
Health Effects

Factories for designing and producing nuclear weapons release radionuclides and toxic chemicals to both air and water. In this report we are particularly concerned about releases to surface and subsurface waters. However, it's important to remember that even when these toxic materials are released to the air they eventually re-deposit on the ground, where rain, wind and processes of erosion carry them to nearby sources of water. These hazardous materials can cause cancer, genetic effects and disease. Radionuclides such as plutonium, americium, cesium, strontium, uranium, technetium and iodine are known carcinogens. DOE facilities also release a variety of metals and volatile organics (VOC) that are harmful. What kinds of emissions are released by weapons production facilities? What health and genetic effects are caused?

What Is Radiation?

To fully understand the dangers associated with materials released at nuclear weapons factories, it is important to know some basics about radiation. While most atoms are stable, others called radionuclides have structures that are out of balance. These radionuclides continually undergo a process of change, called decay, until they are in a more stable form. As they do so, they release energy or atomic particles--radiation.

Some unstable atoms, like thorium, actinium and uranium-235, can occur naturally, though not in the same concentrations found at DOE sites. But many others, like plutonium, are only produced artificially in nuclear reactors, such as those that used to operate at the Hanford and Savannah River Sites. The numerous substances formed and released in the fission process are generally unstable and radioactive.

When radiation from changing radionuclides strikes nearby atoms, it affects them. It does so through a process called ionization. How does this process work?

When radiation strikes an atom, it disrupts the atom's delicate balance. It alters the atom's electrical neutrality, giving it a positive or negative charge. These charged atoms are called ions. Ionization of atoms and molecules inside a living cell causes damage that may eventually become a health problem.

Types of Radiation

Three important types of emissions (radiation) are responsible for ionizing radiation: alpha and beta particles and gamma rays. Alpha particles are positively charged. They are high-energy particles. They travel at relatively slow speeds and have a short range (1 to 8 centimeters in air), but are relatively massive. The human body's outer layer of dead skin is sufficient protection from alpha particles, which cannot normally pass through paper. However, if an alpha particle is inhaled and reaches the lungs, they have sufficient ionizing energy to break through cell walls and do great damage over the short distance they penetrate.

Plutonium is an example of a particularly dangerous form of alpha radiation that was produced in large quantities in the nuclear weapons complex and is now threatening water supplies. At Rocky Flats, for example, plutonium-contaminated effluent traveled off-site via Walnut Creek and contaminated a near-by water supply reservoir, the Great Western reservoir. (Due to this hazard, the reservoir, previously used by the city of Broomfield, is no longer a source for municipal water.)

Beta particles are electrons. They are negative charged, high-energy emissions, traveling close to the speed of light. They travel longer distances in air than alpha particles and cause damage to the surface layers of an organism. But, in general, beta particles are less energetic than alpha particles. Thus they cause less damage than alpha particles when emitted internally, after being ingested with food or inhaled with air. However, they are still dangerous, health-threatening particles.

An example of a beta emitting radionuclide found widely in the nuclear weapons complex is strontium-90. Released in large quantities from the burial grounds at Oak Ridge, strontium-90 has migrated into the ground water. Strontium-90 is of particular concern because inside the body it behaves somewhat like calcium. It is a bone seeker and can be incorporated into human bones for a lifetime. This radionuclide has a long half-life (30 years), is water-soluble and is mobilized by the chemical constituents in the limestone and dolomite rocks found in the vicinity of Oak Ridge.

Gamma rays more closely resemble X-rays and other electromagnetic waves such as light or radio waves, but are much more energetic. While light waves or radio waves do not cause ionization, gamma rays are extremely penetrating, easily passing through lead and several feet of concrete. They can pass through a human body, seriously damaging different organs along the way. Gamma emitting radionuclides therefore do not have to be ingested or inhaled in order to do harm.

Cesium-137 is an example of a radionuclide emitted at nuclear weapons factories that is threatening groundwater. At Hanford, cesium-contaminated effluents from the high-level waste tanks have reached the groundwater and are traveling towards the Columbia River.

Radiation Causes Cancer and Genetic Effects

As we have seen above, ionizing radiation emitted from a radionuclide rips through the living tissue it encounters, disrupting the electrical balance of atoms along the way, and causing disorganization of the cells and tissues. Electrons are knocked out of their shells, leaving incomplete atoms, ions, behind them. Cancer and genetic effects are caused by this rearranging

of the information contained in the cell nucleus, which consists of genes (strings of DNA molecules and proteins) in 46 chromosomes.

The result of cell exposure to ionizing radiation can be either cell death, or alteration. The change can be temporary or permanent. The cell may die and not replicate itself. Or, a free electron can replace the missing electron, repairing the cell. If the cell is altered, it may reproduce, in time creating millions of altered cells. If the radiation damage occurs in germ cells, the sperm or ovum, it can cause defective offspring, who in turn will pass these defects on to future generations.

Whether radiation causes cancer, disease or genetic damage is, therefore, a matter of probability. A radioactive emission may or may not hit the DNA molecules. The affected molecules may or may not be the key to cell multiplication. Age is an important factor. Because radiation has the highest impact on multiplying cells, young children, fetuses and embryos are the most readily affected.

Cancers also appear to occur with a specific latency period, depending on how rapidly cells multiply in a specific organ. But none of this occurs with certainty; it is all a matter of probability. As with smoking, some persons will develop cancer, some not. But contrasting the smoking with non-smoking population, many more lung cancers will occur to smokers. Similarly, individuals exposed to radiation may or may not develop cancers, but a population exposed to radiation will see a general rise in the number of genetic effects, cancers and other diseases.

At low levels, radiation causes lung, bone and other kinds of cancer, leukemia, premature aging, birth defects, sterility, blood composition changes and cataracts of the eye.

One of the most worrisome impacts of radiation on biological systems is genetic mutation. These effects may be dormant for years or decades and the complete effect may not be known for generations. Radiation-induced changes in gene structure can result in mutations to newborns. Chromosomal aberrations may result in a range of genetic effects: spontaneous abortions, underweight births, and severe abnormalities. Genetic effects may be dominant or recessive, that is, may or may not be evident in the first generation after exposure, and may extend out to several generations. The anticipated number of genetic effects is roughly comparable to the number of cancers caused by radiation exposure.

Radioactive materials external to the body can cause a direct radiation dose due to penetrating gamma rays. Radionuclides also can be taken into the body with air, food, water or through an open wound. Depending on the radionuclide and its chemical form, it may remain in the body for minutes or a lifetime; it may travel to bone, muscle or a specific organ. Health effects would then occur to particular organs.

The likelihood of developing cancer, disease or genetic effects is proportional to the amount or dose received by the individual, the rate of exposure and the type of radiation.

As more information on the effects of radiation has become known, estimates of the risk involved have generally increased.

Models of Radiations Impact

Various mathematical models are used to predict the number of excess cancers at low doses where direct measurement is more difficult. The international scientific community and the National Academy of Sciences overwhelmingly endorse the linear no-threshold model. It

assumes the number of cancers and genetic effects is directly proportional to the total population dose. The more radiation received, the greater the number of health effects.

The Department of Energy relies heavily on the fact that radioactivity is greatly diluted by air and water in leaving weapons production plant sites. The Department relies on the principle that "dilution is the solution." But there exists no comfort in dilution since there is no radiation threshold below which health effects do not occur. Since a single alpha, beta or gamma ray can initiate the process of uncontrolled cell multiplication, there can be no lower limit. It is a matter of probability whether a cell is attacked and cancer ensues.

Dilution merely spreads the dose over a larger number of people. As John Gofman, medical doctor, discoverer of uranium-233 and author of *Radiation and Human Health*¹ has pointed out, "even if the risk is small to an individual, it will lead to a sizable number of deaths in a population if many individuals are put at that risk. The aggregate effect of many, widespread, small risks--each considered trivial on a personal basis- can be huge."

The "dilution is the solution" approach is embraced by the Department of Energy at its many nuclear weapons facilities. For example, at the Oak Ridge Reservation, a large amount of radioactivity in the form of uranium, strontium, technetium and cesium is released from the three facilities located on the site into nearby ponds or streams. The radiation levels in the on-site streams are high, but since these streams are small compared to the Clinch and Tennessee Rivers, the dilution is great. The dose to any individual drinking downstream water or eating downstream fish is small, but the number of individuals is very large, in the millions. The total population dose through all pathways to humans has never been calculated by the Department of Energy, and no studies of health effects to downstream communities have ever been carried out.

In instances where studies have been conducted, such as studies of Utah residents and Marshall Islanders downwind of nuclear test explosions, the studies have shown increased cancer rates.

Several important research projects predict a greater number of health effects for a given radiation dose than the US Nuclear Regulatory Commission recognizes. A study by Drs Thomas Mancuso, Alice Stewart and George Kneale² of 29,000 government radiation workers at Hanford, Washington over a 33-year period resulted in a projection of 3,800 cancers per million person-rem, or about 4 times estimates to-date of Japanese bomb survivors. The average yearly dose to Hanford workers was twice background, about 250 millirems per year. The scientist's work was terminated by the US government when their report showing excess cancer deaths among Hanford nuclear workers.³

A study by Dr. Alice Stewart, Queen Elizabeth Medical Centre in Birmingham, England, of leukemias among babies born to mothers who received X-rays during pregnancy showed an increased leukemia rate for doses as low as 1 rem.⁴

The latest report by the Radiation Effects Research Foundation, studying Japanese bomb survivors,⁵ shows a statistically significant increase in excess cancers down to dose levels as small as 5 rems. The Foundation is a joint U.S.-Japan committee that has been following atomic bomb victims.

The body is not able to distinguish between radioactive and nonradioactive chemicals, and will as readily incorporate one as the other. For example, strontium and uranium can lodge in bone, causing bone cancer or leukemia. Strontium-90 remains in bone for a lifetime. Radionuclides lodged in the lung can cause respiratory disease or lung cancer. Inhalation of uranium, plutonium, cesium, and other fission products also may cause increased lung cancers. When ingested, cesium-137 moves to muscle and its daughter product, barium-137m emits a

strong gamma ray. Cesium-137 provides a potent external whole body radiation dose as well. Cesium, which replaces potassium in muscle, would probably be eliminated from the body within two years. Radioactive iodine enters the thyroid, causing thyroid cancer or hyperthyroidism among children. Technetium-99 is not easily digested, and provides an internal dose to the gastro-intestinal tract. Radionuclides remain in the body until eliminated in urine or feces, or until they decay into other chemical forms.

It is extremely difficult to calculate the full effect on humans of radionuclides released from weapons production sites. Calculations must take into account *all* of the possible pathways to humans. Calculating the effects of cesium deposited on the ground, for example, involves the ratio of cesium in the soil to the amount of cesium taken in by plants, for each plant eaten by animals and humans. Consequently, determining the amount of cesium that finds its way into meat and milk requires figuring out how much of the cesium in plants is subsequently passed on to animal flesh and cows' milk. Calculations then must determine the ratio of cesium absorbed from the human gastrointestinal tract into the blood, for an average person on an average diet, and the average time the radionuclide will remain inside a specific organ.

Radiation can also have a promotional or interactive effect. For example, radiation seems to interact with smoking to increase the cancer rate and to shorten the latency period, the interval between which a cancer is initiated and has progressed to the point of being clinically detected. For a given amount of radioactivity inhaled, smokers will experience a significantly higher lung cancer rate, by approximately a factor of 60.

Health impact calculations regarding the nuclear weapons complex also should take into account the effects of the nuclides mixing with or being in the presence of toxic chemicals, such as volatile organic compounds, solvents, chelating agents and heavy metals. One impact of this synergistic effect is how fast radionuclides migrate and therefore get access to human populations. At the Savannah River Site, initially, scientists estimated that it would take hundreds of thousands of years for the plutonium in burial grounds to migrate to the groundwater. Later it was discovered that plutonium can migrate much faster in the presence of solvents, such as tributyl phosphate. Instead of the projected *thousands* of years, it took only 20 years for the plutonium to migrate into the groundwater.⁶

A second aspect of the synergistic effect of radionuclides and toxic chemicals being in the presence of one another is what impact this has on health issues such as rate of uptake in the body, which organs are most impacted, type of damage to cells, etc. At this time, these relationships are very poorly understood.

Large amounts of these non-radioactive but highly toxic substances have been released at the nuclear weapons factories and continue to impact on groundwater and aquifers. Two examples are the Idaho National Laboratory, where trichloroethene (TCE) and other volatile organic compounds have reached the Snake River Aquifer, and the Oak Ridge Reservation, where over 700,000 pounds of mercury was released to the soil and local streams. Studies need to be done to calculate the health impacts of these releases on nearby communities.

Toxic Chemicals

All DOE facilities release toxic chemicals, such as metals and volatile organics, to ground and surface waters. These chemicals are associated with a range of adverse human health effects, such as cancer, genetic effects and nervous system effects. These chemicals can travel

long distances and linger for generations in people and the environment. The populations at risk, especially to mercury and many of the volatile organics, such as TCE, are children and the developing fetus. A list of the metals and volatile organics released by DOE facilities appears in Table 1.

Volatile organics include such chemicals as benzene, toluene, acetone, methyl ethyl ketone, methyl alcohol, perchloroethene, tetrachloroethene, 1,1,1-trichloroethane, chlorofluorocarbons and many others, as seen in Table 1. Toxic heavy metals include lead, mercury, cadmium and chromium.

Categories listed in Table 1 include EPA TSCA Inventory, ACGIH TLV, MCL or TT, and Health Effects. The Environmental Protection Agency (EPA) produced a chemical inventory referred to as the EPA TSCA Status Line. The list is in accordance with the provisions of the Toxic Substances Control Act (TSCA). If those materials are listed in the EPA TSCA Inventory, they were commonly produced or imported into the United States.

The American Conference of Governmental Industrial Hygienists Threshold Limit Values is commonly referred to as the ACGIH TLV. Information pertinent to human health effects of this category is for which workers can be exposed with no ill effects in an 8-hour day, 40-hour workweek. The notation “skin” indicates that the material penetrates intact skin, and skin contact should be avoided even though the TLV concentration is not exceeded.

Some of the reported health effects are the result of experiments on a controlled exposure of laboratory animals to a controlled substance. Known effects on human and questionable effects as a result of exposure to hazardous chemicals are listed. The MCL (Maximum Contaminant Level) is the highest level a contaminant is allowed in drinking water. The TT (Treatment Technique) is a required process intended to reduce the level of a contaminant in drinking water.

As is clear, the full human health impact of metals and volatile organics is known only for a few toxic chemicals, such as arsenic and dioxin. The EPA has not been able to keep up with the variety and complexity of these chemicals. Approximately 11,000 different chlorinated chemical products are produced each year. Virtually all are toxic and make their way into the environment where they are not easily decomposed. As a result, “Every species on earth – including humans – is now exposed to organochlorines that can reduce sperm counts, disrupt female reproductive cycles, cause endometriosis, induce spontaneous abortion, alter sexual behavior, cause birth defects, impair the development and function of the brain, reduce cognitive ability, interfere with the controlled development and growth of body tissues, cause cancer and compromise immunity.”⁷

The lack of information about these materials is often taken as evidence of safety. Essentially toxic chemicals are put out into the environment, and humans become the guinea pigs. Risk assessments are impossible to perform without the basic data.

¹ Goffman, J, *Radiation and Human Health*, Sierra Club Books, San Francisco, 1980

² Kneale, G and A Stewart, “Reanalysis of Hanford Data: 1944-1986 deaths,” in *American Journal of Industrial Medicine*, vol. 23, pp. 371-389, 1993.

³ Bertell, R, *No Immediate Danger : Prognosis for a Radioactive Earth*, 1985 :92

⁴ Stewart, A,

⁵ Pierce, D and Preston, DL. « Radiation-Related Cancer Risks at Low Doses among Atomic Bomb Survivors, *Radiat Res* 154, 178-186, 2000.

⁶ Makhijani et al, *Nuclear Wastelands*, 1999 :253

⁷ Thornton, J, *Pandora's Poison: Chlorine, Health and a New Environmental Strategy*, MIT Press, Cambridge, MA 2000.

Primary References

- "Standards for Protection Against Radiation, Title 10; 10 CFR Parts 19 et al," *Federal Register*, Nuclear Regulatory Commission, January 9, 1986 (51 FR 1092).
- "Radiation Standards and Committed Dose Equivalent Tables for U.S. Department of Energy Population Dose Calculations," Memo to Department of Energy Facilities from William Vaughan, Department of Energy, Washington, DC, August 5, 1985.
- *No Immediate Danger*, Rosalie Bertell, The Book Publishing Company, Summertown, TN, 1985.
- *Radiation and Human Health*, John W Gofman, Sierra Club Books, San Francisco, 1981.
- "Reassessment of Atomic Bomb Radiation Dosimetry," D.L. Preston and D.A. Pierce, Radiation Effects Research Foundation, Technical Report 9-87, Hiroshima, 1987.
- "Interim Guidance on the Implications of Recent Revisions of Risk Estimates and the ICRP 1987 COMO Statement," National Radiological Protection Board, NRPB-GS9, Chilton, Didcot, Great Britain, November 1987.
- "Job Related Mortality Risks of Hanford Workers and their Relation to Cancer Effects of Measured Doses of External Radiation," G.W. Kneale, T. Mancuso, and A.M. Stewart, in *Biological Effects of Low-Level Radiation*, IAEA, Vienna 1983, pp. 363-372. "Radiation Exposures of Hanford Workers Dying from Cancer and Other Causes," T. Mancuso, A. Stewart, and G. Kneale, *Health Physics* 33: 369-85, 1977.
- Thornton, J, *Pandora's Poison: Chlorine, Health and a New Environmental Strategy*, MIT Press, Cambridge, MA 2000.
- US EPA. "Preparing Your Drinking Water Consumer Confidence Report", EPA 816-R-01-003: 6.