Bioassay Monitoring at Los Alamos National Laboratory

A GUIDE
for workers
and their families

Introduction

This booklet was developed by Los Alamos National Laboratory's Internal Dosimetry team, the team that monitors workers for intakes of radionuclides. We decide which workers need to be placed on bioassay monitoring, coordinate with the Bioassay Office to be sure bioassay kits are delivered to workers on time, and interpret the analysis results of the workers' urine samples to determine if there has been a radionuclide intake.

The purpose of this booklet is to help workers and their families understand how we monitor for a radionuclide intake and what to expect if we find one. The information given here explains the basics of radiation safety, the health effects of radiation, and the process of monitoring for and reporting radionuclide intakes.

The Bioassay Office, which distributes and collects kits, can be reached at 667-6275.

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About the cover

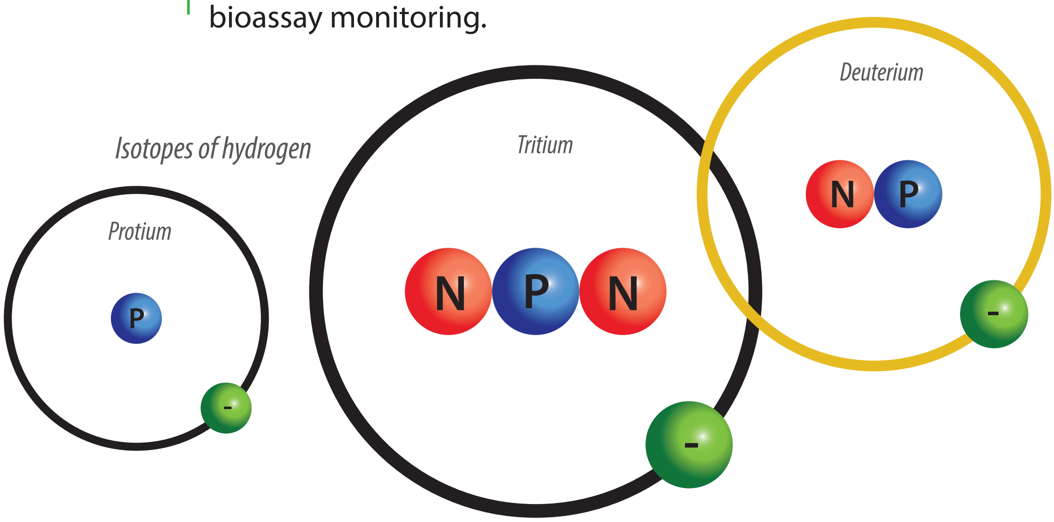
For bioassay monitoring, radiological workers at Los Alamos National Laboratory use kits with sampling bottles such as those shown on the cover.

Monitoring Radiological Workers at Los Alamos

Radiation exposures can be caused by both natural and manmade sources. The vast majority of exposures from manmade sources are intentional and come from medical imaging procedures and cancer therapy. Each year, the average American receives about 300 millirems (mrem) from medical procedures, not including cancer therapy (for which the doses are tens of thousands of times larger), and another 310 mrem from natural background radiation. In addition, some people can be exposed on the job if they work with radiation sources, either natural or manmade.

Some jobs at Los Alamos National Laboratory (LANL) may put workers in proximity to radioactive materials or radiation-producing machines. For those jobs, we adhere to the principle of ALARA: keeping doses "As Low As Reasonably Achievable." This means that we do everything in our power to protect workers while still allowing them to do their jobs.

Before any kind of radiation job starts, it is evaluated by a radiation safety expert, who determines what is needed to minimize exposure and keep workers safe. Some safety measures include providing shields, respirators, and protective clothing, as well as limiting the time workers may spend near radioactive material. We also monitor Laboratory workplaces (using air sampling, alarms, etc.) and the workers themselves to detect any evidence of contamination. Workers wear dosimeters to detect radiation doses from external sources, and they participate in bioassay monitoring to detect internal radiation doses. This booklet covers bioassay monitoring.



Bioassay Monitoring

We perform routine bioassay to monitor workers for internal radiation doses, which occur when radionuclides—radioactive materials—enter a person's body. Radionuclides can gain entry through breathing, swallowing, or skin contact. They can also enter through a wound. We call such events radionuclide intakes, or just intakes. Some jobs cannot be performed without some risk of intakes, but for all jobs at LANL, the work is planned to prevent intakes from happening.

Because many of the radionuclides we work with at LANL do not exist in nature, intakes of them can happen only at work. Some of the work-related radionuclides found at LANL, especially radionuclides such as iodine and cesium, can be detected inside the body (in vivo) using whole-body radiation counters. Others, such as uranium, plutonium, americium, and tritium, are most easily detected after they leave the body, in urine or fecal samples (in vitro). This booklet deals with in vitro bioassay monitoring. Individuals who are subject to in vitro bioassay monitoring will not necessarily experience whole-body radiation counters, but it is possible.

A worker participates in bioassay monitoring if his or her job carries the risk of radionuclide intakes. That risk is determined by the answers to an online questionnaire that is filled out by the worker or the worker's manager when the worker is hired and whenever the worker's job changes. In addition to arranging for routine monitoring, line managers and/or radiation protection managers may request that a worker be tested for a possible intake after a workplace incident.

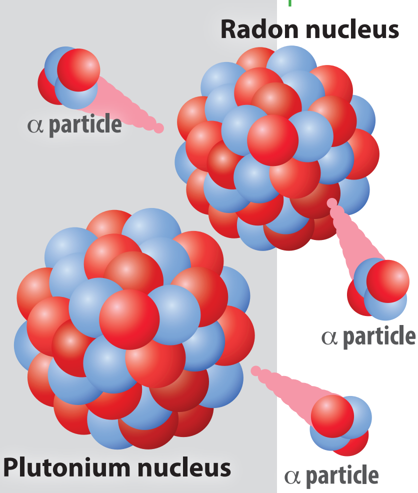
To check for intakes of radionuclides, the Laboratory collects urine samples, which are then processed by LANL chemists.

What kinds of workplace incidents could cause internal radiation doses?

Some workplace incidents can result in intakes or can indicate that an intake has already happened. Some of these incidents, such as fires, are dramatic but thankfully very rare. Usually, incidents that cause us to check for internal doses involve things like the failure of a fume hood or the discovery of small amounts of radioactive material on a worker's skin. Our experience has been that bioassay monitoring performed after an incident frequently confirms that little or no radiation exposure has happened.

What is the difference between an intake and a dose?

As the word suggests, an intake is the introduction of radionuclides into the body, usually by inhalation or ingestion. Dose is the amount of radiation released by radionuclides and absorbed by the body. Radiation doses caused by radionuclides inside the body are called <u>internal</u> radiation doses to distinguish them from <u>external</u> radiation doses, which are caused by sources outside the body (for example, an x-ray machine).



Whether the alpha (α) particles are emitted by plutonium or by naturally occurring elements, such as radon, alpha radiation is the same.

Is the radiation from manmade sources more dangerous than radiation from naturally occurring sources?

While some of the radionuclides encountered at work might not exist in nature, the radiation that comes from them is the same as the radiation that comes from naturally occurring radionuclides. For example, plutonium is a manmade element; it does not occur in nature. But the kind of radiation plutonium releases—alpha particles—is the same kind of radiation released by radon, which exists naturally in soil, groundwater, and the air worldwide.

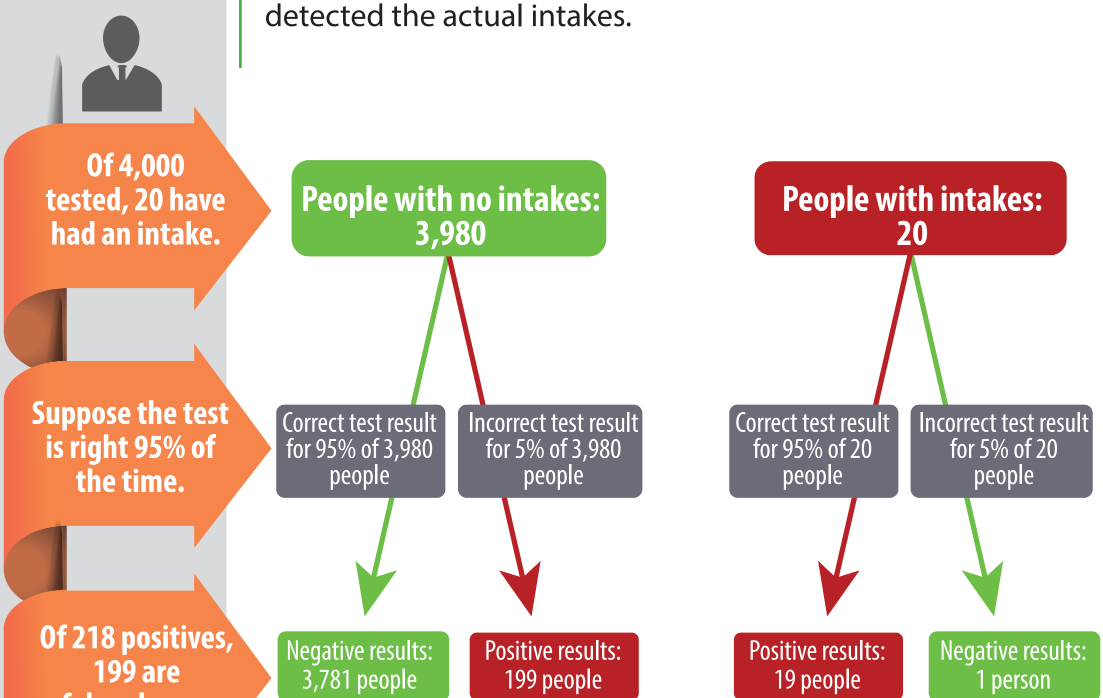
Routine and Special Bioassay

Routine bioassay involves testing regularly scheduled urine samples for the presence of radioactive materials. When a routine bioassay measurement yields a radionuclide count that exceeds what we expect to find in a urine sample, we call that event an elevated routine. An elevated routine requires follow-up in the form of special bioassay—additional urine measurements.

We use these additional urine measurements to determine if there really has been an intake or if the elevated routine was simply a false alarm. Many elevated routines do turn out to be false alarms, so the vast majority of workers who are asked to fill special bioassay kits have not had intakes.

We collect routine urine samples from more than 2,000 workers every year. An average of 50 of those workers (about 2.5 percent) get positive results and are asked to fill special bioassay kits. But of those 50, only about 5, on average, turn out to have intakes. For the other 45, the elevated routine was a false alarm. Special bioassay enables us to cull those false alarms and find the real intakes.

In many cases, we need several special bioassays to be sure we have identified all the false alarms and detected the actual intakes.



Even a very accurate test can produce false alarms. In this hypothetical case, we assume the test is accurate 95% of the time. Even though only 20 of 4,000 people tested (about 2 years of actual LANL worker tests) have had an intake, more than 20 test positive for an intake (get an elevated routine). About 90% of those positives are false alarms, which must be eliminated through additional testing.

Why do all urine sample measurements detect some radiation, even if no intake has occurred?

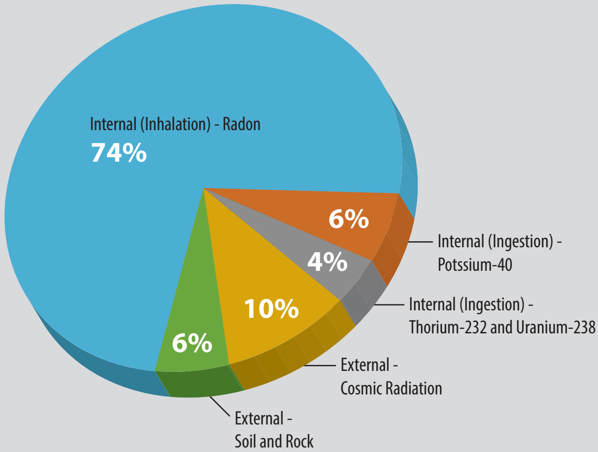
All urine sample measurements detect some radiation because everyone on Earth is exposed daily to naturally occurring radiation, known as background radiation. Background radiation comes from multiple sources: cosmic rays from outer space, the sun, and radionuclides in the ground. We also constantly take radionuclides into our bodies through the air we breathe and the food we eat. After background radiation is accounted for, we expect a worker's internal dose from work-related sources to be zero.

What would cause an elevated routine to be a false alarm?

Because background radiation fluctuates from day to day, we can detect workplace intakes only if the radiation they produce exceeds what might come from the natural fluctuation of background radiation. In addition, some urine samples may become contaminated with radioactive materials during laboratory processing. This means that although a <u>single</u> urine sample can provide strong evidence, it can never tell us with 100 percent certainty if an intake has occurred. To reliably detect real intakes, we need to collect <u>many additional</u> samples from a worker who has an elevated routine, even though we know most elevated routines are false alarms.

Background Radiation

Everyone gets an annual radiation dose because everyone is constantly exposed to natural background radiation. Background radiation gives Americans an average annual dose of 310 mrem, the equivalent of about 30 chest x-rays. More than 80 percent of that dose is an internal dose caused by our inhaling or eating naturally occurring radionuclides, such as radon from the air, uranium from drinking water, and potassium from food. We also get a constant external dose from radionuclides in the ground (terrestrial sources) and from the radiation that arrives from outer space and the sun. Background radiation is indistinguishable from the radiation caused by radionuclide intakes at work.



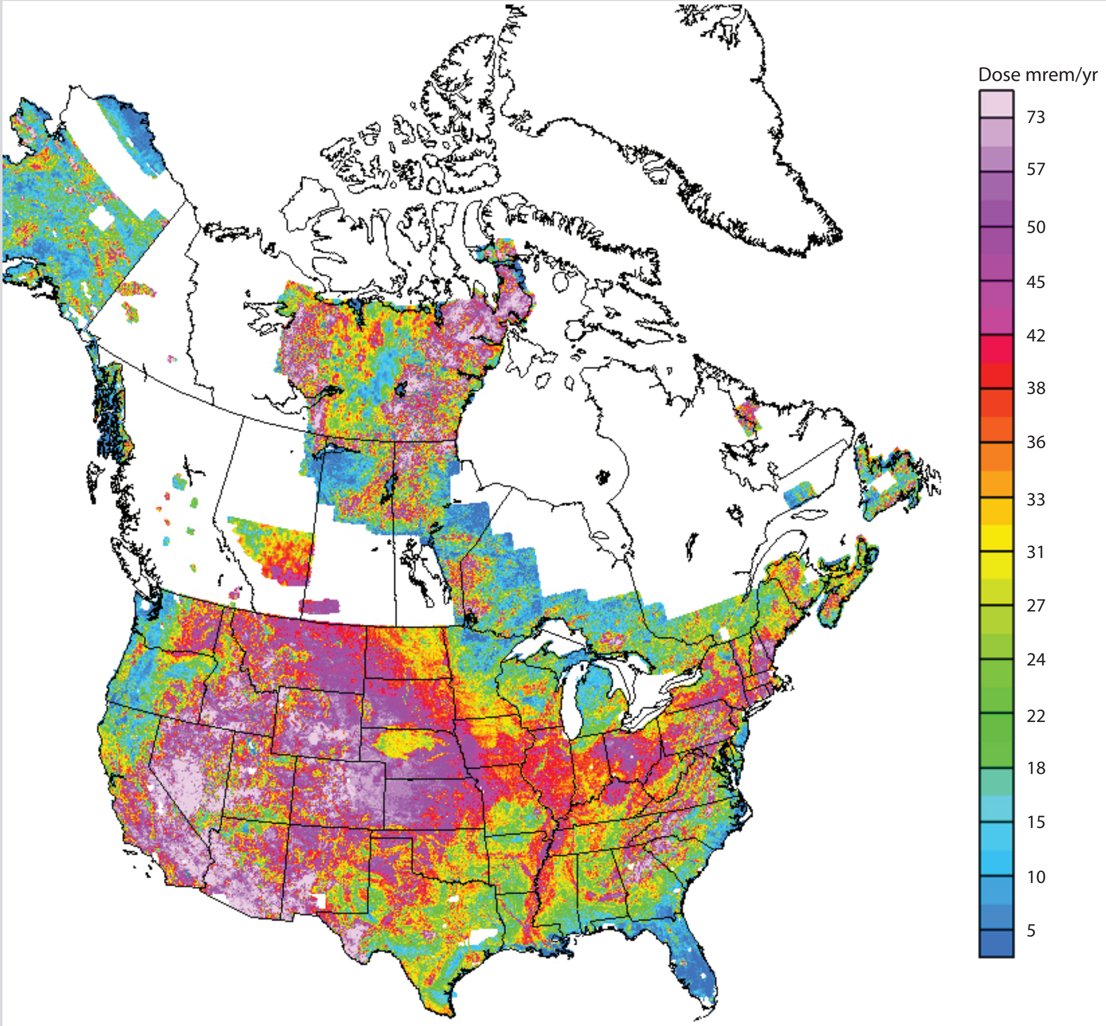
In the United States, more than 80 percent of the dose is an internal dose caused by our inhaling or eating naturally occurring radionuclides.

The background radiation dose a person can receive varies from place to place, depending on geology and elevation. In the United States, the background dose ranges from 131 mrem per year in Florida to 962 mrem per year in South Dakota. The average person living in Los Alamos gets about 520 mrem per year from natural background radiation. This dose is a bit higher than the U.S. average because of our high altitude and our exposure to natural radon.

Radon is a gas that some radioactive materials release into the soil, from which it escapes into the air. It can also enter well water. Radon is one of the biggest sources of background radiation. It is not absorbed by your body, so if you breathe a radon atom into your lungs, you will probably just breathe it out again—no harm done. However, one out of every few million radon atoms will decay before you have a chance to breathe it back out, and when it decays, it emits an alpha particle. That particle can harm sensitive lung cells.

The radiation from outer space (cosmic radiation) and the sun makes up a much smaller but still significant fraction of background radiation. It comes from nuclear fusion, which powers the stars, including our sun. Nuclear fusion produces x-rays, neutrons, and large amounts of heat. Other astronomical events, not all of which are well understood, also produce radiation that can reach Earth.

Manmade sources are an additional source of radiation doses. These doses are intentional because they come from medical procedures such as imaging (x-rays, PET scans, and CT scans) and cancer therapy. Each year, the average American receives about 300 mrem from medical procedures, not including cancer therapy (for which the doses are many thousands of times larger than imaging doses).



This map shows the annual calculated gamma-ray absorbed dose from terrestrial sources. Gamma rays are only a fraction of the total annual dose from background radiation.

Source: derived from U.S. Department of the Interior | U.S. Geological Survey, http://pubs.usgs.gov/of/2005/1413/maps.htm

The Bioassay Kit

Workers placed on routine bioassay monitoring receive urine bioassay kits at intervals determined by the nature of the materials they work with. Instructions for how to provide a sample are included in the kit. It is important that the kit be filled and returned promptly in order to ensure accurate results.

The Bioassay Office makes sure that workers receive their kits and also keeps track of kits that have not been filled and returned. The office can answer any questions about how the kit is provided, used, and returned. Call 667-6275.

Testing and Analyzing the Sample, Interpreting the Results

Every urine sample received by the Bioassay Office is sent to the Laboratory's Nuclear and Radiochemistry group (C-NR). C-NR chemists concentrate and measure the radionuclides found in the sample and report the measurement results to the Internal Dosimetry team.

Workers use bioassay kits to supply urine samples for bioassay monitoring. Kits differ slightly in the number and size of bottles, depending on the type of radionuclide a worker is being monitored for.

The Internal Dosimetry team analyzes C-NR's results to see if there has been an intake. If the bioassay measurement is determined to be elevated, the team begins an investigation (special bioassay), which requires the worker to submit further samples for analysis. The investigation may require several more samples over several months. When the additional samples have yielded a conclusion about whether an intake has occurred, the team reports those findings to the worker.

Why does investigating a possible intake require so much time and so many samples?

Every urine measurement will detect some radiation that has nothing to do with an intake. It might be from natural variations in background radiation, which can look like intakes if they are high enough. The only way we can know for sure if an intake has happened is by collecting more samples and seeing if we continue to detect more than average radiation in each sample.

In addition, simply detecting an intake is not enough for us to determine the dose from that intake. To do that, we also need to know when the intake happened, how big the intake was, how soluble the material was (how quickly it is being absorbed into the body), and other factors. We estimate all of these things using urine measurements, which is the other reason we sometimes need to collect a lot of samples.

Remember that large intakes are much easier to detect than small ones and typically can be detected with fewer samples. So although being asked to submit multiple samples is often alarming, it is actually a sign that the intake, if it happened, must be very small.

How Bioassay Results Are Reported

Results of Routine Bioassay Monitoring

If the result of routine bioassay monitoring is negative (no evidence of an intake), that fact will be indicated on the worker's annual dose report. Workers who have been placed on a special bioassay monitoring protocol to investigate the possibility of an intake will get a report about the results of the investigation.

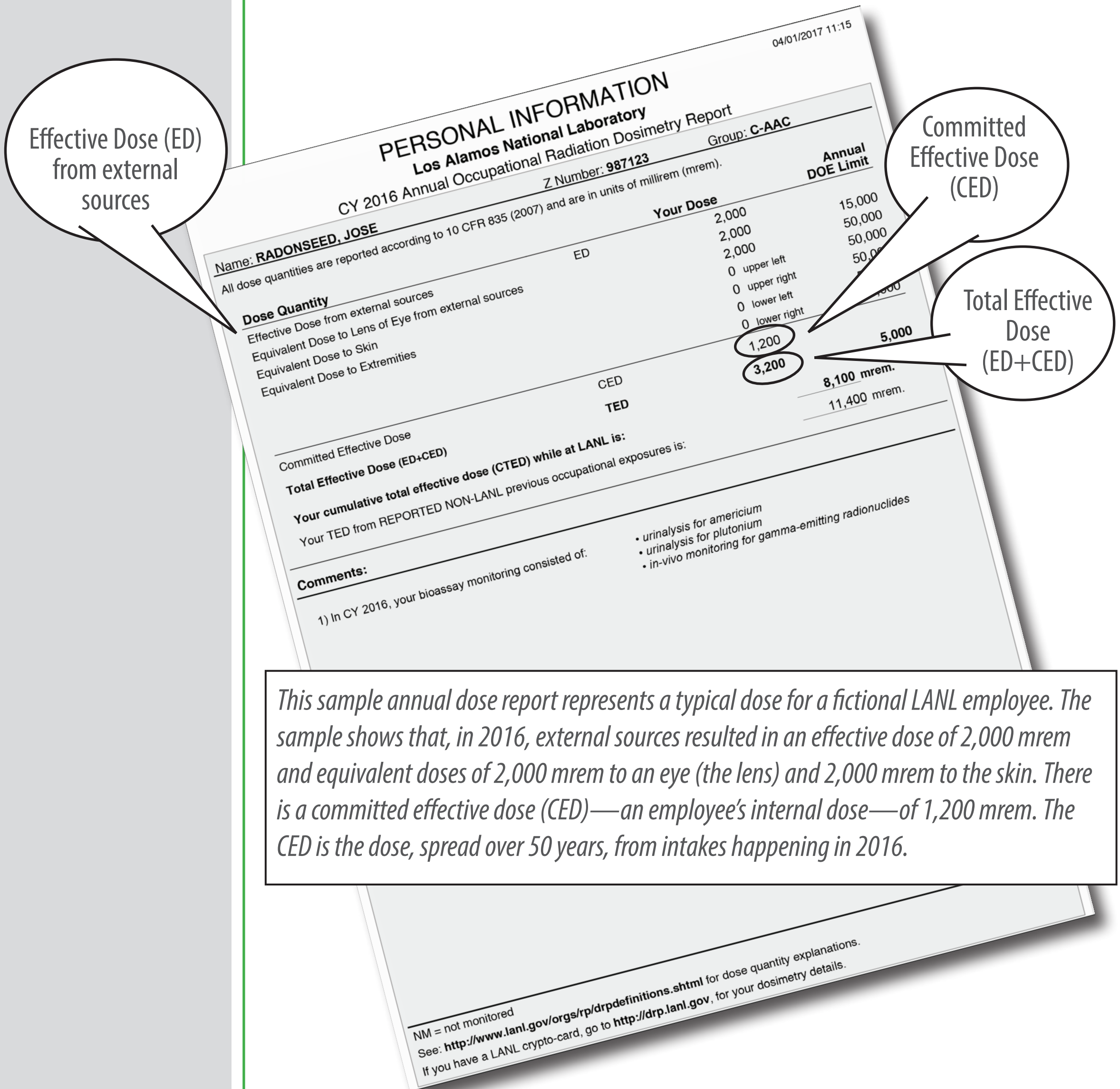
Results of an Investigation

When the investigation of a possible intake, triggered by an elevated routine, reaches a conclusion, we (the Internal Dosimetry team) always call the worker and give him or her a formal report. Calling the worker allows us to explain the process of the investigation, the results, and the health implications, if there are any.

If we determine that an intake has occurred, we also report to the worker's managers and the radiation protection team responsible for the worker's safety. Radionuclide intakes may indicate that the job risk needs to be re-evaluated and/or controlled more effectively.

Annual Report

Every March each worker who is monitored for radiation doses receives a report documenting the total radiation dose from the past year. This dose comprises the effective dose from external sources (external dose, determined by TLD badges) and the committed effective dose (CED) from radionuclide intakes (internal dose, determined by bioassays). Workers whose routine bioassay results are negative for an internal workplace intake will see that they had zero internal dose for the year. The report will indicate all the radionuclides for which the worker was monitored, regardless of whether there was a positive dose.



This sample annual dose report represents a typical dose for a fictional LANL employee. The sample shows that, in 2016, external sources resulted in an effective dose of 2,000 mrem and equivalent doses of 2,000 mrem to an eye (the lens) and 2,000 mrem to the skin. There is a committed effective dose (CED)—an employee's internal dose—of 1,200 mrem. The CED is the dose, spread over 50 years, from intakes happening in 2016.

Radionuclides can remain in the body and cause internal doses for many years after the intake. Rather than reporting just the amount of internal dose that the intake caused in the year when it happened, the annual report provides the CED, which is the total effective dose an intake will cause over the following 50 years.

New urine measurements (e.g., from routine bioassay monitoring) sometimes provide information that allows us to update our dose estimates from past intakes. In that case, a worker's lifetime CED changes on the annual dose report. The CED for a given year is for intakes that occurred in that year. Intakes that occurred in previous years will show only as part of the lifetime dose.

Up-to-date dose estimates for past years are available on the Dosimetry Reporting Project (DRP) website: drp.lanl.gov.

Health Effects of Radiation

Because humans are constantly exposed to natural radiation, our bodies are adapted to deal with moderate levels of radiation. However, a large dose can increase the risk of cancer or cause radiation sickness.

Cancer

Radiation doses (internal or external) greater than about 10,000 mrem increase the risk of dying from cancer. Specifically, with each 10,000 mrem, the chance of developing fatal cancer increases by about 0.55 percent. Intakes that large have happened, but they are very rare.

The majority of intakes detected in workers at LANL are small and result in doses of 10s or 100s of mrem. In spite of many studies spanning more than 70 years, no one knows if doses that small increase the risk of cancer. The risk due to low doses, if it exists, is so small that research studies involving hundreds of thousands of people have been unable to detect it. Suppose a worker got a radiation dose of 1,000 mrem. The risk of dying from cancer increases by 0.55 percent per 10,000 mrem, so if a dose as small as 1,000 mrem could increase the risk of cancer (no one knows if it does), the increased risk would be 0.055 percent. About 20 percent of all Americans are expected to die of cancer. Therefore, the 1,000 mrem would have increased an individual's chances of dying from cancer to 20.055 percent.

Radiation Sickness

Radiation sickness happens a few days or weeks after a person receives a very large radiation dose. A few cases of radiation sickness happened in the early days of Los Alamos but were caused by massive external doses from criticality accidents; they were not caused by intakes.

No one in the history of Los Alamos National Laboratory (or any other U.S. national laboratory) has ever developed radiation sickness from an intake. This is because the dose from a radionuclide intake is delivered gradually over many years, making such doses much less dangerous than doses that happen all at once. Radiation doses exceeding about 100,000 mrem can cause radiation sickness or damage organs and tissues when delivered all at once, which is not how an intake dose is delivered.

No Immediate Health Effects and No Observable Increase in Cancer Risk

Chest x-ray: 2 mrem
Mammogram: 300 mrem
Chest CT scan: 600 mrem
Flight, NY to Los Angeles: 2.5 mrem
Los Alamos background (over 1 year): 520 mrem
LANL dose limit (over 1 year): 2,000 mrem
Regulatory dose limit (over 1 year): 5,000 mrem
Los Alamos background (over 50 years): 26,000 mrem

Increased Cancer Risk, No Radiation Sickness

10,000 mrem: cancer risk up ~0.55%
25,000 mrem: drop in blood cells, no symptoms
66,000 mrem: Mars round trip (8 months)
1,000,000 mrem: largest estimated LANL plutonium dose (over 50 years)

Likely Tissue Damage and/or Radiation (rad.) Sickness

100,000 mrem: mild rad. sickness, cancer risk up ~5%

Up to 600,000 mrem: moderate rad. sickness

12,500,000 mrem: prostate brachytherapy (over many weeks)

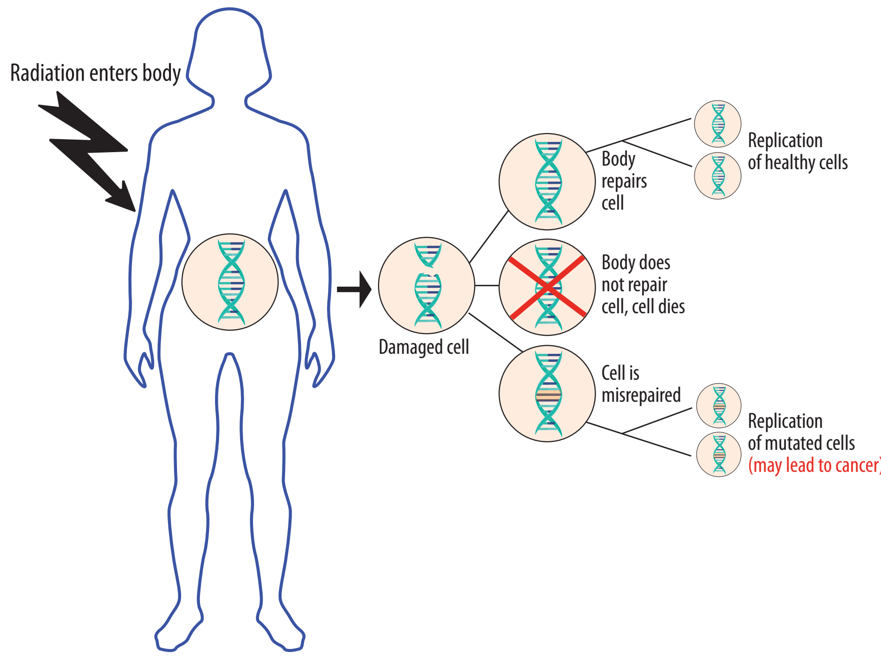
1,100,000 mrem: bone marrow transplant (over 48 hours)

5,000,000 mrem: to organ targeted by cancer therapy (over ~10 weeks)

Lethal Doses

600,000 mrem: fatal (30 days)—
largest dose from "one of world's worst radiological incidents" (IAEA): Goiania, Brazil, 1987
Up to 1,000,000 mrem: severe rad. sickness (1 week)
Above 1,000,000 mrem: fatal (in days)

Shown here are chronic and acute radiation exposures from different sources and the effects of those exposures. Although the dose from targeted radiation therapy is large, it is not fatal because it is delivered to a specific organ and not the whole body. For example, the dose received during a bone marrow transplant would be fatal if delivered all at once, instead of over two days. It should also be noted that the transplant is saving the patient's life.



If there is cell damage from radiation and the cell repairs its DNA, only healthy cells will result when the original cell replicates itself. If mutated DNA is passed on to new cells and enough harmful mutations accumulate, the result may be cancer.

The Mechanism of Radiation Damage

Radiation does its damage through its effect on cells—cell damage and cell death.

Cell damage. In a damaged cell, the genetic material (the DNA) has been mutated. Radiation can mutate DNA by ionizing it. Radiation can also ionize water molecules in the cell, forming unstable molecules called free radicals. Free radicals bond with and damage other molecules, so they also can mutate DNA.

When a cell's DNA is mutated, the cell may do any of the following:

- Repair the damage—In most cases, a cell is able to detect and repair damaged DNA on its own.
- Die, fail to make more cells, or destroy itself—The mutation is not passed on.
- Pass along the mutation when it replicates itself

Rarely, cells with unrepaired or incorrectly repaired mutations are still able to replicate. Most of these cells have mutations that are harmless, but those that do have dangerous mutations are usually identified and destroyed by the body's immune system. However, very rarely, cells with dangerous mutations survive and pass the mutations down to new cells.

If a cell accumulates too many harmful mutations, it may become cancerous. Multiple mutations are needed for cancer to occur, so a single harmful mutation caused by radiation exposure will not immediately lead to cancer. It can, however, increase the chances of cancer developing in the future.

Cell death. When cells cannot repair a mutation caused by radiation, they often destroy themselves in order to destroy the mutation. Or sometimes, the mutations themselves can either kill the cells or prevent them from replicating.

The small number of cell deaths caused by modest radiation doses (up to about 50,000 mrem) does not cause any immediate noticeable health effects. Therefore, the health effects caused by cell death are seen only for very high radiation doses. Since the body is able to replace dead cells, the health effects also depend on how rapidly the radiation is delivered. More than about 100,000 mrem delivered all at once can kill more cells than the body is able to replace and can produce effects such as burns, hair loss, or radiation sickness.

Health Effects of Cell Death and Damage

Cell death and cell damage lead to very different kinds of health effects: deterministic effects (also called threshold effects) and stochastic effects.

Deterministic effects. These effects typically result from cell death and almost always happen when the amount of radiation exposure exceeds some threshold. They almost never happen when the exposure is below that threshold. Deterministic effects include burns, hair loss, or illness and can happen soon after exposure.

Cells are constantly dying and being replaced. Cell deaths caused by modest amounts of radiation do not cause noticeable health effects. However, too much radiation delivered all at once can kill more cells than the body is able to replace. Whether a patient becomes ill depends on how rapidly the radiation is delivered.

For example, cancer patients routinely receive radiation therapy in which the dose is greater than what would be lethal if delivered all at once.

Stochastic effects. Stochastic effects result from cell mutations, but these effects—principally cancer—are not guaranteed to happen, regardless of the amount of radiation exposure. Larger doses increase the probability of cancer developing, but it is always a matter of chance if cancer actually happens.

Cell mutations stimulate the immune system and a damaged cell's own mechanisms for repairing DNA. But it is not known if those mechanisms can prevent small doses from causing stochastic effects in the way they prevent deterministic effects. In any case, any mutation that is not repaired or destroyed by the immune system can take a cell one step closer to becoming cancerous. However, multiple mutations are almost always needed in order for a cell to become cancerous, meaning that cancer may not develop for many years after an exposure—if it happens at all.

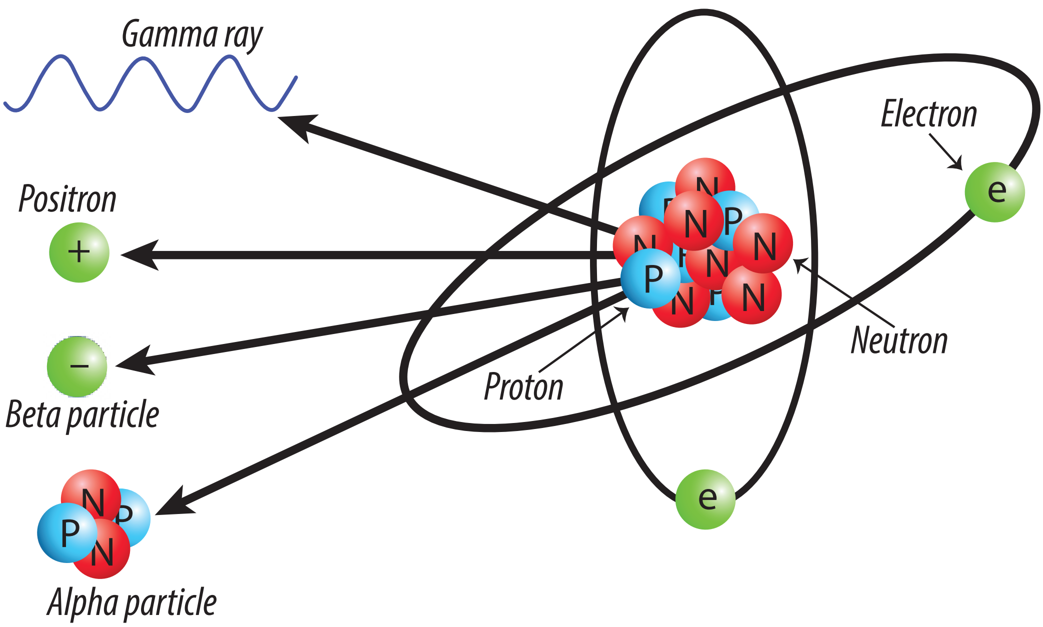
Radiation Basics

What Is Radiation?

Radiation is particles and photons (electromagnetic waves) that have energy. Radiation with enough energy to knock electrons out of atoms is called ionizing radiation. The radiation discussed in this book is ionizing radiation.

When atoms are ionized, they try to regain their lost electron(s) through chemical reactions. These reactions sometimes produce chemicals that can damage cells and genetic material—DNA—which is why ionizing radiation can cause health problems.

Common particles that can ionize include alpha particles, beta particles, and neutrons. Some photons that can ionize atoms are gamma rays, x-rays, and some ultraviolet light. In contrast, radio waves, microwaves, and visible light (including laser light) are nonionizing photons.



Radiation is emitted from an unstable nucleus. Unstable nuclei spontaneously decay by emitting particles (protons, neutrons, and electrons) or photons. An ejected electron that is negatively charged is called a beta particle; one that is positively charged is called a positron. Ejected photons are called gamma rays. Some atoms emit two protons and two neutrons stuck together, and these are called alpha particles.

What Makes an Atom Radioactive?

Atoms are made of a shell of electrons surrounding a dense nucleus of protons and neutrons. If there are too many neutrons or protons, the nucleus is unstable—it can spontaneously decay, spitting out the excess particles. This process releases energy and can produce radiation in the form of alpha particles, beta particles, neutrons, and gamma rays. So, atoms with unstable nuclei are radioactive.

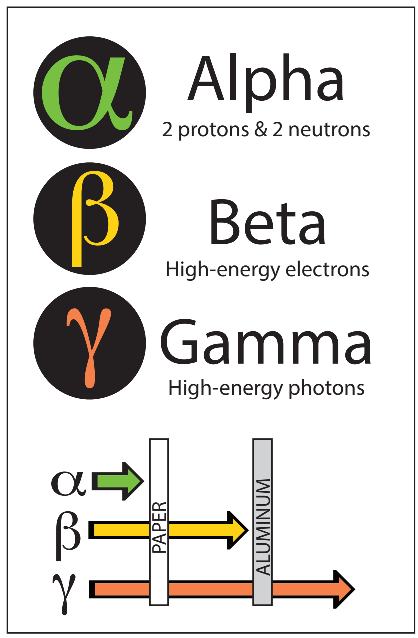
Many types of radioactive atoms can be found in nature, while others can be produced by bombarding certain types of atoms with neutrons in a nuclear reactor or with charged particles in an accelerator. The nuclei of some of the heavier radioactive atoms are so heavy (having so many protons and neutrons) that they split into two lighter nuclei rather than merely ejecting a small particle. This process is called fission, and it can happen spontaneously or when the nucleus absorbs a neutron. Fission also produces gamma rays, neutrons, and other forms of radiation.

Kinds of Radiation

The most common kinds of radiation are photons (x-rays and gamma rays), beta particles, neutrons, and alpha particles.

Although these kinds of radiation are released when unstable atoms decay, they can also be made using x-ray tubes and particle accelerators. Their behavior and what can block the radiation depend on energy, speed, electrical charge (positive, negative, or neutral), and mass (weight).

Energy determines how far the radiation can travel. All other things being equal, radiation that starts out with more energy travels farther, and when it runs



Each type of radiation has characteristics, such as energy and electrical charge, that determine the materials that will block it. In this figure, "gamma" represents both kinds of photons, including x-rays. Neutrons are not shown because a good neutron shield is too complex for easy illustration.

out of energy, it stops. But radiation loses energy each time it hits an atom, so the distance it travels is affected by the number of atoms it hits in the material it passes through.

Radiation going through dense materials—materials with very closely packed atoms (lead, for example)—will hit many atoms, losing energy with each hit until all the energy is used up. So radiation passing through a dense material will stop after traveling a short distance. Radiation passing through lighter materials—materials with widely spaced atoms (air, for example)—will travel greater distances.

Charged particles, such as alpha particles and beta particles, also tend to hit atoms more often, so they travel a shorter distance compared with radiation that has no electrical charge, such as neutrons and photons.

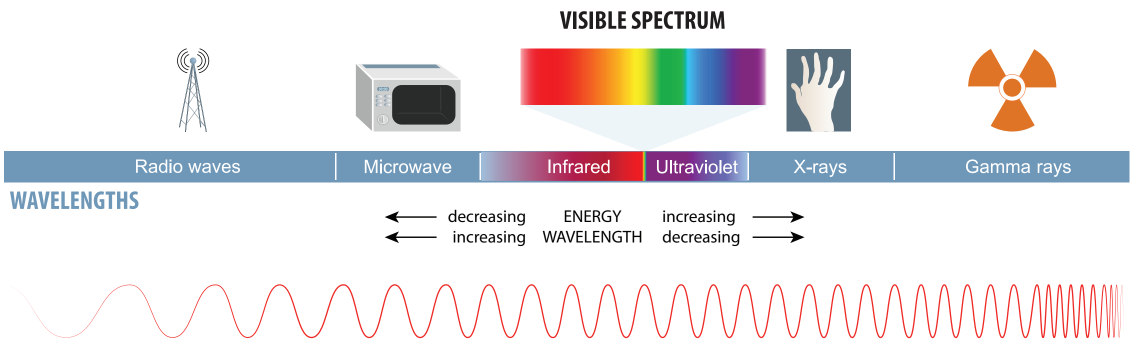
Heavier particles, such as alpha particles, tend to lose more energy each time they hit an atom, so they travel a shorter distance compared with lighter particles, such as beta particles.

Each kind of radiation is discussed here in ascending order of weight.

***Photons* (*gamma rays and x-rays*)**. Much like brown bears and grizzlies, x-rays and gamma rays are the same thing but have different names, depending on their origin. Gamma rays are ionizing photons produced by the decay of atomic nuclei, while all other ionizing photons, such as those produced in a particle accelerator, are called x-rays.

Because they have no mass and no charge, high-energy photons, such as x-rays used for cancer therapy, can be blocked only by several feet of concrete or lead. On the other hand, lower-energy photons, such as the x-rays used for mammograms and dental x-rays, can be blocked by a thin lead apron.

Photons in the form of ultraviolet light are also ionizing. These photons, which are responsible for sunburns and an increased risk of skin cancer, can be blocked by sunscreen and most clothing.



Electromagnetic radiation (photons) travels in waves. The energy of each kind of electromagnetic radiation depends on its wavelength (the distance between wave crests), with shorter wavelengths equaling greater energy. Radiation with wavelengths in the middle of the spectrum accounts for visible light.

Beta particles. There are two kinds of beta particles: high-energy electrons and positrons (anti-electrons). High-energy electrons are produced in particle accelerators and by the decay of atoms of materials such as iodine-131 and tritium. Positrons are produced by the decay of isotopes such as fluorine-18 and potassium-40.

Both kinds of beta particles have an electrical charge and so can be blocked by a layer of clothing or a few sheets of aluminum foil. However, when a positron loses enough energy, it interacts with an electron to form two high-energy x-rays, which have a much greater range and so must be blocked by much thicker materials.

Because high-energy electrons travel short distances, they are useful for targeted cancer therapies. Positrons, which produce x-rays, are extremely useful for a kind of medical imaging called positron emission tomography (a PET scan).

Neutrons. Neutrons come from the nucleus of an atom and are relatively heavy particles with no electrical charge. Neutrons are produced by the decay of isotopes such as beryllium-13 and plutonium-240, as well as by nuclear fission and fusion, which occur in stars, nuclear power plants, and nuclear weapons.

Because neutrons have no charge, they tend to travel farther through materials than even much lighter charged particles do. When neutrons collide with heavy atomic nuclei, they tend to deflect without losing much energy. They lose much more energy when they collide with a material such as hydrogen, which has a light atomic nucleus. For that reason, neutrons are best stopped by materials like water and plastic, which contain a large amount of hydrogen.

At low speeds, a neutron can be absorbed into an atom's nucleus, which often makes that nucleus radioactive. Neutrons are the only common kind of radiation that can make other things radioactive.

Alpha particles. Alpha particles, which consist of two protons and two neutrons bound together, are helium nuclei stripped of their electrons. They are created from the decay of heavy radioactive elements such as radium, uranium, and plutonium. When those elements decay, they spontaneously eject two of their protons and two of their neutrons. Alpha particles weigh 8,000 times more than beta particles do and have double the electrical charge. As a result, they have a very short range.

Alpha particles cannot cause harm from outside our bodies because they cannot pass through the top (dead) layer of skin. They can be blocked by a sheet of paper or even a few millimeters of air. However, alpha particles can be dangerous if formed by radionuclides inside the body.

Radiation and Cancer

For doses greater than 10,000 mrem (double the federally mandated annual limit for U.S. radiation workers), the probability of developing cancer increases by 5.5 percent for each 100,000 mrem. Here at LANL, for safety's sake, we assume that all doses, even doses less than 10,000 mrem, represent some cancer risk. However, there is no evidence to support this. According to the Health Physics Society, the overall risk of health effects from such doses, if it exists, is so small that it will never be detected. In spite of that, LANL policy on dose limits is stricter than federal policy. At LANL the annual dose limit for radiation workers is 2,000 mrem.

In the United States, about 200 out of 1,000 people will develop fatal cancer. This high "background rate" is one of the most important reasons why it is so difficult to know the risk posed by small radiation doses. The current federal dose limit for radiation workers in the United States is 5,000 mrem. Given that the risk of fatal cancer increases by 5.5 percent for every 100,000 mrem, 5,000 mrem would increase that risk by about 0.3 percent. In other words, for 1,000 people exposed to 5,000 mrem, the radiation would cause 3 cases of fatal cancer in addition to the 200 that would have happened anyway.

Of course, for any randomly chosen group of 1,000 people, there is a very good chance that 203 of them would have the bad luck to develop fatal cancer, even without a work-related radiation dose. For that reason, far more than 1,000 subjects would be needed to discover the effect of a radiation dose of 5,000 mrem. Although hundreds of thousands of people have been studied over more than half a century, the effect of 5,000 mrem, if it exists, is so small that it has so far proven impossible to distinguish it from random chance.

Comparison of Risk in Terms of Decreased Life Expectancy

Occupation or activity over 50 years*	Decreased life Expectancy (in days)
Demolition	1,500
Coal or uranium mining	1,100
Firefighting	800
Railroad	500
Agriculture	300
Construction	200
Transportation/public utilities	160
Average of all occupations	60
Government	55
Radiation worker with dose of 1,000 mrem/year	50
Service	45
Trade	30
Single radiation dose of 1,000 mrem	1.5

**Although not every worker spends 50 years in these jobs, especially the most physically demanding ones, the 50-year measure is the industry standard for gauging risk over time.*

Helpful Resources

Resources for Los Alamos Employees and Their Families

Employee Assistance Program
The Laboratory's Employee Assistance Program provides free counseling to employees and their families in the event of an intake. It can help employees talk to their families and friends without causing fear or misunderstanding.

Los Alamos Radiation Protection Website
This website, available on the Yellow network, provides information about the Laboratory's radiation protection philosophy and practices. It also provides links where you can access your dose history.

In Vitro Bioassay Services Website
This website, available on the Yellow network, provides information about the in vitro (urine) bioassay program, including how employees are enrolled in bioassay monitoring and how they should fill their kits. It also provides phone numbers where you can ask questions about your bioassay kit.

Information about Radiation Safety and Internal Dosimetry

Environmental Protection Agency
The Environmental Protection Agency's website offers information about radiation protection and natural background radiation. You can find this information by using the site's Search feature.

Health Physics Society
The society maintains a great website with information about radiation exposure.

Google Scholar
This website is an excellent resource for finding free peer-reviewed literature about ionizing radiation (and many other subjects).

***Los Alamos Science,* Number 23, 1995, Radiation Protection and the Human Radiation Experiments**

The journal *Los Alamos Science* was published by the Laboratory from 1980 to 2006. This issue (Number 23) is devoted to the history of radiation safety. It is full of useful information, informative interviews, and interesting (sometimes alarming) history. The article "On the Front Lines" is an interview with Los Alamos employees who had large intakes of plutonium. Many of these people were involved in the Manhattan Project. Google "Los Alamos Science" to access the journal's archives.

Radiation Effects Research Foundation

This cooperative U.S.-Japan foundation is a scientific organization dedicated to studying the health effects of atomic bomb radiation. It is responsible for the longest-running study of this type. Google the foundation to reach its information-packed website.

U.S. Nuclear Regulatory Commission

The U.S. Nuclear Regulatory Commission (NRC) website gives information about the health effects of radiation (search for "radiation protection"). The site also provides links to relevant NRC brochures and fact sheets.

World Health Organization, "Ionizing Radiation, Health Effects and Protective Measures"

The website for the World Health Organization (WHO), an agency of the United Nations, offers information on ionizing radiation. "Ionizing Radiation, Health Effects and Protective Measures" can be found on the WHO website by clicking on "Fact Sheets" under Health Topics, Resources.

Glossary

Absorbed Dose

Absorbed dose is the amount of energy deposited by radiation per unit mass of a material. Because it is related to the fraction of a material's molecules that have been ionized, absorbed dose is useful for predicting deterministic events, such as whether a specific organ or tissue will stop working properly.

ALARA

ALARA is an acronym for the fundamental goal of radiation safety, which is to keep radiation doses "As Low As Reasonably Achievable."

Annual Occupational Radiation Dosimetry Report

Every March each employee who is being monitored for radiation doses receives a report documenting the total radiation dose from the previous calendar year.

Background Radiation

Background radiation is the radiation that exists naturally on Earth. It comes from sources such as cosmic rays and radionuclides in the soil. The dose from background radiation in Los Alamos is about 520 mrem per year. Background radiation is separate from the radiation a worker may be exposed to in the workplace, which is occupational radiation.

Bioassay Measurement

Bioassay measurement is a type of measurement in which radioactive materials are measured to determine their behavior inside a person. Measurements performed directly on a person are <u>in vivo</u> measurements, while those performed in a test tube are <u>in vitro</u> measurements. At the Laboratory, we use either urine (in vitro) or whole-body radiation counter (in vivo) bioassay measurement to determine how much radioactive material is present in the body and how quickly it is moving amongst the various organs and tissues.

Bioassay Office

The Bioassay Office is responsible for distributing and picking up bioassay kits. It tracks the status of kits until the final measurement results are reported by the Laboratory's Nuclear and Radiochemistry group. You can call the Bioassay Office (667-6275) at any time to ask about the status of your kit.

Chelation Therapy

Chelation therapy involves administering a drug that binds itself to heavy metals, such as plutonium and americium, and causes them to be removed from the body (typically through urine). This can dramatically reduce the radiation dose that a person is likely to receive as the result of an intake. Chelation therapy is effective only if given shortly after the intake occurs and should be administered only when the benefit outweighs the risk.

Committed Effective Dose

The committed effective dose is the total effective dose an individual receives over the course of 50 years as the result of a radionuclide intake.

Deterministic Effect

A deterministic effect of radiation exposure, sometimes called a threshold effect or non-stochastic effect, is an effect that always occurs beyond a certain dose threshold but does not occur below that threshold. Examples include sunburns, hair loss, and radiation sickness. Deterministic effects are the result of cells being killed by radiation exposure. The effects usually appear within hours or days of exposure.

Dose

Dose is the amount of radiation absorbed by the body. External doses are doses from radiation sources outside the body, for example, an x-ray machine. Internal doses are doses from radiation sources inside the body, for example, a radionuclide intake. The health risk from a dose depends on the type of radiation involved and the particular tissue that receives the dose. See Equivalent Dose and Effective Dose for more information.

Dosimeter

A dosimeter is a device that measures radiation dose. One type of dosimeter is a thermoluminescent dosimeter, known as a TLD, which is generally worn as a badge. Dosimeters are used to monitor the amount of external radiation dose workers receive and to let them know if radiation levels around them have increased.

Dosimetry Reporting Project
On the Dosimetry Reporting Project website (DRP.lanl.gov), an employee can find his or her up-to-date dose estimates for past years.

Effective Dose
Effective dose is the sum of the equivalent doses to the organs, each of which is adjusted to account for the organ's sensitivity to radiation. Effective dose represents the total cancer risk.

Elevated Routine Bioassay
An elevated routine bioassay (or elevated routine) is a routine urine sample measurement that yields a radionuclide count exceeding what is expected. Although most elevated routines turn out to be false alarms, they are a warning that an intake may have occurred. For that reason, an elevated routine triggers special bioassay.

Equivalent Dose
Equivalent dose is the absorbed dose to an organ adjusted to account for the effectiveness of the type of radiation.

Intake
An intake is an event in which radioactive materials are taken into the body. Radioactive materials can enter the body through the lungs, digestive tract, skin (in the case of tritium), or wounds (such as cuts or abrasions).

Internal Dosimetry
Internal dosimetry is the science of detecting intakes of radionuclides and determining the committed dose that is likely to result from them.

Internal Dosimetry Team
The Internal Dosimetry team is responsible for monitoring Laboratory employees for intakes of radionuclides and reporting the findings from the employees' bioassay measurements. This booklet was developed by the Internal Dosimetry team.

Radiation
Radiation is photons and particles that carry enough energy to ionize an atom, that is, remove electrons from around the atom's nucleus. When atoms are ionized, they try to regain their lost electron(s) through chemical reactions. In living creatures, those reactions sometimes lead

to chemicals that can damage cells. Technically, whenever we use the word "radiation" in this book, we are talking about ionizing radiation.

Radionuclide

A radionuclide is any atom that emits radiation when its nucleus "decays" to a lower energy state, often transforming itself into a new kind of atom.

Routine Bioassay

Routine bioassay involves regularly scheduled measurements of in vitro samples (urine samples) submitted by workers whose jobs require monitoring for intakes of radioactive materials.

Special Bioassay

Special bioassay involves a series of measurements of urine samples (usually submitted once a month) to determine if a worker who has had an elevated routine bioassay has really had an intake. Investigating a possible intake requires several special bioassays and may take several months.

Stochastic Effect

A stochastic effect, or random effect, affects the probability that something will happen. The most important stochastic effect of large radiation doses is an increase in the probability that a person will develop cancer. Radiation-induced cancers, if they happen, can take many years to occur.

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NNSA
National Nuclear Security Administration