass	gram (gm)		
	kilogram (kg)	1,000 gm; 2.205 lb	
	metric ton (t; tonne)	1,000 kg; 1.1 short tons	
	ounce (oz)	28.4 gm	
	pound (lb)	16 oz; 454 gm	
	short ton (ton)	2,000 lb; 0.91 metric ton	normal U.S. ton

Physical quantity	Unit of Measure	Equivalence	Comments
Energy	joule (J)	basic metric unit of energy; amount used by a one watt light bulb lit for 1 second	
	erg	one-ten-millionth of a joule	
	calorie (cal)	4.2 joules	
	kilocalorie (kcal)	1,000 calories	measure for food
	kilowatt-hour (kWh)	3,600,000 joules	1 kilowatt for 1 hr
	electron-volt (eV)	0.16 billion-billionth of a joule	(see Note 4)
Radio-activity	becquerel (Bq)	1 disintegration per second (dps)	
	disintegration per minute (dpm)	1/60 Bq	
	curie (Ci)	37 billion Bq	
Dose	rad	100 ergs per gram	
	gray (Gy)	1 joule/kg; 100 rad	standard unit
	roentgen	0.87 rad to air; about 0.96 rad to living tissue	
	rem	100 ergs/gram for gamma and beta radiation; 5 ergs/gram for alpha radiation	
	sievert (Sv)	100 rem	

Notes:

1. In the case of "British" units, the measures are U.S. versions. The British imperial gallon is 20 percent larger than the U.S. one (277.4 cubic inches versus 231 cubic inches). The British long ton is 2,240 pounds versus the U.S. short ton of 2,000 pounds.

2. Prefixes are attached to basic units (meters, grams, joules, watts, electron-volts, curies, becquerels, rads, grays, rems, sieverts) to create units that are different by various multiples of 10. The common prefixes are: *pico-* (one-trillionth); *nano-* (one-billionth); *micro-* (one-millionth); *milli-* (one-thousandth); *centi-* (one-hundredth); *kilo-* (thousand), *mega-* (million); *giga-* (billion); *tera-* (trillion). Hence *nano*curie is one-billionth of a curie; *mega*curie is one million curies, and so on. These prefixes are abbreviated by their first letters, except micro, which is abbreviated by the Greek letter "mu," which is written "µ."

3. Rads and grays measure the deposition of energy in tissue. Rems and sieverts measure biological damage. Rems and rads are equivalent for gamma and beta radiation. Alpha radiation is far more damaging per unit of energy deposited in living tissue. The current conversion factor from rads (or grays) to rems (or sieverts) for alpha radiation is 20—that is, multiply rads of alpha radiation by 20 to get rems. This factor of 20 is just the currently accepted one; it may change from one official assessment of radiation damage to another, as it has in the past. It is called the *"quality factor"* or *Q factor*, for short.

4. An electron-volt is the energy gained by an electron as it accelerates through an electric potential of one volt. An electric potential is similar to a gravitational potential—the higher you take a mass, the greater energy it has when it is released and drops to the ground. Units of electron-volts (and multiples of eV) are used to measure energies of nuclear, atomic, and molecular (chemical) phenomena.

Science Challenge

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.

The Science Challenge is a regular Science for Democratic Action feature. There is no way to learn arithmetic except to do it! We offer twenty 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 20 people enter and there is more than one correct entry, the winners will be chosen at random. The deadline for submission of entries is November 15, 1992. People with science, math, or engineering degrees are not eligible.

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