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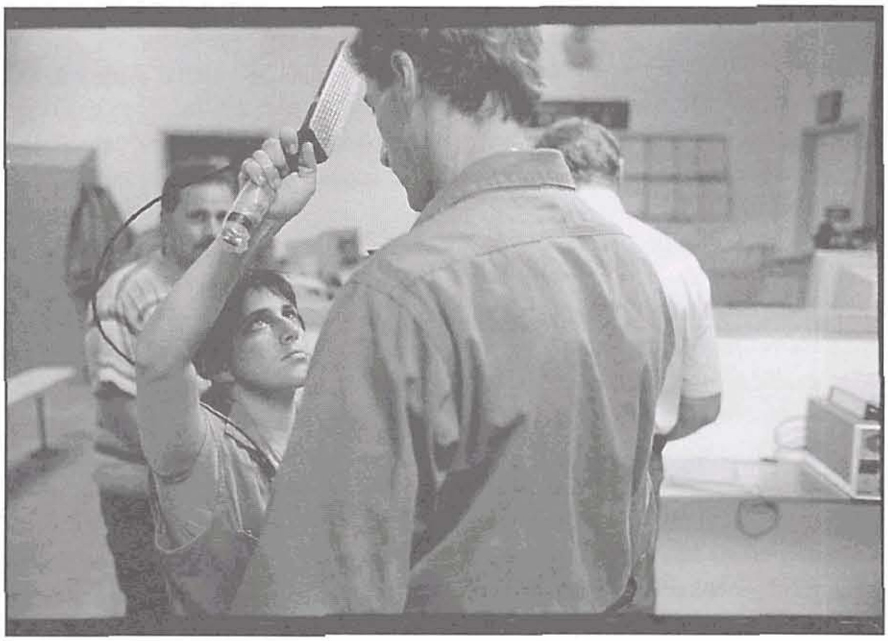
Worker Radiation Dose Records Deeply Flawed

BY ARJUN MAKHIJANI AND BERND FRANKE



ROBERT DEL TREDICI

A worker at the Plutonium Finishing Plant at Hanford, Washington receives a whole-body survey to detect potential radioactive contamination.

As part of its responsibility for the production and testing of nuclear weapons, the Department of Energy (DOE) and its predecessor agencies (the Atomic Energy Commission, 1947–1974; and the Energy Research and Development Administration, 1974–1977) have been responsible for ensuring that workers were not exposed to more than the allowable amounts of radiation. The DOE has also been responsible to adhere to what is called the "ALARA" principle—the idea that radiation exposures should be kept "As Low As Reasonably Achievable" with available technology.

The goal of setting radiation dose limits and following the ALARA guideline is to protect worker health by limiting exposure. But if exposure is not properly measured, radiation exposure regulations cannot be enforced, nor can guidelines be followed. Health monitoring personnel may not be aware of instances when workers are overexposed. Diseases that workers may be at greater risk of contracting may go undetected, harming them and their families. Health studies based on worker dose data would produce misleading results because dose records would be incomplete and knowledge of doses would be inaccurate.

From the beginning of the nuclear era until 1989, *radiation doses from radioactive materials inhaled or ingested by workers were not calculated or included in worker dose records.* This was revealed by DOE in a background paper sent to IEER on April 7, 1997.[1] DOE and its predecessor agencies did make measurements of internal exposure to radioactive materials, though often sporadic (see below), mainly by taking urine samples. After the mid-to-late 1960s, there was also selective use of more sophisticated counters that

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Editorial
Identify Groups of Workers at Risk

As noted in the accompanying article, the Department of Energy has stated that it did not calculate internal doses for workers, and therefore did not integrate them into dose records until 1989. This single fact means that historical worker dose records for 500,000 to 600,000 DOE workers are open to question and that a large number of them—those belonging to workers at risk of internal exposure—are flawed.

The DOE was not actually required to do such integration of internal and external doses, as we note in the article. Still, in the 1950s it was possible to crudely calculate internal worker doses and enter them into worker dose records (though such estimates would often have underestimated exposures). Relatively precise estimates were possible after the mid-1960s by matching up urine data with direct measurements of lung burdens, as IEER did in the case brought against

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National Lead of Ohio by workers at the Fernald Plant in 1991. (See SDA Vol. 5 No. 3). But the AEC, its successor agencies, and their contractors did not make the effort until 1989, when new regulations required it.

As the case of iodine-131 in fallout out shows, (see article, p. 3) the nuclear weapons establishment chose not to properly inform the public about the risks and sacrifices that it was imposing upon them. The counterpart for workers of the public relations campaign that accompanied atmospheric testing was constant reassurances that doses were under allowable limits—and vigorous contestation of worker compensation claims even though the DOE and its predecessor agencies had failed to do their homework on what worker exposures actually were, and though relatively accurate estimates were possible after the mid-1960s.

> *Relatively precise estimates of internal doses were possible after the mid-1960s.*

It is time for the DOE to straighten out the mess by commissioning an independent assessment of the state of internal and external dose data. Simultaneously, the DOE must expeditiously review workers' records to determine which *groups of workers* who labored to make and test this country's huge nuclear arsenal were at risk of high internal exposures and/or high lifetime exposures. The reconstruction of individual worker doses would be a very costly and difficult exercise, which would in many or most cases also be frustrating because huge uncertainties will inevitably remain. That is why we advocate the calculation of doses to groups of workers to determine at-risk groups for the purposes of medical monitoring and, if warranted, compensation. That way most resources can be devoted to workers rather than technical studies.

It is also possible that the DOE and its contractors have used incomplete dose records to argue its case in compensation cases and other lawsuits. It is improper for the government to continue to fight workers' claims based on exposure data that systematically underestimated doses. A review should be conducted to determine if DOE or its contractors have presented any pre-1989 records as accurate data on internal worker doses.

Private industry failed to calculate internal worker doses until the 1991–1994 period. We have not examined any set of data relating to workers in the private sector of the nuclear industry. The industry's failure to measure internal doses needs to be reviewed and an assessment should be made of its impact on workers.

There are two rays of hope in this dismal picture. One is that DOE began in 1989 to incorporate internal dose estimates into worker dose records. The other is that DOE and its predecessor agencies appear to have taken sufficient measurements to enable group worker doses to be approximately calculated, at least in the one instance where IEER has had access to the raw data. Since its inception, the DOE has made some effort to track individual worker exposures, which has undoubtedly resulted in lower overall exposures then would have occurred if no effort were made. But these measures have been grossly inadequate. If the DOE can spend $4.5 billion a year on laboratory testing and computer simulation of nuclear weapons, which we have found to be essentially unnecessary for maintaining safety (See SDA Vol. 5 No. 2), it can find the resources to do justice to the people exposed to radiation while building nuclear weapons.

—ARJUN MAKHIJANI AND BERND FRANKE

SCIENCE FOR DEMOCRATIC ACTION

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Let Them Drink Milk

Iodine-131 Doses from Nuclear Weapons Testing

BY PAT ORTMEYER

. . .it seems necessary to adopt a rather conservative attitude toward the involuntary exposure of the general populations. An error on the radical side will not be immediately apparent, but the chickens will inevitably come home to roost at some later date.

—Howard L. Andrews,
National Institutes of Health,
September 13, 1953[1]

The National Cancer Institute (NCI) recently released results of its 14-year study showing that fallout of iodine-131 from atmospheric tests conducted in Nevada in the 1950s and early 1960s resulted in thyroid doses to virtually all of the 160 million people living in the United States at the time. The estimated 150 million curies of iodine-131 released from the tests resulted in a cumulative average thyroid dose to the population of 2 rad.[2] Children were particularly affected: their doses averaged 6 to 14 rad, with some doses as high as 112 rad. Prior to this study, the most recent estimates of children's thyroid doses from iodine-131 in fallout, reported to Congress in 1959 and cited as recently as 1997, gave a dose range for children of 0.2 to 0.4 rad—15 to 70 times less than the NCI dose estimates. [3] (Note: These are estimates of thyroid doses, not whole body doses. See Centerfold table on dose.)

Thyroid irradiation increases the risk of cancer to children. A 1995 peer-reviewed publication says there is "convincing evidence" of increased thyroid cancer risk to children under age 15 whose thyroids are exposed to 10 rad or more.[4] This study mostly concerned individuals exposed to external radiation sources such as X-rays, but the effect on tissues from ionizing radiation from internal sources is essentially the same.[5] (See footnote for full explanation.)

Thyroid cancer is relatively rare, but the NCI estimates that 10,000 to 75,000 thyroid cancers can be expected as a result of these doses, roughly five to ten percent of which will be fatal. (The upper estimate of 75,000 is more plausible, since the lower estimate assumes that internal radiation doses from iodine-131 are "as little as one-fifth as hazardous" as the same dose of external radiation.[6] This assumption is very dubious, not based on human data, and not protective of public health.) About 70 percent of thyroid cancers due to iodine-131 fallout have yet to be diagnosed, according to the NCI,[7] and survivors of thyroid cancer require lifelong treatment with a synthetic thyroid hormone essential for metabolism and other physiological functions. Thyroid irradiation has also been linked to other thyroid disorders, such as autoimmune hypothyroidism, autoimmune thyroiditis, hyperthyroidism incident to Grave's disease, and thyroid nodules.[8] Estimates of the level of dose at which these effects occur vary considerably.

> *Some of the highest thyroid doses in the country were in areas far from the test site.*

While NCI has not estimated the number of children who were put at risk due to fallout, simple demographics coupled with the published numbers indicate that millions of people who were under 15 during the period in question may have received over 10 rad. Doses to girls may be of particular significance, as the incidence of thyroid cancer among women is more than twice that of men.[9]

Iodine can be inhaled, or ingested through contaminated eggs, cottage cheese, or leafy plants and vegetables. But the main pathway of exposure was through ingestion of contaminated milk. As fallout settled on fields and pastures after each test, cows and goats would eat the grass and the iodine would become concentrated in their milk. Children received higher doses because in general they consumed more milk than adults, and their thyroids were smaller and growing more rapidly. The estimated 20,000 people in the country at the time who drank goat's milk also received higher doses —up to 20 times greater than those drinking cow's milk—because goat's milk concentrates iodine-131 more than cow's milk.[10] Doses to goat's milk drinkers could, in the most affected counties, have been as high as 180 to 316 rad.

High doses were not limited to those areas directly downwind of the tests. Local precipitation or wind patterns in areas far from the test site caused selective deposition of fallout, or "hot spots," a phenomenon understood by the Atomic Energy Commission (AEC) from the time of the first test, "Trinity," in 1945. As a result, some of the highest estimated thyroid doses in the country were in areas far from Nevada, such as in Meagher County, Montana, with an average dose of 15.8 rad, and Custer County, Idaho with 15.4 rad. Other high doses were estimated throughout the midwest: 8.6 rad in Lyman, South Dakota (26 to 60 rad for children), and 8.1 rad in Lewis County, Missouri (24 to 57 rad for children).[11]

The Atomic Energy Commission understood early on that locating the test site in the western part of the

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directly measure radionuclides in workers' bodies. The DOE was not required by regulations to calculate worker doses, but only to keep records of whether workers were internally exposed to more than certain amounts of radionuclides.

The lack of historical internal dose data in worker dose records has important consequences for public policy on health issues, for scientific investigations of radiation risk, and most of all for the more than half-a-million workers (and their families) who have been involved since the Manhattan Project in making and testing US nuclear warheads. In 1989, DOE began to correct this historical problem by initiating a program of integrating internal and external worker doses.

Exposure Limits

Limits for allowable exposure have varied over the years, and have generally tended to decline as evolving knowledge about the cancer risks from radiation indicated that the dangers it posed were greater than previously thought. (See Centerfold.) In order to ensure that workers are not overexposed, the most important routes of exposure must be properly monitored. Consideration must also be given to the fact that ionizing radiation affects people in various ways.

When only external radiation is involved, measurement of worker dose is accomplished by the use of film badges, (small photographic plates sensitive to gamma and beta radiation), or thermoluminiscent dosimeters (reusable devices that measure external radiation—also referred to as TLDs). These devices can measure how much radiation a worker has been exposed to, but not the amount of radiation that may have been taken into the body through inhalation, ingestion or other means.

Internal radiation exposure occurs when radioactive materials get inside the body and decay, irradiating nearby tissues. Internal radiation is often more organ-specific than external radiation. If the radionuclides become lodged in particular parts of the body, such as the lungs or bones, for instance, these areas are irradiated far more than others. Risk of internal exposure is high in workplaces where the air becomes contaminated with radioactive materials or dust, as has frequently occurred in various kinds of uranium processing plants and in uranium mines. Workers can also be exposed internally through ingestion of radioactive materials (if the radioactive materials get into the mouth from the air, for example) or by absorption through wounds or cuts.

From the beginning of the nuclear era until 1989, internal radiation doses were not calculated or included in worker dose records.

Internal exposure is less likely in situations where the radioactive materials are sealed or separated in some other way from the work environment, such as in glove boxes. However, if accidents occur in these situations, or if equipment such as a ventilating system or glove box is not efficient or in proper working order, then workers could be exposed internally as well.

For almost the entire period of nuclear weapons production, limits have been imposed on exposure from both internal and external routes. Some current limits apply to combined external and internal exposure, while past limits have applied specifically to particular organs, such as the lungs. For instance, the limit for lung exposure until 1958 was 15 rem per year for workers and off-site populations. It was lowered for off-site populations to 1.5 rem per year in 1959.

Monitoring Doses

Internal dose is monitored in various ways. One common way is to measure radionuclide concentrations in urine. If one knows the rates of excretion corresponding to various body burdens, then is possible to calculate these body burdens and thereby infer the radiation dose.

Another method is to measure the gamma radiation being emitted by the radionuclide inside the body. Since a portion of gamma radiation penetrates the body, a fraction of the gamma rays emitted by radionuclides inside the body escape outside it. This is measured by putting the worker or part of his or her body into a "counter," which is a chamber that measures gamma radiation. Thus, we have "whole body counters," "lung counters," and so on. Care must be taken to exclude or adjust for other sources of environmental radioactivity in the measurement of internal body burdens, notably radon and its decay products.

Internal doses can also be assessed indirectly by measuring the concentrations of radionuclides in the air in the plant. In areas where exposure is more likely, workers can wear portable air monitoring devices to measure concentrations of radionuclides in the "breathing zone"—that is, in the air very close to their faces. Internal worker doses can be estimated if breathing rates, efficiencies of protective devices worn by workers (if any), and other factors are known.

It is essential that radiation monitoring be carried out accurately and in sufficient detail. For instance, film badges and TLDs must be stored properly when not in use, so that they are not contaminated between worker exposure times. Also, workers at risk of internal exposures must be monitored frequently enough to accurately determine internal body burdens of radionuclides. This is because over time the body eliminates radionuclides;

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some are excreted in a very short time, while others are eliminated very slowly. (The amount of time it takes to eliminate half of the body burden of a radionuclide is called its biological half-life.) It is also important to know the chemical form of the inhaled or ingested radionuclide because the rate at which it is eliminated from the body depends on the solubility of the particular chemical compound.

Failure to Monitor

The April 7, 1997 background paper sent to IEER by the US Department of Energy Office of Worker Protection Programs and Hazards Management clearly set forth what IEER had suspected for several years, that

> . . . [u]ntil 1989 in DOE, and 1991-1994 in the nuclear industry (NRC and Agreement States) internal radiation doses were not calculate [sic] for workers. Radiation activity in excreta or percent of body burdens were recorded in the DOE prior to 1989.

Thus, while workers were being monitored for internal body burdens, these body burdens were not being translated into radiation dose estimates; nor were any radiation dose estimates corresponding to internal radionuclide body burdens entered into the dose records of workers.

While there was no regulatory requirement to actually calculate worker doses, the lack of internal radiation dose estimates in worker dose records means that the records of workers who were at risk of internal exposures are incomplete, misleading, and inaccurate. The degree of incompleteness and inaccuracy will vary from one worker to the next, from one historical period to the next, and from one facility to the next. But the overall result is that *large numbers of workers have received information about their radiation exposures which systematically understates their actual exposures.*

Another consequence of the incomplete internal dose records before 1989 is that in compensation cases involving workers who had internal exposures, the DOE and its contractors may have based their arguments on incomplete data that underestimated exposures. Many cases may therefore have been unjustly decided against workers. Whether the DOE or its predecessor agencies knowingly omitted internal dose information from some worker compensation cases is, at this time, an open question, but a reasonable one to pose.

While it is not possible to give an accurate estimate of the proportion of the 500,000 to 600,000 workers who have worked for the DOE that were at risk of exposure beyond allowable limits, we note that at the uranium processing plant in Ohio, commonly called the Fernald Plant, most workers were at risk in the early years. In fact, in 1955, the worst year for worker exposure, IEER estimates that almost 90 percent of workers were exposed to more than the allowable dose limit of 15 rem to the lung. (See SDA Vol. 5 No. 3.)

There are a number of other direct consequences of seriously incomplete dose records:

- Internal exposures of uranium workers may also have led in some cases to heavy metal poisoning, notably of the kidneys. Such cases could have been better detected had internal dose information been a part of dose records.
- Improper medical diagnoses may have resulted in some cases because dose records were incomplete.
- Corrective measures to improve working conditions were likely delayed or not implemented in many cases because dose records did not show overexposures.

The problem was most acute in the period before the mid-to-late 1960s for two reasons. First, evidence indicates that this was the period when workplace conditions were the dirtiest and when workers were at higher risk of exposure. This observation cannot be used to arrive at conclusions about specific workers or even specific plants. But to date, most of the evidence we have examined indicates that for various reasons, exposures were generally highest in this period.

Second, this period is prior to the availability of counting techniques that allowed for direct measurement of body burdens. Action levels were set for radionuclides in urine. So long as the content of specific radionuclides was below these action levels, body burdens and worker doses were assumed to be below the maximum allowable limits. After lung- and body-counters became available in the early 1960s, there were delays in using them. Even after they were brought into use, for example in 1968 at Fernald, urine measurements continued to be the main method for monitoring internal dose.

Unfortunately, the monitoring procedure adopted by the DOE and its contractors was flawed. IEER's analysis of Fernald dose records in 1985 revealed the following problems:

- The lung burden inferred from urine data was consistently underestimated because of improper assumptions about the ratio of urinary excretion per unit of uranium lodged in lung tissues.
- Urine was not monitored for all radionuclides.
- Urine monitoring was generally too infrequent to allow for accurate determination of body burdens and their change with time. Since many chemical forms of radionuclides are excreted relatively rapidly, infrequent monitoring was likely to miss doses from accidents and other occasional but high exposures. Further, in many cases, urine measurements were so infrequent that even chemical forms with relatively long biological half-lives would not have been accurately detected. As a result, low urine concentrations may not have corresponded to low exposure, but merely to a long

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time lapse between the intake of the radionuclide and the taking of urine samples (or lung counts).

- The solubility of the compound inhaled or ingested was not determined or, if known, was not recorded.
- The relationship of urine sampling time to exposure was, in most cases, unknown.

As a result of all these factors, the assumption that the dose was below allowable limits if the concentration of a radionuclide in urine was below the action level was scientifically unsound. Even when the actual doses were below allowable limits, the internal doses should have been entered into worker dose records and added to external doses in appropriate ways.

Whole-Body and Organ-Specific Doses

Radiation standards limit dose both to specific organs as well as to the whole body. Consider, for example, doses to the lung. The lung may be exposed by external gamma radiation from sources outside the body, resulting in doses essentially equal to those for other organs in the body. It may also be exposed from inhaled radionuclides. In order to ensure compliance with the lung dose limit, which was 15 rem in the 1950s through 1980s, DOE and its contractors only had to consider internal body burdens of radionuclides. (However, as we have indicated, before 1989 internal doses were not calculated from these data.) In most cases, such as at the Fernald plant, lung doses were inferred from measurements of uranium in urine. If these were found to be below allowable concentrations, compliance with the 15 rem/year limit was assumed to have been demonstrated.

In the period since the late 1980s, the regulatory practice has been to use "committed effective dose equivalents."[2] In this model, "effective dose" is calculated by multiplying doses to individual organs or tissues, like the thyroid, bone tissue, or the lung, with a weighting factor that accounts for the relative likelihood of cancer mortality from exposure to a particular organ. This allows exposures to a single organ and exposure of the whole body to be considered together. Further, internal organ doses are calculated on the basis of a fifty-year "committed" dose—that is, the entire dose from a radionuclide to an organ over a fifty year period (in most cases, the majority of the dose is delivered in a few years or less). These two concepts, "effective dose equivalent" and "committed dose" are put together to arrive at "committed effective dose equivalent." For regulatory purposes, the entire committed dose is attributed to the year in which the radionuclide is incorporated into the body. But even in this new practice, the organ doses arising from internal radiation must be known, because without that data, the correct effective dose equivalent cannot be calculated. This change in regulations requiring calculation of effective dose equivalents caused DOE to begin to move to a policy of integrating internal and external radiation doses.

The same institutional outlook that put weapons production before environmental protection also relegated sound worker dose records into second place until after the Cold War.

While the unavailability of precise scientific techniques before the mid-1960s would have precluded accurate internal dose assessment, the doses could have been inferred from urine data and integrated into dose records, but were not. After the mid-1960s, the AEC and its contractors could have made relatively accurate worker dose estimates, but still failed to do so. It would appear that the same institutional outlook that put weapons production before environmental protection also relegated sound worker dose records into second place until the Cold War began to wind down.

Consequences of Underestimating Dose

Underestimation of internal doses is not just poor practice for worker health protection. It also creates problems for epidemiological studies. Accurate epidemiological work is needed to estimate the health risk of radiation exposure, and this requires studies with sound data on doses to various groups of workers.

Cohort studies, for example, compare the health status of people with various degrees of exposure. Such studies are common among worker populations and help to assess the risk of exposure to radiation (or other disease-causing agents). But if worker dose records are distorted by omission of a crucial component of dose, highly exposed workers and workers with low exposures could be jumbled up in ways for which no statistical control is possible.

For instance, studies that consider external exposure only would group workers with low external doses together and those with high external doses in another group. If some or all of the low external exposure group workers had higher internal doses than the high external exposure group, the study would be comparing workers with high exposure to others also with high exposure![3] Such a study would be misleading and tend to underestimate risk estimates. By contrast, if the high external exposure group had even higher internal exposures, the study would also be misleading and would tend to overestimate radiation risk.

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The April 1997 DOE background paper also points out that lifetime dose records have not been carefully maintained though the risk to workers is based on lifetime radiation dose. If dose records are not transferred from one contractor to the next at a plant, or from one plant to another when the worker changes jobs, worker health as well as public health is compromised because it becomes impossible to accurately track the health effects of occupational exposure. Of course, this is another complicating factor in doing epidemiological studies and assessing radiation risk.

External Exposure Data

The state of external dose data also needs to be carefully examined. The DOE has admitted the following problems[4]:

- External exposure data are often incomplete and unreliable.
- Raw dose data and electronic versions of the data (which are often used by researchers in studies) do not always agree.
- In some cases, worker dose records contain entries stating that the dose was zero, regardless of what the actual dosimeter reading may have been.

Finally, there were very few measurements made of worker exposure to non-radioactive hazardous materials. But we do know from the nature of work done at nuclear weapons plants that many workers were exposed to or were at risk of exposure to acids, organic solvents, beryllium, fluorine and fluorides, and heavy metals.

As a result of all of these problems we can conclude that knowledge of workplace exposure during nuclear weapons production and testing was poor, and the results of at least some epidemiological studies are likely to be misleading. At present, it is impossible to say what health effects might be revealed by properly conducted studies. But we can say with confidence that the radiation doses for large numbers of workers were higher than those that are apparent from their dose records because internal doses were omitted until 1989, and because there were many deficiencies in other dose records.

1 The background paper was faxed to IEER on April 7, 1997 as preparation for a meeting an IEER staff member was attending with the staff of DOE's Office of Worker Protection Programs and Hazards Management on April 14, 1997.

2 This model is referred to as the "ICRP 30 dosimetric model." ICRP is the International Committee on Radiological Protection. The model was announced in publication 30.

3 This kind of situation is quite possible because many important radionuclides, including uranium-238, plutonium-239, strontium-90, and tritium would typically provide low external doses but high internal doses.

4 For more on problems with DOE's external dose data see A. Makhijani, H. Hu, and K. Yih, eds., *Nuclear Wastelands*, (Cambridge: MIT Press, 1995), pp. 262-63.

A CENTERFOLD FOR TECHNO-WEENIES

Exposure and Dose

This Centerfold provides information about dose in rad and how it relates to energy deposited in tissue, as well as a brief history of the evolution of radiation exposure standards and regulations. We also include additional information about iodine-131 and thyroid doses received by the US public during the years of atmospheric testing.

Relationship between energy deposited and dose in rad

A rad is defined as the deposition of 100 ergs of energy per gram of tissue. Since the measurement is *per gram,* then the same dose in rad can reflect very different radiation exposures, depending on the mass into which the energy is deposited:

If the dose is:	... and the total mass into which the energy is deposited is:	... then the total energy deposited is:
2 rad	2 grams (weight of an infant's thyroid)	400 ergs*
2 rad	20 grams (weight of an adult's thyroid)	4,000 ergs
2 rad	70,000 grams (the official definition of "standard man" in radiation protection practice; equal to about 154 lbs.)	14 million ergs

Conversely, the same amount of deposited energy can result in very different *doses*, depending on the mass into which the energy is deposited:

If the total energy deposited is:	... and the total mass into which the energy is deposited is:	... then the dose is:
4,000 ergs	2 grams (weight of an infant's thyroid)	20 rad
4,000 ergs	20 grams (weight of an adult's thyroid)	2 rad
4,000 ergs	70,000 grams (the official definition of "standard man" in radiation protection practice; equal to about 154 lbs.)	0.0006 rad

* In everyday terms, an erg is a very small amount of energy. It takes almost 1.5 trillion ergs to light a 40-watt bulb for one hour. But in the context of the tiny cells that make up living beings, 100 ergs is a large amont of energy. One erg is enough energy to disrupt tens of billions of the chemical bonds that hold molecules together.

For more on rad, rem and roentgen, see "Dear Arjun," page 13.

Iodine-131

■ **General:** Its name is from the Greek word "iôeides," meaning "violet colored," after the violet color of iodine in a gas form. As a solid it is shiny, black and non-metallic. In its non-radioactive form occurs on land and in sea in sodium and potassium compounds, and is necessary for proper functioning of the thyroid.

■ **Half-life:** 8.04 days.

■ **Atomic number:** 53.

■ **Decay mode:** beta radiation.

■ **Sources**: Fission product created in nuclear reactors and in nuclear weapons explosions.

■ **Release of iodine-131 per kiloton of fission explosive power**: 125,000 curies.

■ **National Cancer Institute estimate of iodine-131 releases from the Nevada Tests:** 150 million curies.

■ **Organ most affected:** thyroid.

■ **Main pathway**: milk.

■ **Other pathways**: ingestion of other dairy products, vegetables, fruits, and eggs; inhalation; and external irradiation.

■ **Direct physical effects:** radioactive iodine damages or destroys thyroid cells.

■ **Health effects:** Increased risk of thyroid tumors, notably in children. Likely increase of thyroid cancer risk in children exposed before the age of 15 years. Children under five at highest risk. Females have more than twice the risk of males. Linked to other thyroid disorders, such as autoimmune hypothyroidism, autoimmune thyroiditis, hyperthyroidism incident to Grave's disease, and thyroid nodules.

■ **NCI estimate of thyroid dose from Nevada Tests averaged over entire country**: 2 rad.

■ **NCI estimate of thyroid dose to children aged 3 months to five years in high fallout areas**: 27 to 112 rad.

■ **Official iodine-131 release estimate from Chernobyl:** 7.3 million curies—decay-corrected to ten days after the start of the accident.

■ **Iodine-131 inventory in the Chernobyl reactor on April 26, 1986, the day the accident started**: approximately 83 million curies.

■ **IEER's rough estimate of actual releases from Chernobyl over the course of the ten-day fire**: 10 to 15 million curies (assuming the official estimate of a 20% release fraction is correct).

Chronology of External Radiation Exposure Standards

1931–34	US Advisory Committee on X-Ray and Radium Protection (precursor to the National Council on Radiation Protection and Measurements) adopts X-ray "tolerance dose" of 0.1 roentgen *per day*.
1940–41	US Advisory Committee proposes, but does not implement, lowering the X-ray tolerance dose to 0.02 roentgen *per day*.
1942	U. of Chicago Metallurgical Laboratory adopts a "maximum permissible exposure" standard of 0.1 roentgen *per day*. Becomes standard for entire Manhattan Project.
1954	Atomic Energy Commission adopts National Bureau of Standards recommended dose limit of 5 rem *per year*. Sets additional limits for internal exposures at 15 rem per year for most organs.
1959	Dose limit for workers remains 5 rem per year. AEC also adopts dose limits for the public equal to one-tenth of those allowed for workers: 0.5 rem for external exposure; and 1.5 rem for most organs for internal exposure.
late 1980s –1990	Department of Energy adopts dose limit for the public of 100 millirem (0.1 rem) per year; dose limit for workers remains 5 rem per year. A new model for calculation of internal doses to workers is adopted, the "*committed effective dose equivalent*." (See main article.)
1991	International Committee for Radiological Protection recommends worker dose limit be reduced to 2 rem per year. Recommendation is not adopted by DOE.

NOTE: For external radiation sources, roentgen and rem are considered to be equivalent.

Sources: 1931–34, 1940–41, and 1942: Barton Hacker, *The Dragon's Tail*, (Berkeley: University of California Press, 1987), Appendix A, pp. 163–64; **1954:** US Atomic Energy Commission, AEC Manual, TN-000-22, Chapter 0522, Vol. 0000, Part 0500, AEC-0522-01, BMBP, (US AEC, Feb. 26, 1954), 0522-01.h; and National Bureau of Standards (NBS) *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissile Concentrations in Air and Water*, Handbook 52, (Washington: US Dept. of Commerce, March 20, 1953); **1959:** NBS, *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure*, Handbook 69, (Washington: US Dept. of Commerce, June 5, 1959), pp.4-6; **late 1980s–1990:** US Dept. of Energy, Office of Environmental Safety and Health, *Order: DOE 5400.5*, (US DOE, February 8, 1990), II.1a; **1991:** International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Annals of the ICRP, Vol. 21, No. 1–3, (Oxford, New York: Pergamon Press, 1991), p. 72, parg. (S25).

IEER Releases New Report on "Clean-up" of Nuclear Weapons Complex

More than half a century of nuclear weapons production in the United States has created tens of millions of cubic meters of long-lived radioactive waste, decommissioning problems associated with thousands of contaminated facilities, and environmental problems involving contaminated land and water. The production of 70,000 nuclear warheads and bombs would have resulted in a problem of environmental remediation and waste management in any case. But the neglect and mismanagement of radioactive and toxic wastes have created problems that are far more costly than they might have been; some appear to be intractable with current technology.

IEER's newly released report, *Containing the Cold War Mess,* looks at the problem of environmental remediation and waste management of the nuclear weapons complex through case studies of three rather different problems, each important in its own way: a) transuranic waste management; b) high-level waste tank farms at Hanford; and c) radium- and thorium-contaminated waste at Fernald. It also outlines alternatives that could be considered in reforming the environmental management program of DOE. The main findings of this report and a summary of recommendations are given below.

Main Findings

1. Nuclear weapons production and associated activities have created tens of millions of cubic meters of dangerous wastes and roughly two billion cubic meters of contaminated soil and water.

2. Since 1989, DOE has made considerable progress in characterizing many of the crucial problems of environmental remediation and waste management in the nuclear weapons complex, but much remains to be done.

3. DOE is proceeding with the most expensive environmental program in history without national remediation standards to govern and guide the process.

4. Despite about $40 billion dollars in expenditures since 1989, DOE does not have a sound direction, plan, priorities, or implementation strategy for dealing with remediation and waste management problems. Institutional factors are the single most crucial element in DOE's failure to achieve a sound direction.

The principal institutional problems that we have identified are:

- an attachment to Cold War technologies related to weapons research, development, testing, and production
- a tendency toward "monumentalism"—that is, rushing into big projects without proper preparatory scientific and engineering work (this tendency perhaps deriving from a desire to also maximize the flow of funds into the weapons complex)
- a lack of sound internal scientific and technical peer review that actually matters in decision-making, or in approval and implementation of large projects, and a corresponding tendency to ignore inconvenient extra-departmental advice
- a tendency to approve large budget increases for contractors without thorough engineering-based reviews of the problems that led to the budget changes
- a failure to learn lessons from past mistakes
- an attachment to the Yucca Mountain and Waste Isolation Pilot Project (WIPP) repository programs out of institutional, legal, political, and financial inertia even though these are compromising a much larger effort to remediate the weapons complex, manage long-lived highly-radioactive wastes, and develop a scientifically sound long-term high-level waste management program
- a lack of independent regulation of DOE's nuclear activities.

5. The U.S. waste classification system is an unsound basis for implementing waste management or environmental remediation decisions. (See SDA Vol. 6 No. 1.)

6. DOE is not holding contractors sufficiently accountable for project mismanagement and poor technical decisions.

7. A number of problems cannot be satisfactorily solved with presently available technology. Sound research and development and careful project planning will be needed over a long period.

Main Recommendations

The most important single reform that is needed is institutional in nature. DOE can make internal reforms at once. It should:

- create a project review structure for large projects that is both technical and financial in scope
- create a standing advisory committee to review projects from early stages through implementation both as regards their technical aspects and the reasonableness of budgets from an engineering standpoint. The majority of members on this committee should be free of conflicts of interest in regard to contracting with DOE or its contractors.
- reinstate the practice of issuing annual Baseline Environmental Management Reports, and make them more complete by including all sites, whether

See **Report**, *page 16*

Milk, *from page 3*

country would result in fallout spreading over most of the country. In a 1948 memo, an Air Force meteorologist advised the committee assigned to finding a test site that "Because the United States is predominantly under the influence of westerly winds, it seems obvious that the eastern coast areas of the United States may provide a suitable site."[12] But the site was located in the west, where the proximity to the weapons laboratories would allow for acceleration of the weapons program.

Doses Avoidable

Iodine-131 is a relatively short-lived radionuclide with a half-life of 8 days. (See Centerfold for more information.) Therefore, radioactivity levels in contaminated milk would have decreased significantly several weeks after the time of detonation, making most of the iodine-131 doses to the public avoidable. Contaminated milk could have been dumped or diverted from the market and used for products such as dried milk, butter or cheese, which take longer to process and would allow time for the radioiodine to decay. But the government made no such provisions, though they were aware as early as 1953 of the "milk pathway," the primary route of exposure for iodine-131 in humans. Warnings about iodine-131 in milk were also issued at the 1955 United Nations Conference on Peaceful Uses of Atomic Energy, where researchers suggested that the then-allowable air concentration limits for iodine-131 were ten thousand times too high and should be lowered:

> This limit should be reduced by four orders of magnitude to assure radiation safety for grazing animals. Approximately the same reduction is required for the safety of humans eating large quantities of fresh garden produce and drinking milk from cows grazing on iodine 131-contaminated pasture.[13]

An Oxford University delegation to the conference stressed that "human beings whose diet consists largely of milk, notably infants . . . because of their youth may be considered super-susceptible to the effects of radiation."[14] The advice of the UN delegates, while ignored by the AEC, was heeded by British officials in 1957 when, after a reactor accident that resulted in a release of 16,000 to 27,000 curies of iodine-131, ordered that milk within a 200-square mile area around the plant be dumped as a health precaution.

But even in the early 1960s, when the milk pathway was widely understood, the US government refused to acknowledge the risk of iodine-131 contamination or take measures to reduce it. In 1962 officials in Utah and Minnesota diverted possibly contaminated milk from the market when iodine levels exceeded radiation guidelines set by the Federal Radiation Council (FRC). In response, the FRC, whose members included the chairman of the AEC and the Secretary of Defense, declared that they did "not recommend such actions" and that such "countermeasures may have a net adverse rather than favorable effect on the public well-being."[15] Further, the FRC made the remarkable determination that their own radiation guidelines should not be applied to fallout without further detailed studies because "any possible health risk which may be associated with exposures even many times above the guide levels would not result in a *detectable* increase in the incidence of disease"[16] (emphasis added). Since thyroid cancers can develop many years after radiation exposure and are therefore not immediately detectable, this reassurance was highly misleading.

While the public was not warned to refrain from milk consumption and was continually reassured that fallout posed no danger, the AEC was providing advance notice of tests, including "forecasts of contaminated areas based on meteorological data"[17] to the National Association of Photographic Manufacturers. This was done so that they could "anticipate local contamination and take preventive action"[18] to protect photographic film from being ruined by radiation exposure. The warning to the photographic industry began in 1951—the first year of testing in Nevada—as a result of the Eastman Kodak Company's threat to sue the AEC over damaged film from nuclear fallout. The warnings continued throughout the atmospheric testing program but were not extended to the public.

Other Doses from Fallout

The United Nations Scientific Committee on the Effects of Atomic Radiation estimates that globally, iodine-131 doses comprise only about 2% of the overall radiation dose from weapons testing (dose integration time to the year 2000).[19] Ninety-eight percent of the dose is from other radionuclides. These calculations do not take hot spots into account, which may increase the relative share of iodine-131 dose. In addition, in areas of high precipitation both in the US and in other countries, hot spots probably resulted in high concentrations of other radionuclides besides iodine-131. Further work is needed to clarify which populations were most affected by testing throughout the world. Soviet and Chinese testing could have affected populations in Alaska, for example, and there may be incidences of hot spots in the Pacific, including Hawaii, from French, British, and US Pacific area testing. There is also evidence from the NCI study that hot spots occurred in Canada and may have occurred in northern Mexico from Nevada tests.

A thorough assessment of the effects of all nuclear testing—not just US tests—is needed so that those at risk of high doses can receive proper screening. Soviet tests, for example,

See **Milk**, *page 12*

Milk, *from page 11*

had a larger total fission yield than US tests (110.9 megatons compared to 72.1 megatons), and the combined fission yield of Chinese, British and French tests was 34.2 megatons. IEER estimates that only a small fraction of the cesium-137 in the soil in the eastern United States is due to fallout from detonations at the Nevada Test Site. In light of the NCI findings, we make the following recommendations:

- An international study should be funded to carry out a global assessment of the effects of nuclear weapons testing and should follow a process that is open to the general public.
- France, Britain, China and the former Soviet Union should make public all their data on fallout.
- Further study should be conducted to assess the risk of cancer and other thyroid disorders from radiation doses.
- The US government should provide thyroid screening for those who were children at the time of atmospheric testing living in high fallout areas in the United States. The Agency for Toxic Substances and Disease Registry has suggested screening for those who received a cumulative dose of 10 rad or more while they were age 15 or younger.[20]
- The results of the NCI study should be made widely available to the public in a format that is accessible and understandable so that those who may be at risk can receive proper screening in a manner that reduces risk of disease.

This article is based on an article that appeared in the November-December issue of The Bulletin of the Atomic Scientists, *entitled "Worse Than We Knew." It is available on the web at* "www.bullatomsci.org," *and on IEER's webpage,* "http://www.ieer.org/latest/iodnart.html."

The full text of NCI's study can be found on the web at "http://www.rex.nci.nih.gov/massmedia/Fallout/contents.html."

1 Howard L Andrews, "Residual Radioactivity Associated With the Testing of Nuclear Devices Within the Continental Limits of the United States," September 13, 1953, pp. 7–8, supplement to the report of The Committee To Study the Nevada Proving Grounds.

2 A rad is a unit of absorbed dose of radiation, equivalent to the deposition of 100 ergs of energy per gram of tissue. According to NCI, two rad is about equal to the radiation dose from 5 mammograms. (See table in Centerfold.)

3 E.B. Lewis, "Aspects of Somatic Effects of Fallout Radiation," statement in *Fallout From Nuclear Weapons Tests, Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Congress of the United States, Eighty-Sixth Congress, First Session on Fallout from Nuclear Weapons Tests, May 5, 6, 7, and 8, 1959*, (Washington, US Government Printing Office, 1959), Vol. 2, p. 1553; and Merril Eisenbud and Thomas Gesell, *Environmental Radioactivity From Natural, Industrial, and Military Sources*, Fourth Edition, (San Diego: Academic Press, 1997), p. 312.

4 Elaine Ron, et. al, "Thyroid Cancer after Exposure to External Radiation: A Pooled Analysis of Seven Studies," *Radiation Research*, vol. 141, 1995, pp. 259.

5 Iodine-131 decays through beta radiation. Radiation risk for cancer from external gamma radiation is considered to be about the same as that from internal beta radiation. The theoretical reason for this equivalency is that damage to tissue from radiation exposure is not produced by the gamma photons that deliver the energy but by the electrons which are liberated as a result of the ionization caused by the photons. Therefore, in the case of internal iodine-131 doses compared to external X-ray doses, it does not matter if the photon originates externally or internally. "Once a photon liberates an electron, the subsequent events depend only on the properties of the electron and not on the gamma photon that liberated it." Jacob Shapiro, *Radiation Protection, A Guide for Scientists and Physicians*, Third Edition, (Cambridge: Harvard University Press, 1990), p. 22. Of course, in practice, some of the details of the ways in which electrons and photons of various energies transfer energy to living cells can create differences in biological effect.

6 National Cancer Institute Press Release, "Questions and Answers on the NCI Fallout Report," August 1, 1997, pp. 2–3.

7 ibid, p. 3.

8 Jan Beyea, "Fallout exposures from US weapon tests: health effects other than thyroid cancer," Testimony before the Senate Appropriations Committee on Labor, Health and Human Services and Education, October 1, 1997.

9 National Cancer Institute Press Release, July 25, 1997, p. 3.

10 "Executive Summary, National Cancer Institute Study Estimating Thyroid Doses of I-131 Received by Americans From Nevada Atmospheric Nuclear Bomb Tests," p. 4. (Released in National Cancer Institute Press Packet, August 1, 1997.)

11 NCI, Interim Final, Table Total/D, "Estimates of per capita average (geometric means: GM) individual thyroid doses, associated uncertainties (geometric standard deviations: GSD), and populations in each county of the contiguous U.S. resulting from all tests," pp. 1–51. (Released in NCI Press Packet, August 1, 1997.)

12 Colonel B.G. Holzman, USAF, Staff Meteorologist, memorandum to Admiral Parsons, "Subject: Site for Atomic Bomb Experiments," April 21, 1948. Annex A in US Commanding Lieutenant General J.E. Hull's memorandum to the US Army Chief of Staff, "Subject: Location of Proving Ground for Atomic Weapons," p. 12. (The area suggested was coastal North Carolina. It is important to note that testing in this region would also have caused significant problems, but the suggestion of the site indicates an awareness that testing in the west would cause widespread fallout.)

13 R.C. Thompson, H.M. Parker, and H.A. Kornberg, (General Electric Company), "Validity of Maximum Permissible Standards for Internal Exposure," in *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy*, Vol. 13: Legal, Administrative, Health and Safety Aspects of Large-Scale Use of Nuclear Energy, (New York: United Nations, 1956), 1956, Vol. 13, p. 203.

14 A.C. Chamberlain, J.F. Loutit, R.P. Martin, and R. Scott Russell, (Atomic Energy Research Establishment, Harwell: Medical Research Council and Department of Agriculture, University of Oxford), "The Behaviour of I^{131}, Sr^{89} and Sr^{90} in Certain Agricultural Food Chains," in United Nations, 1956, Vol. 13, p. 360.

15 Federal Radiation Council Press Release, "Federal Radiation Council Position on Current Fallout Levels," September 17, 1962, pp. 1, 3.

16 ibid, p. 2.

17 US Atomic Energy Commission, *Twenty-first Semiannual Report of the Atomic Energy Commission*, (Washington: US Government Printing Office), January, 1957, p. 211.

18 US Atomic Energy Commission, "Report by the Director of Military Application, Summary of Relations between the AEC and the Photographic Industry Regarding Radioactive Contamination from Atomic Weapon Tests, from January through December 1951," January 17, 1952, p. 8.

19 IEER and International Physicians for the Prevention of Nuclear War, *Radioactive Heaven and Earth*, (New York: Apex Press, 1991), p. 37. Figures are based on whole body committed effective dose equivalent.

20 Robert F. Spengler, ed., "Hanford Medical Monitoring Program: Background Consideration Document and ATSDR Decision," publication number PB97-193072, (Atlanta: US Dept. of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry), July 1997, p. 37.

Errata

In **SDA Vol. 6 No. 1** (on radioactive waste management), the entry in the "Radioactivity" column of the "Depleted Uranium" row on the table appearing on pages 10-11 should read "0.2." In that same table, the entry in the "Regulatory Status" column of the "Uranium Mill Tailings" row should read "UMTRA and Uranium Mill Tailings Radiation Control Act."

In **SDA Vol. 5 No. 4** (on MOX), lines 9 and 10 of the middle column of page 2 should read, ". . . between 8 to 10 million gallons of liquid waste . . ." Our thanks to James C. Warf of Los Angeles, CA for pointing out this error. *You win $25!* **This is a standing offer to SDA readers!** IEER will award $25 to the first person sending in a correction of arithmetic errors appearing in SDA, as well as our gratitude for keeping us on our toes!

"Dear Arjun"

Dear Arjun:

What's the difference between a rad, a rem, and a roentgen?

—Mixed-up in Margaritaville

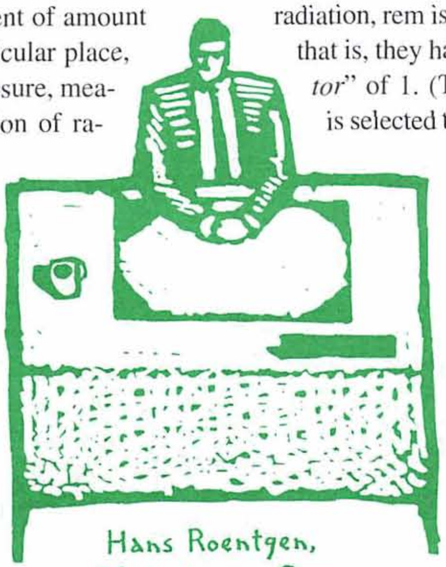
Dear Mixed-Up:

In the 1960s in the United States, individuals who were deeply involved with the so-called counter-culture were sometimes referred to as *radical,* or *"rad"* for short. There were also individuals who didn't want to rock the boat too much, but still liked to be associated with the counter-culture, who were called *"rem,"* short for "regularly enlightened mainstreamers." Everyone else was considered by the rad and rem to be part of the "rank and file," which was later shortened to "*roentgen* file," after a particularly mainstream leader of the time, Hans Roentgen.

But unbeknownst to these radicals, *rad, rem* and *roentgen* had already been used as units to express doses from radiation exposure. Radiation dose is calculated in a number of ways, including measurement of amount of radiation at a particular place, measurement of exposure, measurement of absorption of radioactivity, and of relative effect of that absorption on different organs or types of tissue. Dose calculations take into account the type of radiation involved (alpha, beta, gamma, or neutrons). Radiation doses can also be expressed in standard international units, sieverts or grays (one sievert equals 100 rem, one gray equals 100 rad).

A ***rad,*** or "radiation absorbed dose," is a unit of *absorbed* dose equivalent to the deposition of 100 ergs of energy per gram of tissue. (See Centerfold for more on rad and ergs.) Since a rad measures deposition of energy *per gram of tissue,* a 2-rad dose to a certain organ, like the thyroid (which weighs roughly 20 grams), reflects a very different total deposition of energy than does a 2-rad dose to the entire body (typical weights range from 40,000 to 100,000 grams).

A ***rem***, or "radiation equivalent man," is a unit of absorbed dose that takes into account the relative biological damage caused by the various ways that ionizing radiation deposits its energy in tissue (known as the Relative Biological Effectiveness, or RBE). In general the larger the amount of energy absorbed, the larger the biological damage. For beta and gamma radiation, rem is equivalent to rad; that is, they have a "*quality factor*" of 1. (The quality factor is selected to approximate the RBE as it relates to overall risk, and is used in regulatory practice to convert radiation dose measured by energy deposited to radiation dose measured in terms of biological damage.) For alpha radiation, which involves heavy particles, much more damage is done per unit of energy deposited, increasing the ratio between damage to tissue and energy deposited. The currently accepted quality factor for alpha radiation is 20, but may change as more is learned about damage due to ionizing radiation. Neutron radiation has a varying quality factor between 5 and 20, depending on neutron energy. Rem is the unit used to express regulatory limits for radiation exposures.

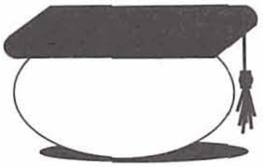


Hans Roentgen, Mainstream Guy

A ***roentgen*** (abbreviated "R" and pronounced "rent-gen") measures gamma and beta radiation dose based on the amount of ionization in the air. It is the common form of calibration of radiation measuring instruments because the beta and gamma radiation ionize air inside the instrument, creating electrically charged particles which can be measured by creating an electric current in the instrument. A roentgen is a unit of radiation dose that causes an ionization charge equal to 2.58×10^{-4} (0.000258) coulombs per kilogram of air.* Because it measures ionization in air and not in tissue, there is no exact, fixed correspondence between roentgen and rad, but an approximate equivalence is that one roentgen equals 0.93 rad for non-bony biological tissue. Since the uncertainties in dose calculation are typically far larger than 7 percent, one roentgen is often considered about equal to one rad, for convenience.

* A coulomb is a unit of electrical charge. The charge of an electron is 1.6 x 10-19 coulombs.

It Pays to Increase Your Jargon Power



by
Dr. Egghead

1. body burden

a. The strain felt by writers when they have written introductory and closing paragraphs, but still have to write the rest of an essay.

b. What diet pill companies want people to believe they have.

c. What you feel when you get the bill from the auto body shop.

d. The amount of a radioactive material deposited in the body at a given point in time (in units of mass or radioactivity).

2. whole body counter

a. A specially-designed surface in diners where customers can eat while lying down.

b. Someone not content to do just a headcount.

c. A hospital employee whose job it is to count how many whole bodies come out of the operating room.

d. A chamber equipped with instruments to measure gamma radiation being emitted from anywhere in the body.

3. ALARA

a. The younger, lesser-known sister of Evita.

b. Name of a failed apple harvesting company.

c. Acting in the manner of Ra.

d. Acronym for "As Low As Reasonable Achievable." Usually "ALARA Principle," which dictates that radioactivity released to the environment and radiation doses be not merely in compliance with regulations, but further reduced below the allowable limits, given the technologies and financial resources available.

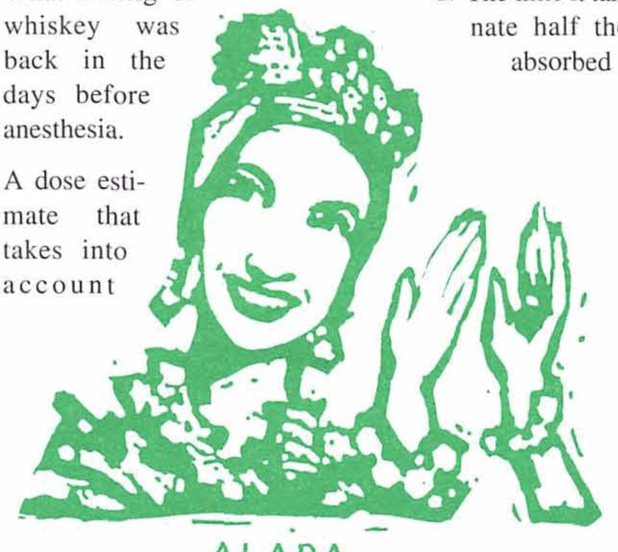
4. effective dose equivalent

a. The number of naps taken during the day by a nuclear plant operator working night shifts to effectively enable him or her to stay awake on the job.

b. The dose delivered by a placebo that works as intended.

c. What a swig of whiskey was back in the days before anesthesia.

d. A dose estimate that takes into account the combined effects of internal and external radiation, the selective uptake and distribution of radionuclides, and their varying effects on different organs. The effective dose equivalent is calculated by multiplying the dose to an individual organ, such as the lung, by a weighting factor which addresses the likelihood of a cancer mortality from radiation exposure to that particular organ.



ALARA

5. biological half-life

a. The time it takes for half a room of biology students to fall asleep.

b. The portion of a soccer player's life spent playing halfback.

c. The time it takes for half a log to decay.

d. The time it takes the body to eliminate half the mass of a given absorbed radionuclide.

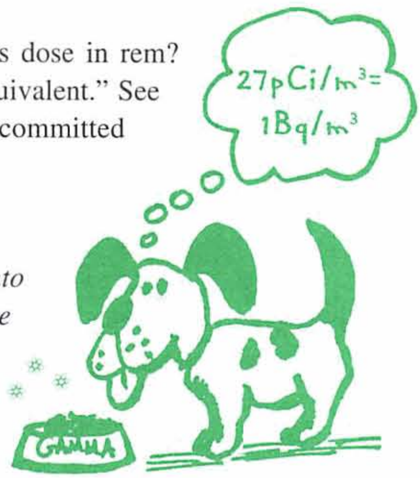
ATOMIC PUZZLER

Gamma dosing on the job . . .

Back in the late 1980s, when Dr. Egghead's trusty sleuthing dog Gamma was just a pup, the Department of Energy began using a method of worker dose calculation referred to as the "committed effective dose equivalent." Even then, Gamma was interested in such things and would entertain himself by calculating effective dose equivalents for workers. (Always the workhound, that Gamma.) He recently fetched his old records and was hoping for some help in completing some unfinished dose estimates. Note that Gamma was at that time learning the Standard International units of becquerels and sieverts, and so was converting from rems and picocuries to sieverts and becquerels. His notes are reprinted below, paw prints, conversions, and all, except for the final dose calculation:

- A worker is exposed to an annual average concentration of uranium-238 of 27 picocuries per cubic meter of air—or 1 becquerel per cubic meter of air.
- The worker breathes 9.6 m^3 (cubic meters) of air on each working shift (8 hours) and works 200 shifts per year.
- The dose conversion factor for the lung is 9.84×10^{-4} rem per picocurie—or 2.66×10^{-4} sieverts per becquerel. (Gamma converted rems to sieverts by dividing by 100. He then multiplied the result by 27 because there are 27 picocuries per becquerel. Try it!)
- The weighting factor for the lung is 0.12.
- Assuming no other organ is affected, what is this worker's dose in rem? (Note: This dose is called the "committed effective dose equivalent." See main article.) Round to 2 decimal points. What is the committed effective dose equivalent in sieverts?

Hint: The dose conversion factor is used to convert radiation intake into dose. The weighting factor converts the lung dose into the effective dose equivalent.



Gamma the puppy calculating worker doses.

Send us your answers via fax (301-270-3029), e-mail (ieer@ieer.org), or regular mail (IEER 6935 Laurel Ave., Suite 204, Takoma Park, MD 20912), postmarked by **Dec. 19, 1997.** IEER will award 25 prizes of $10 each to people who send in a solution to the puzzle (by the deadline), right or wrong. There is one $25 prize for a correct entry, to be drawn at random if more than one correct answer is submitted.

Report, *from page 10*
closed or operational.

Such internal reforms are unlikely to solve the entrenched problems that we have discussed above. We recommend that President Clinton appoint a commission on Institutional Reform of Environmental Remediation and Waste Management. The commission should hold hearings around the country and make definitive recommendations within a six- to twelve-month period.

Whatever the reform chosen, general technical principles will need to be adopted and reforms implemented to restructure the environmental management program. Specifically, the government should:

1. *Create a new, rational, environmentally-protective system of radioactive waste classification* according to longevity and specific activity, so that comparable hazards are managed comparably.

2. *Coordinate waste management and environmental remediation* and make reduction of short-term risks compatible with minimizing long-term risks.

3. *Approach remediation with independently enforced, national, health-based clean-up and waste management standards*, including specific provisions to protect groundwater resources and mandatory guidelines to keep doses as low as reasonably achievable (ALARA) both for workers and for off-site populations. The ALARA guideline for releasing sites for unrestricted use should be to remediate to background levels, if reasonable, or else to keep doses to under 2 millirem per year (which is the British ALARA guideline).

4. *Suspend the politically expedient Yucca Mountain and WIPP repository programs and put in place a scientifically sound program of long-term high-level waste management*, including repository research, subseabed disposal research, and research on materials to contain radioactivity that are analogous to natural materials that can last for millions of years.

5. *Provide funds and technical support to communities that have residual contamination* so that they can monitor the environment and keep themselves informed. Such funds are needed to protect communities against future known risks and also against risks due to inadequate characterization or present incomplete understanding of risks. The size of the fund should depend on the size and character of the residual radioactive and non-radioactive hazardous contamination of land, remaining structures, surface waters, river beds, and groundwater, as well as the total amount of radioactivity and non-radioactive hazardous material left in disposal areas on site.

6. *Manage non-radioactive toxic components of wastes in ways that do not seriously compromise management of radioactive components.*

7. *Stabilize waste so as to greatly reduce or eliminate the most serious environmental and health threats* and store it on-site while sound long-term management strategies are developed.

8. *Provide the states, Indian tribes, and the public (with special emphasis on the affected communities and workers) with timely information* so that they can participate effectively in decision-making.

To order a copy of the full 300-page report, see the publication information box on p. 7.

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