BRIGHAM YOUNG
UNIVERSITY

DEE F. ANDERSEN
ADMINISTRATIVE VICE PRESIDENT

THE GLORY OF GOD
IS INTELLIGENCE

Refer to Docket No. 50-262

March 9, 1992

Alexander Adams, Jr.
Project Manager Non-Power Reactors,
Decommissioning and Environmental
  Project Directorate
Division of Advanced Reactors
  and Special Projects
Office of Nuclear Reactor Regulation

Dear Sir:

In response to the questions received from your office dated January 9, 1991, we have prepared the following information:

1. A table of contents is enclosed.

2. A copy of Figure 1 is enclosed.

3. Statistical analysis reports will be prepared and maintained for NRC review.

4. Core samples will be obtained by drilling a one quarter inch hole in the respective material and placing a one gram sample of the material removed by the drill into LSC counting fluid for alpha and beta analysis using LSC counting techniques (it is assumed that gamma contamination will be picked up with standard surface survey instruments).

5. A "Training Program Outline", is enclosed.

6. We will be using RAMP Industries Incorporated with offices in Denver, Colorado as our radioactive waste broker. The Brigham Young University Radiation Safety Officer is charged with assuring compliance with all shipping and waste disposal regulations as well as monitoring the activities of our broker.

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7. One milliliter of shielding water and one milliliter of tap water (the shielding tank was filled with culinary water in 1967) were placed in liquid scintillation counting cocktail and each sample was counted ten times. The resulting means for the counts were respectively, 169.9 for the tap water and 169.6 for the shielding water. Calculated standard errors for the means were 2.57 and 4.09. Assuming that the true mean for the tap water in this area is 169.9 there is a 95 % probability that the true mean for the shielding water is less than 8 cpm above the background. Since efficiency for ^{14}C is approximately 90% using this methodology and the more radiotoxic materials in general have an efficiency approaching 100% there is a 95% probability that the true contamination of the shielding water is less than 9 dpm per milliliter of water. This translates to a possible contamination level of 4.09×10^{-6} microcuries per milliliter. In addition NRC Region IV pulled a sample of shielding water for analysis and we have requested the results from their analysis. Prior to discharging the water we will repeat the analysis using 2 milliliters of water and a 20 minute count.

8. The Pu/Be source was leak tested at the time of removal and the tests results were less than 0.0001 microcuries of removable surface contamination. In addition the exposure rate (gamma) survey taken at the time of removal was 0.2 mrem/hour at one meter from the surface of the source and the neutron flux was 5 neutrons per second per square centimeter at one meter from the surface of the material with the thermal neutron shield in place.

Application has been made to transfer this source to License UT 2500091 which currently has a license limit of 83.5 grams of plutonium-239.

9. No material will be released for unrestricted use unless it can be demonstrated to be within the following limits at a 95% confidence level.

a. 5000 dpm/100 cm^2 for fixed beta/gamma contamination.
b. 1000 dpm/100 cm^2 for removable beta/gamma contamination.
c. 100 dpm/100 cm^2 for fixed alpha contamination.
d. 20 dpm/100 cm^2 for removable alpha contamination.

While we will accumulate the data on the above material we will not release any material as non-radioactive from the reactor facility until the data including statistical analysis has been reviewed by the NRC.

10. We shall not release facilities to unrestricted use unless we can, demonstrate with at least a 95% probability, that exposure rates associated with those facilities are not more than 5 uR/hour above background at one meter from the surface of those facilities.

11. Survey instruments shall be calibrated within four weeks of the start of decommissioning activities. Since the time schedule submitted involves five weeks for completion of the project the instrument calibration will be performed within three months

of the completion of the project. This is in keeping with new guidelines proposed by the Division of Radiation Control which allow survey instrument calibration at 3 month intervals. In addition the instruments will be checked with an appropriate calibrated source at least daily while they are in use.

Sincerely,

Dee F. Andersen

cc: Bill Beach, NRC Region IV

STATE OF UTAH)
: ss.
COUNTY OF UTAH)

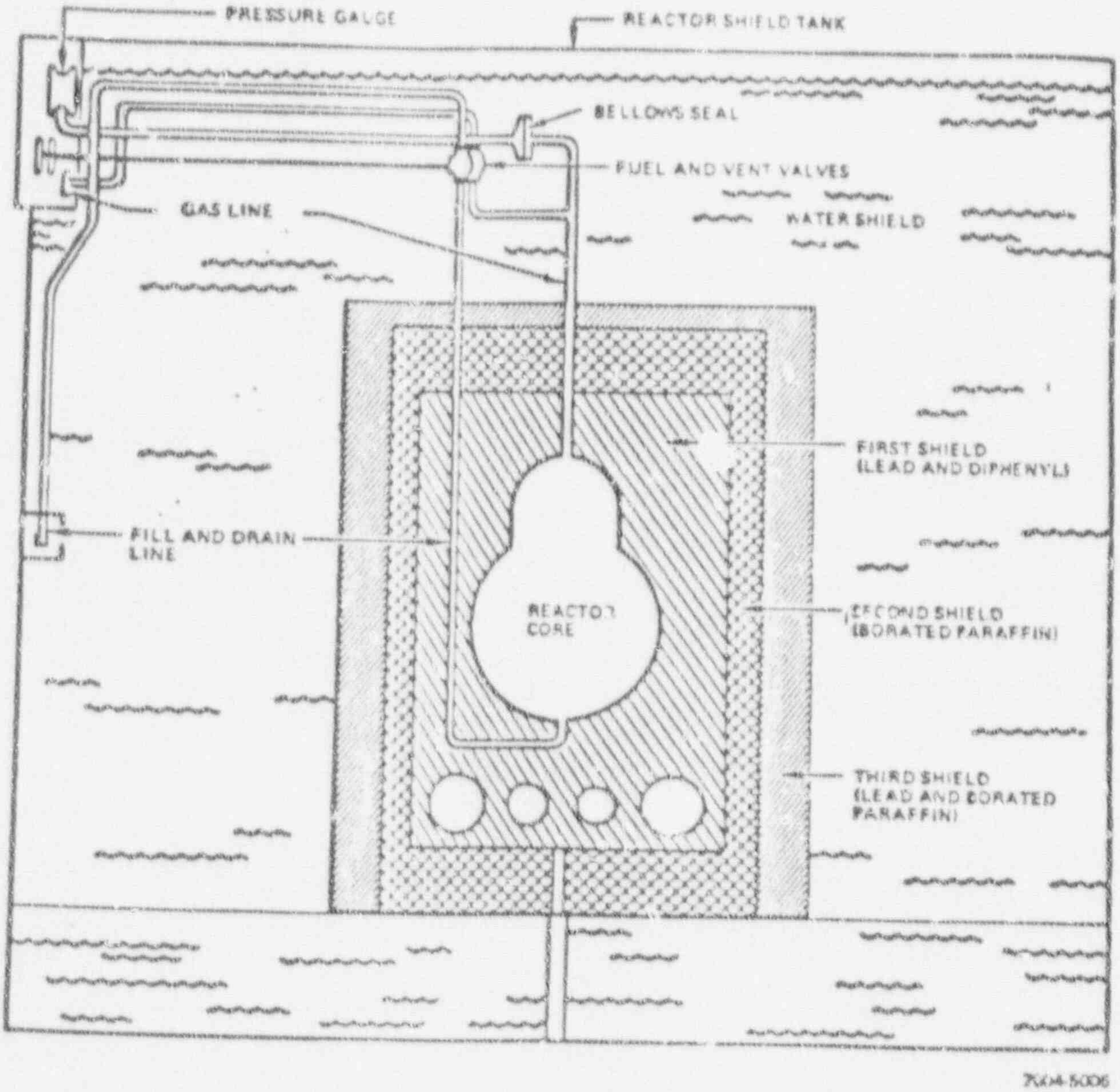
Subscribed and sworn to (or affirmed) before me this 9th day of March, 1992 by Dee F. Andersen, the Administrative Vice President of Brigham Young University.

L. COLETTE PINKNEY
NOTARY PUBLIC - STATE of UTAH
BYU GEN. COUNSEL A-350 ASB
PROVO, UTAH 84602
COMM. EXP. 12-5-94

L. Colette Pinkney
Notary Public

Figure 1

Reactor Cross Section



Shielding and Piping

RADIATION SAFETY TRAINING OUTLINE

1. Tissue Damage

   1.1. DNA
   1.2. Protein
   1.3. Free Radicals

2. Ionizing Radiation and its interactions with matter.

   2.1. Compton Effect
   2.2. Bremsstraahlung
   2.3. Specific Ionization
   2.4. Pair Production
   2.5. Photoelectric effect
   2.6. Shielding
   2.7. Neutrons

3. Types of Ionizing Radiation.

   3.1. β origin and characteristics
   3.2. α origin and characteristics
   3.3. γ origin and characteristics
   3.4. X-ray
   3.5. Neutrons

4. Waste Disposal

   4.1. NRC regulations.

5. Personal Protection.

   5.1. Dosimetry
   5.2. Surveys
   5.3. Leak checking new material
   5.4. Shielding, distance, time
   5.5. Accident response.

      5.5.1. 1. protect life and health
      2. Safely limit the spread
      3. Notify RSO

6. Regulations.

   6.1. Waste Disposal.
   6.2. Pregnancy.
   6.3. NRC
   6.4. 10 CFR part 20
   6.5. Security. Locked or attended
   6.6. Reporting. 8-2222 or 911

7. Radiotoxicity.

   7.1. Biological half life.
   7.2. Target Organ.
   7.3. Specific Ionization.

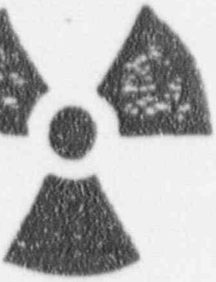
8. Units Of Measurement.

   8.1. roentgen
   8.2. RAD
   8.3. REM
   8.4. Gray
   8.5. Sievert
   8.6. Becquerel
   8.7. Coulombs/kg (C/kg)

9. Instrumentation

   9.1. Liquid Scintillation
   9.2. Solid Scintillation
   9.3. Geiger-Muller Counter
   9.4. Ionization Chamber
   9.5. Gas Proportional Counter

BASICS OF RADIOACTIVITY



In order to assist in the training of users and potential users of radioactive materials, the Radioisotope Committee is preparing a series of information sheets which will explain in simple terms various aspects of radioactivity and radiation safety. These will be distributed to all interested persons in areas where radioactive materials are present. Suggestions are requested for new ideas and new topics which can be used in the series.

WHAT IS RADIOACTIVITY?

Radioactivity occurs when the nuclei of certain unstable atoms emit particles allowing the atoms to become more stable. Each atom is characterized by an atomic mass A and an atomic number Z. This is characterized for the atom X as ${}^{A}_{Z}X$. If the A/Z ratio is too large or too small, the atom becomes unstable and emits either an alpha particle (α) or a beta particle (β) to stabliize the atom. This disintegration may leave the nucleus in an excited state, in which case one or more gamma rays (γ) will be emitted. This process is known as nuclear decay or radioactivity.

WHAT IS NUCLEAR FISSION?

When atoms reach the mass of uranium or plutonium, the nucleus may become unstable and split into two fragments of roughly the same size. Extra neutrons are emitted in course of the fission. These neutrons may stimulate the fission of additional uranium or plutonium atoms, causing a chain reaction. If sufficient fissionable uranium and plutonium are present to sustain the chain reaction, the critical mass is reached and the chain reaction will continue until the mass drops below criticality by any of a number of mechanisms. Nuclear reactors operate on the principle of controlling the rate of chain reaction. Nuclear weapons achieve the state of an uncontrolled chain reaction.

WHAT IS AN ALPHA PARTICLE?

An alpha particle is the nucleus of an helium atom consisting of two protons and two neutrons. They are emitted only from atoms more massive than lead with an atomic number of 82, with the exception of samarium which has an atomic number of 62. Alpha particles are emitted with high energies, usually between 4 and 9 million electron volts (Mev) and are monoenergetic. Because of their great mass and electric charge, alphas have short ranges of a few milimeters in air. Because of the short range, alphas present little hazard from external radiation. The high energy release, however, could cause problems if the materials containing alpha radiation are ingested in the body.

WHAT IS A BETA?

A beta particle is an electron or positron which is emitted from the nucleus of an atom. Its properities resemble those of any electron or positron of comparable energy. Betas range in energy from a few thousand electron volts (kev) to several Mev. Betas are not monoenergetic as are alphas but have a range of possible energies with any particular disintegration. The most probable energy of emission is approximately one-third that of the maximum energy possible from that disintegration. Since betas are much less massive than alphas, the range is considerably greater for comparable energies. The maximum range of betas emitted by tritium in air is about 4 millimeters, the maximum range of betas from carbon-14 is about 25 centimeters, and betas resulting from the decay of strontium-90 could penetrate as much as 10 meters of air. Betas may produce X rays as they interact with matter in the process of losing energy.

WHAT ARE GAMMA RAYS?

Gamma rays are the electromagnetic radiation emitted by the nuclei of atoms during decay. Gammas are identical to X rays with energies ranging from several kev to a few Mev. Since gammas have no electrical charge, their penetration is greater than that of alphas and betas of comparable energy. The term "range" has no meaning with gammas as it has with alphas and betas since there is no stopping distance associated with gammas. The intensity of the beam decreases exponentially with respect to the mass of the materials through which the beam passes. Since gammas are extremely penetrating with small amounts of localized energy loss, the greatest hazard is usually from external exposure. Some elements, however, such as iodine will localize in a small organ of the body such as the thyroid and cause possible radiation damage if the materials is ingested in large quantities.

WHAT IS A NEUTRON?

A neutron is a neutrally charge particle emitted from the nucleus of some atoms. It reacts only by nuclear reactions with matter and is extremely penetrating with a large release of energy when absorbed. Special precautions need to be taken when working with neutron emitting materials.

BACKGROUND RADIATION

COSMIC RADIATION

Cosmic radiation originates when charged particles bombard the earth from outer space. These particles interact with the earth's magnetic field which turns many of the particles away. Those which reach the atmosphere react with it producing secondary particles which continue to interact with the atmosphere causing a cascading of charged particles descending through the atmosphere. In these reactions, cosmic rays are absorbed by the atmosphere, losing energy, such that the concentration of charged particles is greater at higher altitudes than at sea level. In Utah, the annual dose from cosmic radiation is about 115 mrem; however, the annual dose is only about 30 mrem in Hawaii and in the United States the average dose is 45 mrem.

TERRESTRIAL RADIATION

The earth is composed of rocks containing uranium and thorium in varying concentrations over the different portions of the earth. Those areas containing these elements in higher concentrations have greater background radiation levels than those areas with smaller concentrations of these elements. Some areas of India, Brazil, and France have background radiation levels exceeding those allowed for radiation workers. In Utah, the average terrestrial component of background radiation is 40 mrem per year, while in Colorado it is as high as 150 mrem per year. Since uranium and thorium are natural components of both sand and rock, cement, brick, and stone buildings will normally have higher radiation levels inside them than will frame or steel buildings.

AIRBORNE RADIOACTIVITY

One of the natural decay products of uranium and thorium is radon gas which diffuses out of the rocks and soil into the air we breathe. This decays into daughter products which collect on dust and can accumulate in the lungs of people breathing the air. This type of exposure is common around soils with high uranium content such as the Vitro tailings in Salt Lake City. Radon gas usually accumulates in higher concentrations inside buildings built on these tailings or constructed from sand from the tailings. Heavy rainfall slows down the diffusion of radon gas out of the ground resulting in lower concentrations of radon in the air than found during dry spells. Other radioactive elements found in the air are carbon-14, tritium, and berillium-7, but they are in such low concentrations that they are insignificant. The average annual exposure to airborne radioactivity is about 4.5 mrem.

RADIOACTIVITY IN WATER

As water passes through the soil it picks up minerals which may be radioactive. The most prevelent contaminants are potassium-40, which comprises the body's greatest natural dose of radioactivity, and radon gas. Other radioactive elements are also present in water depending on the natural composition of the rocks through which the water passes and the effects of radioactive fallout.

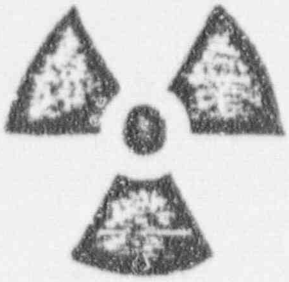
RADIOACTIVITY IN FOOD

All food that we eat has certain amounts of radioactivity. Health officials are very concerned about increases in the natural intake of radioactivity resulting from nuclear fallout, waste disposal, or other contamination of the food chain. A good way to test fallout after a nuclear explosion is to measure the radioactive iodine in milk produced by cows in the suspected area. Concentrations of radioactivity in the body due to foods eaten vary widely from one area to another. Allowable levels of waste disposal in one area may be governed by the radioactivity naturally occuring in the food of another area. Potassium-40 is the most abundant isotope and is distributed uniformly throughout the tissues of the body. Radium seeks bone structure and remains in the body for many years. Carbon-14 is a natural contaminant in small concentrations which distributes itself throughout the body. The annual exposure to the gonads from ingested radioactivity may be as high as 20 mrem per year.

RADIOACTIVE FALLOUT

A thermonuclear explosion vaporizes the materials near the blast and carries great amounts of sand and vapors into the upper atmosphere. The larger of these highly contaminated particles drop to the earth within a few miles of the blast site. Smaller particles remain in the atmosphere until participated out by rain or snowfall. Some contaminants remain in the upper atmosphere for years, covering the globe with a layer of radioactivity. When this radioactivity reaches the earth it becomes part of the food chain as explained above and may create problems if the levels in a local area become too high. Estimates of the average dose to a person in the United States during the next 70 years are placed between 400 and 900 mrem to the bone. Exposures to other parts of the body are even less.

RADIATION-MEASURING INSTRUMENTS



ION-CHAMBER DOSIMETERS

The original radiation-measuring device was the electroscope. The chamber walls form the cathode while the anode consists of a flexible fiber attached to the central electrode. When a static charge is placed on the anode, the fiber is repelled from the electrode and remains in that state until the system is discharged. Radiation passing through the chamber ionizes the air, which then discharges the system. The rate of discharge indicates the amount of radiation present. Pocket dosimeters use this principle by adding a microscope eyepiece and a scale to follow the movement of the fiber and measure the amount of discharge.

ION-CHAMBER SURVEY METERS

An ion chamber can be constructed of a thin wire anode inside a chamber with the walls forming a cathode. A constant charge can be applied between the anode and cathode with the discharge current being measured by an electrometer. Each ion pair produced by the radiation in the chamber contributes one electron toward the discharge current, so the reading is proportional to the radiation present or the exposure. The unit of exposure due to X rays and gamma rays is the Roentgen (R), and exposure is measured as Roentgens per hour (R/hr). Ion chambers are difficult to construct with great accuracy because of the small currents which must be measured and spurious noise which comes from the electronics of the system.

PROPORTIONAL COUNTERS

If the electric field between the anode and cathode of an ion chamber is increased, electrons released during ionization caused by radiation will be able to ionize additional atoms before they reach the anode. This cascading effect creates larger pulses which are dependent upon the field strength and also upon the energy released by the ionizing radiation. This makes it possible to distinguish between alpha radiation and beta radiation. A unit characterizing the amount of energy absorbed by a unit mass of material is known as the rad or Radiation Absorbed Dose. The rad is used for measuring all types of ionizing radiation, whereas the Roentgen applies only to X rays and gammas.

GEIGER COUNTERS

If the applied voltage between the anode and cathode is sufficiently great, each ionizing event resulting from radiation will cause an avalanche effect which will fill the entire chamber. Thus, each ionizing praticle will create a large pulse which is easily detected and independent of the energy of the ionizing radiation. A quenching gas must be included within the chamber to recharge the chamber after each event. If the radiation levels are sufficiently high that quenching isn't completed before the next event, counts are lost. The readings from Geiger counters are registered in counts per minutes (cpm). Some Geiger counters have scales marked in R/hr or mR/hr but these scales are calibrated for gammas of one energy only and must be adjusted for gammas of differing energies.

SCINTILLATION CRYSTAL COUNTERS

The crystals of certain materials such as sodium iodide (NaI) will scintillate, or emit light, when exposed to ionizing radiation, especially gammas. This light can be detected by a photomultiplier tube, which in turn gives a measure of the energy being released by the radiation. Gammas of different energies can be distinguished through proper electronic circuitry enabling the identification of radioisotopes by their gamma spectrums.

LIQUID SCINTILLATION COUNTERS

To enable the detection and measurement of low-energy betas such as tritium, carbon-14, and sulphur-35, the radioactive material is suspended in a material which scintillates due to the radiation passing through it. A geometry efficiency of nearly 100 percent can be achieved by suspending the radioactive material within the detecting medium. The light is detected by photomultiplier tubes and pulses of differing energies can be distinguished through proper electronic circuitry.

FILM DOSIMETERS

Ionizing radiation exposes film in the same manner as light exposes it. The amount of radiation causing the exposure is determined by measuring the light density of the film. The results obtained by measuring film density are influenced by such factors as age, fabrication processes, and the developing of the film, as well as other factors which make quality control difficult. For many years, film dosimeters were the best available means of recording personnel exposures over a period of time. Today, TLD dosimeters are replacing film in many areas.

THERMOLUMINESCENT DOSIMETERS

Certain ceramic materials will trap energy released by radiation passing through it. This energy can be released by heating the ceramic material, which luminesces or gives off light in proportion to the radiation absorbed. These devices are called thermoluminescent devices or TLDs and are used as personnel dosimeters.

MEASURING RADIOACTIVITY

RADIOACTIVE DECAY

The chemical properties of elements are characterized by the electrons surrounding the nucleus, which in turn are determined by the number of protons in the nucleus. Nuclear properties of an atom are characterized by the ratio of neutrons to protons in the nucleus, or the A/Z ratio. Each element contains atoms with the same number of protons, but isotopes of the element contain varying numbers of neutrons. When the number of neutrons in an atom is either too great or too small to balance the number of protons, the atom is unstable and decays emitting either an alpha or beta particle. The atom resulting from this decay or disintegration may be excited and emit gammas before resting in a stable state. The nature of radioactive decay is a property of each unstable isotope and is unique with each isotope. The probability of an atom in a radioactive material decaying within a specified time is measurable and is known as the activity of the material. Activity of a radioactive material is measured in curies (2.2×10^{12} disintegrations per minute (dpm)), millicuries (2.2×10^{9} dpm), or microcuries (2.2×10^{6} dpm). Specific activity is the activity per unit mass or unit volume of the material such as millicuries per gram or microcuries per microliter.

HALF LIFE

The activity of a radioactive material may be known at one point in time but it changes as some atoms decay, decreasing the total number of atoms which are unstable. The activity at any point of time can be characterized by the formula $A = A_0 e^{-\lambda t}$, where A is the activity of interest, A_0 is the known activity at the time $t = 0$, λ is the decay constant which is a property of the radioactive isotope, and t is the time since the activity was known. The activity will decrease to half of its original activity in the time $t = T_{\frac{1}{2}}$ which is known as the half life of the material. In other words, the activity will decrease by one-half in each half life. The half life of a radioactive material is a property of the radioisotope and is characterized by $T_{\frac{1}{2}} = 0.693/\lambda$. The half life of tritium is 12.33 years, of carbon-14 is 5730 years, of phosphorus-32 is 14.31 days, and of iodine-125 is 59.7 days.

IONIZING RADIATION

Radiation, whether in the form of alphas, betas, gammas, or X rays, with sufficient energy to ionize atoms is known as ionizing radiation. An atom is ionized when it loses one or more electrons from its electron orbitals through interaction with the radiation. The conventional method of detecting ionizing radiation is to construct a chamber with a thin wire anode and a conducting outer surface which serves as a cathode. A static electric field is then maintained between the anode and cathode. As ionizing radiation passes through the chamber it ionizes molecules of air or gas within the chamber. The electrons are attracted toward the anode, and the heavier positive ions are attracted toward the cathode. A discharge can then be measured in the electrical circuitry connecting the anode with the cathode of the instrument. An ion counter will record a small current, but a Geiger counter will record a series of pulses, each in proportion to the ionizing radiation entering the chamber. The majority of portable radiation-detection devices utilize the concept of an ionization chamber.

COUNTING EFFICIENCY

The problem with measuring radioactivity is in relating the reading on the meter of an instrument with the amount of radioactivity present. Alphas and many betas may be absorbed by the walls of the detector without entering the counting chamber. On the other hand, high energy gammas may pass through the chamber in great numbers without interacting with the ionizing gas, and, therefore, never be detected. The ratio between the number of counts measured and the activity of the material being measured is known as the counting efficiency. The efficiency or sensitivity of a radiation detector or counter depends on many factors. The basic factors which must always be considered are (1) the intrinsic efficiency of the counter, (2) the background count rate, (3) absorption factors, and (4) geometry. These factors will be discussed below, concluding the topic of Measuring Radiation.

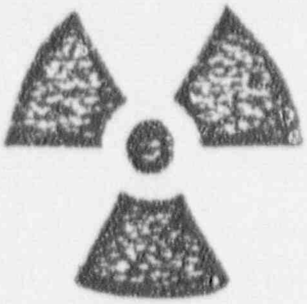
1. The intrinsic efficiency is the probability that radiation entering the sensitive volume of the detector will actually be counted. This depends on the construction of the detector as well as the nature of the radiation. Charged particles will be detected in a gas-filled chamber with about 100 percent efficiency until saturation or over-loading occurs, but only 1 percent of the gammas entering the chamber may be detected.

2. A certain amount of ionizing radiation is around us at all times. This is known as the natural background. Sometimes the amount of activity we are trying to detect is hidden in the statistical variation of the background. The background, therefore, must be considered in any measurement taken and can vary widely between instruments, location, and even the day in which measurements are made.

3. Charged particles such as alphas and betas lose energy while passing through matter. When the kinetic energy is gone, they stop or are absorbed, and can no longer be detected. Absorption may occur in the material itself, in the walls of the detector, or in the air between. Care must be taken in measuring radiation which may be absorbed so that zero readings on the meter aren't interpreted as no radioactivity. A good instrument design must be coupled with proper survey techniques in order to measure or even detect some materials such as tritium and carbon-14.

4. Radiation is emitted from a radioactive material in a random manner in all directions. Unless the detector surrounds the radioactive source, the geometric factor must be considered. A detector with 100 percent intrinsic efficiency and no absorption could only detect 50 percent of the radiation emitting from a flat surface. A hand-held probe any distance from the source will detect a smaller fraction of the emitted radiation depending on the fraction of solid angle incorporated by the detector. A geometric correction must also be made to account for the size of the source with respect to the size of the detector. An extended source will give a different reading than a point source of the same activity.

BIOLOGICAL EFFECTS OF RADIATION



REM, THE UNIT OF BIOLOGICAL EXPOSURE

The biological effects of radiation are due to energy absorbed by tissues from the radiation passing through. Some forms of radiation such as neutrons and alpha particles are more destructive to tissues than are gammas and betas of the same energy. The unit of radiation exposure which relates the exposure in rads to the biological effect of each particular type of radiation is called the rem. The number of rems is determined by multiplying the exposure in rads by a quality factor, "Q", which is equal to 1 for gamma and beta radiation, 10 for alphas, and 1-10 for neutrons depending on the neutron energy.

STRUCTURE AND NATURE OF CELLS

All tissue is made of cells consisting of both a nucleus which contains genetic information and cytoplasm within which cell functions and growth take place. Some cells such as bone marrow or blood-forming cells are active and divide frequently. Other cells such as bone or muscle cells are more mature and have less activity. Cells of a small child or a fetus are much more active than those of an adult. The radiosensitivity of cells is directly related to cell activity or how frequently cells divide producing new tissue.

EFFECT OF RADIATION ON CELLS

As radiation penetrates cells, it loses energy to the cell material. Since about 70 percent of the cell is composed of water, the majority of the radiation interacts with the water to form ions or free radicals, which, in turn, enter into chemical and biological reactions within the cell. Radiation can also break molecular bonds causing confusion in enzymes or genetic information. Certain radioisotopes can be incorporated into vital cell functions, which functions are modified when the isotope decays and forms another element. An example is that of carbon 14 decaying into nitrogen 14 which has different properties from those of carbon.

Cells have natural mechanisms to repair damage caused by radiation and other factors, but if the amount of damage exceeds the ability to repair, the cell either dies or begins to malfunction. It is the excessive death or malfunctioning of cells in tissues which cause the biological effect.

SOMATIC EFFECTS

Somatic effects are short-term biological effects which can be medically identified and related to radiation. These may include damage to the blood and bone marrow, lymphatic system, digestive tract, reproductive organs (which might cause temporary or permanent sterility), central nervous system, thyroid gland, eyes (through the formation of cataracts), lungs, liver and gallbladder, kidneys, circulatory system, skin, hair, and bones. The severity of these somatic effects are related to the type and amount of radiation received, the age and physical health of the person exposed, the portion of the body exposed, and how vital the organ is to body processes. It is often possible to medically assist a vital body process which has been damaged, allowing the person to live until the organs can regenerate themselves, repair the damage, and being functioning normally. Severe damage to the digestive tract and the central nervous system are usually fatal.

LATENT EFFECTS

Sometimes radiation causes damage which doesn't manifest itself for many years. These effects may be a shortening of life, cancer, tissue effects like cataracts or sterility, and effects on growth, especially to the fetus. Each of these effects results from combinations of diverse causes, radiation being one potential factor. They are difficult to attribute to radiation or any other single factor except through a statistical analysis of numerous persons (or animals) receiving specified levels of exposures which are evaluated over long periods of time. In this respect, radiation is one of many environmental pollutants to which we are continually exposed.

GENETIC OR HEREDITARY EFFECTS

Genetic effects are not manifest in the generation receiving the radiation exposure. They are caused only by mutations transmitted sexually from one generation to the next. Since mutations occur naturally, and since high radiation doses will destroy cells rather than leave them viable in a mutated state, these effects are extremely difficult to detect. No genetic effects due to radiation have ever been identified in man. Genetic effects have been observed in animals exposed to high levels of radiation, but not for low exposures approximating natural background. The fear of creating a weird beast through radiation exposure is scientifically unfounded.

CONCLUSION

Radiation affects the biological processes of cells in the tissues and organs of the body. The severity of the effect is a result of the type and amount of radiation exposure as measured in rems, the radiosensitivity of the tissues which are exposed, how vital the exposed organs are to body functions, the age and health of the exposed individual, as well as other factors not enumerated herein. These effects may manifest themselves as somatic effects which are easily recognized, latent or long-term effects, or genetic and hereditary effects. Latent and hereditary effects are difficult to identify because of other factors which contribute to any effects which might be observable.

The quantitative relationship between half-life, T, and decay constant, λ, may be found by setting A/A_0 in equation (4.18) equal to $\frac{1}{2}$, and solving the equation for t. In this case, of course, the time is the half-life.

$$\frac{A}{A_0} = \frac{1}{2} = e^{-\lambda T},$$

$$T = \frac{0.693}{\lambda}. \tag{4.21}$$

Example 4.4

Given that the decay constant for ^{226}Ra is 4.38×10^{-4} per year, calculate the half-life for radium.

$$\lambda\; \underset{T}{T} = \frac{0.693}{\lambda\, T}\; x \qquad \lambda = \frac{0.693}{\lambda}$$

$$= \frac{0.693}{4.38} \times 10^{-4}\ \mathrm{yr}^{-1}$$

$$= 1580 \text{ years.}$$

Average Life

Although the half-life of an isotope is a unique, reproducible characteristic of that isotope, it is nevertheless a statistical property, and is valid only because of the very large number of atoms involved. (One microgram radium contains 2.79×10^{15} atoms.) Any particular atom of a radioisotope may disintegrate at any time, from zero to infinity, after it is observed. For some applications, such as in the case of dosimetry of internally deposited radioisotopes (to be discussed in Chapter 6), it is convenient to use the average life of the radioisotope. The average life is defined simply as the sum of the lifetimes of the individual atoms divided by the total number of atoms originally present.

The instantaneous disintegration rate of a quantity of radioisotope containing N atoms is λN. During the time interval between t and $t + dt$, the total number of disintegrations is $\lambda N dt$. Each of the atoms that decayed during this interval, however, had existed for a total lifetime t since the beginning of observation on them. The sum of the lifetimes, therefore, of all the atoms that decayed during the time interval between t and $t + dt$, after having survived since time $t = 0$, is $t\lambda N dt$. The average life of the radioactive species, τ, is

$$\tau = \frac{1}{N_0} \int_0^\infty t\, \lambda\, N\, dt, \tag{4.22}$$

where N_0 is the number of radioactive atoms in existence at time $t = 0$. Since

$$N = N_0 e^{-\lambda t},$$

we have

$$\tau = \frac{1}{N_0} \int_0^\infty t\, \lambda\, N_0 e^{-\lambda t}\, dt. \tag{4.23}$$

This expression, when integrated by parts, shows the value for the mean life of a radioisotope to be

$$\tau = \frac{1}{\lambda}. \tag{4.24}$$

If the expression for the decay constant in terms of the half-life of the radioisotope,

$$\lambda = \frac{0.693}{T},$$

is substituted into equation (4.22), the relationship between the half-life and the mean life is found to be

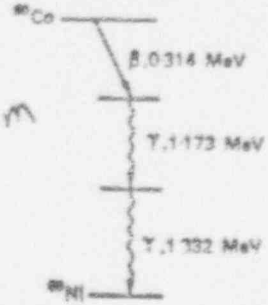
$$\tau = \frac{T}{0.693} = 1.45\, T. \tag{4.25}$$

The Curie

Uranium-238 and its daughter ^{234}Th each contain about the same number of atoms per gram; approximately 2.5×10^{21}. Their half-lives, however, are greatly different; ^{238}U has a half-life of 4.5×10^{9} years while ^{234}Th has a half-life of 24.1 days (or 6.63×10^{-2} years). Thorium-234, therefore, is decaying 6.8×10^{10} times faster than ^{238}U. Another example of greatly different rates of decay that may be cited is ^{35}S and ^{32}P. These two radioisotopes, which have about the same number of atoms per gram, have half-lives of 87 and 14.3 days respectively. The radiophosphorous, therefore, is decaying about 6 times faster than the ^{35}S. When radioisotopes are used, the radiations are the center of interest. In this context, therefore, $\frac{1}{6}$ of a gram of ^{32}P is about equivalent to 1 g of ^{35}S in radioactivity, while 15 micromicrograms of ^{234}Th is about equivalent in activity to 1 g of ^{238}U. Obviously, therefore, when interest is centered on radioactivity, the gram is not a very useful unit of quantity. To be meaningful, the unit for quantity of radioactivity must be based on activity. Such a unit is called the *curie* (symbolized by Ci) and is defined as follows:

> The curie is the activity of that quantity of radioactive material in which the number of disintegrations per second is 3.7×10^{10}.

It should be emphasized that, although the curie is defined in terms of a number of disintegrating atoms per second, it is not a measure of rate of decay. *The curie is a measure only of quantity* of radioactive material. The phrase "disintegrations per second" as used in the definition of the curie is not synonymous with number of particles emitted by the radioactive isotope. In the case of a simple pure beta emitter, for example, 1 curie, or 3.7×10^{10} disintegrations per second, does in fact result in 3.7×10^{10} beta particles per second. In the case of a more complex radioactive isotope, however, such as ^{60}Co, Fig. 4.12, each disintegration releases 1 beta particle and 2 gamma photons; the total number of radiations, therefore, is $3 \times 3.7 \times 10^{10}$, or 11.1×10^{10} per second per curie ^{60}Co. In the case of ^{40}K, Fig. 4.6, on the other hand, 20% of the beta decays are accompanied by a single quantum of gamma radiation. The total number of emissions from 1 curie ^{40}K, therefore, is



2.2 x 10^12 cpm

Fig. 4.12. Cobalt-60 decay scheme.

$$3.7 \times 10^{10} + 0.2 \times 3.7 \times 10^{10} = 4.44 \times 10^{10} \text{ per sec.}$$

For health physics, as well as for many other purposes, the curie is a very large quantity of activity. Submultiples of the curie, as listed below, therefore are used:

1 millicurie (mCi) = 10^{-3} Ci
1 microcurie (μCi) = 10^{-6} Ci
1 nanocurie (nCi) = 10^{-9} Ci
1 picocurie (pCi) = 10^{-12} Ci

3.3 No d/m [illegible]

3. d/m [illegible]

[illegible]

Multiples of the curie that are frequently used are the kilocurie and the megacurie. These quantities are generally not abbreviated.

Specific Activity

Note that the curie, although used as a unit of quantity, does not mention anything about the mass or volume of the radioactive material in which the specified number of disintegrations per second occur. The concentration of radioactivity, or relationship between the mass of radioactive material and the activity, is called the specific activity. Specific activity is the number of curies per unit mass or volume. The specific activity of a carrier free radioisotope, that is, a radioisotope that is not mixed with any other isotope of the same element, may be calculated as follows:

If λ is the decay constant in units of reciprocal seconds, then the number of disintegrating atoms per second among an aggregation of N atoms is simply

$$\frac{\text{disintegrations}}{\text{second}} = \lambda N.$$

If the radioisotope under consideration weighs 1 then, according to equation (4.20), the number of atoms is simply equal to

$$N = \frac{6.03 \times 10^{23} \text{ atoms/mole}}{A \text{ g/mole}},$$

where A is the atomic weight of the isotope. The activity per unit time, therefore, is

$$\lambda N = \frac{\lambda \times 6.03 \times 10^{23}}{A} \frac{\text{dis}}{\text{sec/g}}. \qquad (4.26)$$

Equation (4.26) gives the desired relationship between activity and weight of an isotope. The unit for activity in the equation may be converted from disintegrations per second to curies by application of the fact that there are 3.7×10^{10} disintegrations per second per curie:

$$\text{Specific activity} = \frac{\lambda \times 6.03 \times 10^{23}/A \text{ dps/g}}{3.7 \times 10^{10} \text{ dps/curie}}.$$

$$\text{Specific activity} = 1.63 \times 10^{13} \frac{\lambda}{A} \frac{\text{curies}}{\text{gram}}. \qquad (4.27)$$

Note that the decay constant, λ, in equation (4.27), must be in reciprocal seconds. Equation (4.27) may be rewritten in terms of half-life rather than decay constant.

$$\text{S.A.} = \frac{1.63 \times 10^{13}}{A} \times \frac{0.693}{T} = \frac{1.13 \times 10^{13}}{A \times T} \frac{\text{curies}}{\text{g}}. \qquad (4.28)$$

U.S. NUCLEAR REGULATORY COMMISSION

July 1981

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 8.29
(Task OH 902-4)

INSTRUCTION CONCERNING RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

A. INTRODUCTION

Section 19.12 of 10 CFR Part 19, "Notices, Instructions and Reports to Workers; Inspections," requires that all persons working in or frequenting any portion of a restricted area be instructed in the health protection problems associated with exposure to radioactive materials or radiation. This guide describes the instruction that should be provided to the worker concerning biological risks from occupational radiation exposure. Additional guides are being or will be developed to address other aspects of radiation protection training.

B. DISCUSSION

It is generally accepted by the scientific community that exposure to ionizing radiation can cause biological effects that are harmful to the exposed organism. These effects are classified into three categories:

Somatic Effects: Effects occurring in the exposed person that, in turn, may be divided into two classes:

> *Prompt effects* that are observable soon after a large or acute dose (e.g., 100 rems[1] or more to the whole body in a few hours), and
>
> *Delayed effects* such as cancer that may occur years after exposure to radiation.

Genetic Effects:[2] Abnormalities that may occur in the future children of exposed individuals and in subsequent generations.

Teratogenic Effects: Effects that may be observed in children who were exposed during the fetal and embryonic stages of development.

Concerns about these biological effects have resulted in controls on doses to individual workers and in efforts to control the collective dose (person-rems) to the worker population.

NRC-licensed activities result in a significant fraction of the total occupational radiation exposure in the United States. Regulatory action has recently focused more attention on maintaining occupational radiation exposure at levels that are as low as is reasonably achievable (ALARA). Radiation protection training for all workers who may be exposed to ionizing radiation is an essential component of any program designed to maintain exposure levels ALARA. A clear understanding of what is presently known about the biological risks associated with exposure to radiation will result in more effective radiation protection training and should generate more interest on the part of the worker in minimizing both individual and collective doses. In addition, radiation workers have the right to whatever information on radiation risk is available to enable them to make informed decisions regarding the acceptance of these risks. It is intended that workers who receive this instruction develop a healthy respect for the risks involved rather than excessive fear or indifference.

At the relatively low levels of occupational radiation exposure in the United States, it is difficult to demonstrate a relationship between exposure and effect. There is considerable uncertainty and controversy regarding estimates of radiation risk. In the appendix to this guide, a range of risk estimates is provided (see Table 1). Information on radiation risk has been included from such sources as the 1980 National Academy of Sciences' Report of the Committee on the Biological Effects of Ionizing Radiation (BEIR-80), the International Commission on Radiological Protection (ICRP) Publication 27 entitled "Problems in Developing an Index of Harm," the 1979 report of the science work group of the Interagency Task Force on the Health Effects of Ionizing Radiation, the 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR report), and numerous published articles (see the bibliography to the appendix).

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[1] In the International System of Units (SI), the rem is replaced by the sievert. 100 rems is equal to 1 sievert (Sv).

[2] Genetic effects exceeding normal incidence have not been observed in any of the studies of exposed humans.

C. REGULATORY POSITION

Strong management support is considered essential to an adequate radiation protection training program. Instruction to workers performed in compliance with § 19.12 of 10 CFR Part 19 should be given prior to assignment to work in a restricted area and periodically thereafter. In providing instruction concerning health protection problems associated with exposure to radiation, all workers, including those in supervisory roles, should be given specific instruction on the risk of biological effects resulting from exposure to radiation.

The instruction should be presented both orally and in printed form to all affected workers and supervisors. It should include the information provided in the appendix to this guide.[3] The information should be discussed during training sessions. Each individual should be given an opportunity to ask questions and should be asked to acknowledge in writing that the instruction has been received and understood.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which an applicant or licensee proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the methods described in this guide will be used in the evaluation of the training program for all individuals working in or frequenting any portion of a restricted area and for all supervisory personnel after December 15, 1981.

If an applicant or licensee wishes to use the material provided in this guide on or before December 15, 1981, the pertinent portions of the application or the licensee's performance will be evaluated on the basis of this guide.

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[3] Copies of the appendix to this guide are available at the current Government Printing Office price, which may be obtained by writing to the U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Publications Sales Manager. This appendix is not copyrighted, and Commission approval is not required to reproduce it.

U.S. NUCLEAR REGULATORY COMMISSION

APPENDIX TO REGULATORY GUIDE 8.29

INSTRUCTION CONCERNING RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

This instructional material is intended to provide the user with the best available information concerning what is currently known about the health risks from exposure to ionizing radiation.[1] A question and answer format has been used. The questions were developed by the NRC staff in consultation with workers, union representatives, and licensee representatives experienced in radiation protection training. Risk estimates have been compiled from numerous sources generally recognized as reliable. A bibliography is included for the user interested in further study.

The biological effects that are known to occur after exposure to high doses (hundreds of rems[2]) of radiation are discussed early in the document; discussions of the estimated risks from the low occupational dose (<5 rems per year) follow. It is intended that this information will help develop an attitude of healthy respect for the risks associated with radiation, rather than unnecessary fear or lack of concern. Additional guidance is being or will be developed concerning other topics in radiation protection training.

* * * * * * *

1. *What is meant by risk?*

Risk can be defined in general as the probability (chance) of injury, illness, or death resulting from some activity. However, the perception of risk is affected by how the individual views its probability and its severity. The intent of this document is to provide estimates of and explain the basis for possible risk of injury, illness, or death resulting from occupational radiation exposure. (See Questions 9 and 10 for estimates of radiation risk and comparisons with other types of risk.)

2. *What are the possible health effects of exposure to radiation?*

Some of the health effects that exposure to radiation may cause are cancer (including leukemia), birth defects in the future children of exposed parents, and cataracts.[3] These effects (with the exception of genetic effects) have been observed in studies of medical radiologists, uranium miners, radium workers, and radiotherapy patients who have received large doses of radiation. Studies of people exposed to radiation from atomic weapons have also provided data on radiation effects. In addition, radiation effects studies with laboratory animals have provided a large body of data on radiation-induced health effects, including genetic effects.

The observations and studies mentioned above, however, involve levels of radiation exposure that are much higher (hundreds of rems) than those permitted occupationally today (<5 rems per year). Although studies have not shown a cause-effect relationship between health effects and current levels of occupational radiation exposure, it is prudent to assume that some health effects do occur at the lower exposure levels.

3. *What is meant by prompt effects, delayed effects, and genetic effects?*

a. Prompt effects are observable shortly after receiving a very large dose in a short period of time. For example, a whole-body[4] dose of 450 rems (90 times the annual dose limit for routine occupational exposure) in an hour to an average adult will cause vomiting and diarrhea within a few hours; loss of hair, fever, and weight loss within a few weeks; and about a 50 percent chance of death within 60 days without medical treatment.

b. Delayed effects such as cancer may occur years after exposure to radiation.

c. Genetic effects can occur when there is radiation damage to the genetic material. These effects may show up as birth defects or other conditions in the future children of the exposed individual and succeeding generations, as demonstrated in animal experiments. However, excess genetic effects clearly caused by radiation have not been observed in human populations exposed to radiation. It has been observed, however, that radiation can change the genes in cells of the human body. Thus, the possibility exists that genetic effects can be caused in humans by low doses even though no direct evidence exists as yet.

4. *In worker protection, which effects are of most concern to the NRC?*

The main concern to the NRC is the delayed incidence of cancer. The chance of delayed cancer is believed to depend

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[1] Ionizing radiation consists of energy or small particles such as gamma, beta, or alpha radiation emitted from radioactive materials which, when absorbed by living tissue, can cause chemical and physical damage.

[2] The rem is the unit of measure for radiation dose and relates to the biological effect of the absorbed radiation.

[3] Cataracts differ from other radiation effects in that a certain level of dose to the lens of the eye (≈ 200 rems) is required before they are observed.

[4] It is important to distinguish between whole-body and partial-body exposure. 100 rems to the whole body will have more effect than 100 to a hand. For example, exposure of a hand would affect a small fraction of the bone marrow and a limited portion of the skin.

on how much radiation exposure a person gets; therefore, every reasonable effort should be made to keep exposures low.

Immediate or prompt effects are very unlikely since large exposures would normally occur only if there were a serious radiation accident. Accident rates in the radiation industry have been low, and only a few accidents have resulted in exposures exceeding the legal limits. The probability of serious genetic effects in the future children of workers is estimated in the BEIR[5] report, based on animal studies, at less than one-third that of delayed cancer (5-65 genetic effects per million rems compared to 160-450 cancer cases). A clearer understanding of the cause-effect relationship between radiation and human genetic effects will not be possible until additional research studies are completed.

5. *What is the difference between acute and chronic exposure?*

Acute radiation exposure, which causes prompt effects and may also cause delayed effects, usually refers to a large dose of radiation received in a short period of time; for example, 450 rems received within a few hours or less. The effects of acute exposures are well known from studies of radiotherapy patients, some of whom received whole-body doses; atomic bomb victims; and the few accidents that have occurred in the early days of atomic weapons and reactor development, industrial radiography, and nuclear fuel processing. There have been few occupational incidents that have resulted in large exposures. NRC data indicate that, on the average, 1 accidental overexposure in which any acute symptoms are observed occurs each year. Most of these occur in industrial radiography and involve exposures of the hands rather than the whole body.

Chronic exposure, which may cause delayed effects but not prompt effects, refers to small doses received repeatedly over long time periods; for example, 20-100 mrem (a mrem is one-thousandth of a rem) per week every week for several years. Concern with occupational radiation risk is primarily focused on chronic exposure to low levels of radiation over long time periods.

6. *How does radiation cause cancer?*

How radiation causes cancer is not well understood. It is impossible to tell whether a given cancer was caused by radiation or by some other of the many apparent causes. However, most diseases are caused by the interaction of several factors. General physical condition, inherited traits, age, sex, and exposure to other cancer-causing agents such as cigarette smoke are a few possible contributing factors. One theory is that radiation can damage chromosomes in a cell, and the cell is then directed along abnormal growth patterns. Another is that radiation reduces the body's normal resistance to existing viruses which can then multiply and damage cells. A third is that radiation activates an existing virus in the body which then attacks normal cells causing them to grow rapidly.

What is known is that, in groups of highly exposed people, a higher than normal incidence of cancer is observed. Higher than normal rates of cancer can also be produced in laboratory animals by high levels of radiation. An increased incidence of cancer has not been demonstrated at radiation levels below the NRC limits.

7. *If I receive a radiation dose, does that mean I am certain to get cancer?*

Not at all. Everyone gets a radiation dose every day (see Question 25), but most people do not get cancer. Even with doses of radiation far above legal limits, most individuals will experience no delayed consequences. There is evidence that some radiation damage can be repaired. The danger from radiation is much like the danger from cigarette smoke. Only a fraction of the people who breathe cigarette smoke get lung cancer, but there is good evidence that smoking increases a person's chances of getting lung cancer. Similarly, there is evidence that the larger the radiation dose, the larger the increase in a person's chances of getting cancer.

Radiation is like most substances that cause cancer in that the effects can be seen clearly only at high doses. Estimates of the risks of cancer at low levels of exposure are derived from data available for exposures at high dose levels and high dose rates. Generally, for radiation protection purposes these estimates are made using the linear model (Curve 1 in Figure 1). We have data on health effects at high doses as shown by the solid line in Figure 1. Below about 100 rems, studies have not been able to accurately measure the risk, primarily because of the small numbers of exposed people and because the effect is small compared to differences in the normal incidence from year to year and place to place. Most scientists believe that there is some degree of risk no matter how small the dose (Curves 1 and 2). Some scientists believe that the risk drops off to zero at some low dose (Curve 3), the threshold effect. A few believe that risk levels off so that even very small doses imply a significant risk (Curve 4). The majority of scientists today endorse either the linear model (Curve 1) or the linear-quadratic model (Curve 2). The NRC endorses the linear model (Curve 1), which shows the number of effects decreasing as the dose decreases, for radiation protection purposes.

It is prudent to assume that smaller doses have some chance of causing cancer. This is as true for natural cancer-causers such as sunlight and natural radiation as it is for those that are man made such as cigarette smoke, smog, and man-made radiation. As even very small doses may entail some small risk, it follows that no dose should be taken without a reason. Thus, a principle of radiation protection is to do more than merely meet the allowed regulatory

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[5] The National Academy of Sciences established a committee on the Biological Effects of Ionizing Radiation (BEIR) whose 1980 report on the effects on populations of exposure to low levels of ionizing radiation provides much of the background for this guide.

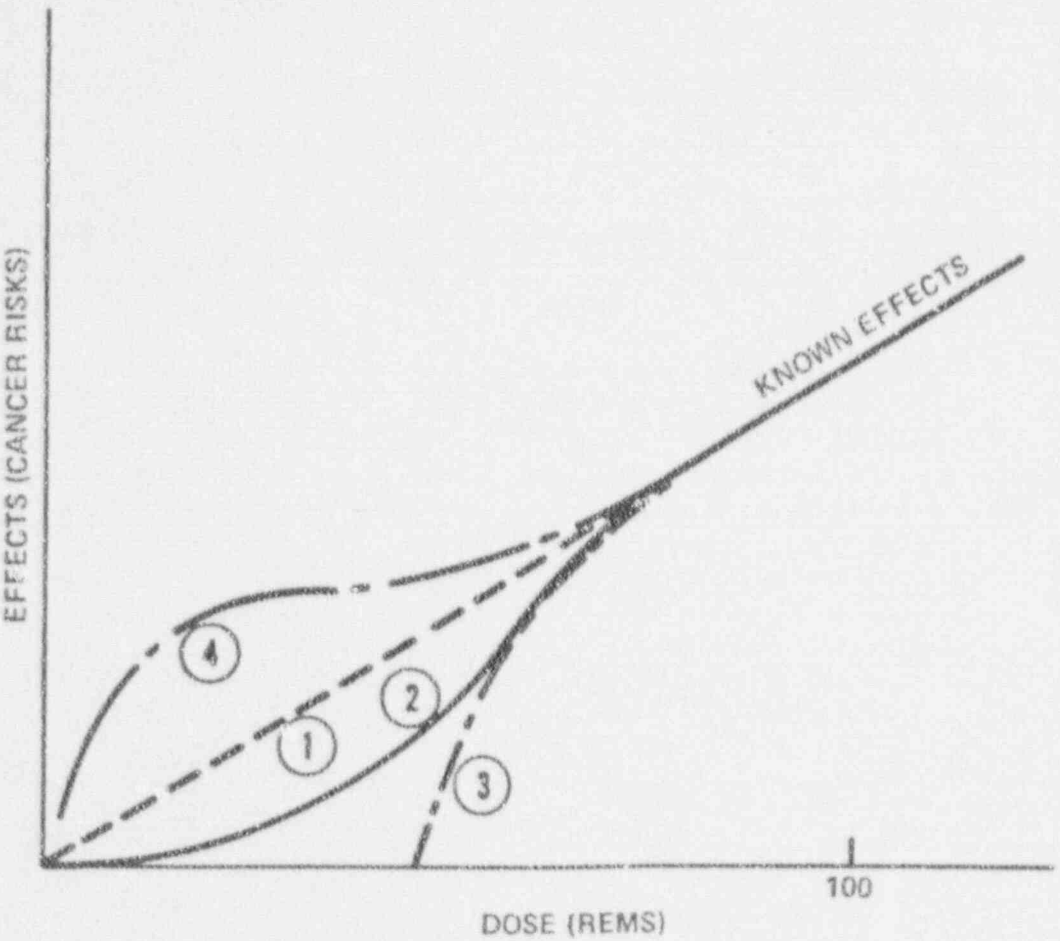

Figure 1. Some proposed models for how the effects of radiation vary with doses at low levels.

limits; doses should be kept as low as is reasonably achievable (ALARA).

We don't know exactly what the chances are of getting cancer from a low-level radiation dose, but we can make estimates based on extensive scientific knowledge. The estimates of radiation risks are at least as reliable as estimates for the effects from any chemical hazard. Being exposed to typical occupational radiation doses is taking a chance, but that chance is reasonably well understood.

It is important to understand the probability factors here. A similar question would be: If you select one card from a full deck, will you get the ace of spades? This question cannot be answered with a simple yes or no. The best answer is that your chances are 1 in 52. However, if 1000 people each select one card from full decks, we can predict that about 20 of them will get an ace of spades. Each person will have 1 chance in 52 of drawing the ace of spades, but there is no way that we can predict which persons will get the right card. The issue is further complicated by the fact that in 1 drawing by 1000 people, we might get only 15 successes and in another perhaps 25 correct cards in 1000 draws. We can say that if you receive a radiation dose, you will have increased your chances of eventually developing cancer. It is assumed that the more radiation exposure you get, the more you increase your chances of cancer.

Not all workers incur the same level of risk. The radiation risk incurred by a worker depends on the amount of dose received. Under the linear model explained above, a worker who receives 5 rems in a year incurs 10 times as much risk as another worker (the same age) who receives only 0.5 rem. The risk depends not only on the amount of dose, but also on the age of the worker at the time the dose is received. This age difference is due, in part, to the fact that a young worker has more time to live than an older worker, and the risk is believed to depend on the number of years of life following the dose. The more years left, the larger the risk. It should be clear that, even within the regulatory dose limits, the risk may vary a great deal from one worker to another. Fortunately, only a very few workers receive doses near 5 rems per year; as pointed out in the answer to Question 19, the average annual dose for all radiation workers is less than 0.5 rem.

A reasonable comparison involves exposure to the sun's rays. Frequent short exposures provide time for the skin to repair. An acute exposure to the sun can result in painful burning, and excessive exposure has been shown to cause skin cancer. However, whether exposure to the sun's rays is short term or spread over time, some of the injury is not repaired and may eventually result in skin cancer.

The effect upon a group of workers occupationally exposed to radiation may be an increased incidence of cancer over and above the number of cancers that would normally be expected in that group. Each exposed individual has an increased probability of incurring subsequent cancer. We can say that if 10,000 workers each receive an additional 1 rem in a year, that group is more likely to have a larger incidence of cancer than 10,000 people who do not receive the additional radiation. An estimate of the increased probability of cancer from low radiation doses delivered to large groups is one measure of occupational risk and is discussed in Question 9.

8. *What groups of expert scientists have studied the risk from exposure to radiation?*

In 1956, the National Academy of Sciences established advisory committees to consider radiation risks. The first of these was the Advisory Committee on the Biological Effects of Atomic Radiations (BEAR) and more recently it was renamed the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR). These committees have periodically reviewed the extensive research being done on the health effects of ionizing radiation and have published estimates of the risk of cancer from exposure to radiation (1972 and 1980 BEIR reports). The International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP) are two other groups of scientists who have studied radiation effects and published risk estimates (ICRP Publication 26, 1977). These two groups have no government affiliation. In addition, the United Nations established an independent study group that published an extensive report in 1977, including estimates of cancer risk from ionizing radiation (UNSCEAR, 1977).

Several individual research groups or scientists such as Alice Stewart, E.S. Gilbert, T.F. Mancuso, T.W. Anderson, to name a few, have published studies concerning low level radiation effects. The bibliography to this appendix includes several articles for the reader who wishes to do further study. The BEIR-80 report includes analysis of the work of many independent researchers.

9. *What are the estimates of the risk of cancer from radiation exposure?*

The cancer risk estimates (developed by the organizations identified in Question 8) are presented in Table 1.

In an effort to explain the significance of these estimates, we will use an approximate average of 300 excess cancer cases per million people, each exposed to 1 rem of ionizing radiation. If in a group of 10,000 workers each receives 1 rem, we could estimate that three would develop cancer because of that exposure, although the actual number could be more or less than three.

TABLE 1

Estimates of Excess Cancer Incidence from Exposure to Low-Level Radiation

Source	Number of Additional[a] Cancers Estimated to Occur in 1 Million People After Exposure of Each to 1 Rem of Radiation
BEIR, 1980	160-450[b]
ICRP, 1977	200
UNSCEAR, 1977	150-350

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[a] Additional means above the normal incidence of cancer.

[b] All three groups estimated premature deaths from radiation-induced cancers. The American Cancer Society has recently stated that only about one-half of all cancer cases are fatal. Thus, to estimate incidence of cancer, the published numbers were multiplied by 2. Note that the three groups are in close agreement on the risk of radiation-induced cancer.

The American Cancer Society has reported that approximately 25 percent of all adults in the 20- to 65-year age bracket will develop cancer at some time from all possible causes such as smoking, food, alcohol, drugs, air pollutants, and natural background radiation. Thus in any group of 10,000 workers not exposed to radiation on the job, we can expect about 2,500 to develop cancer. If this entire group of 10,000 workers were to receive an occupational radiation dose of 1 rem each, we could estimate that three additional cases might occur which would give a total of about 2,503. This means that a 1-rem dose to each of 10,000 workers might increase the cancer rate from 25 percent to 25.03 percent, an increase of about 3 hundredths of one percent.

As an individual, if your cumulative occupational radiation dose is 1 rem, your chances of eventually developing cancer during your entire lifetime may have increased from 25 percent to 25.03 percent. If your lifetime occupational dose is 10 rems, we could estimate a 25.3 percent chance of developing cancer. Using a simple linear model, a lifetime dose of 100 rems may have increased your chances of cancer from 25 to 28 percent.

The normal chance of developing cancer if you receive no occupational radiation dose is about equal to your chance of getting any spade on a single draw from a full deck of playing cards, which is one chance out of four. The additional chance of developing cancer from an occupational exposure of 1 rem is less than your chances of drawing an ace from a full deck of cards three times in a row.

Since cancer resulting from exposure to radiation usually occurs 5 to 25 years after the exposure and since not all cancers are fatal, another useful measure of risk is years of life expectancy lost on the average from a radiation-induced cancer. It has been estimated in several studies that the average loss of life expectancy from exposure to radiation is about 1 day per rem of exposure. In other words, a person exposed to 1 rem of radiation may, on the average, lose 1 day of life. The words "on the average" are important, however, because the person who gets cancer from radiation may lose several years of life expectancy while his coworkers suffer no loss. The ICRP estimated that the average number of years of life lost from fatal industrial accidents is 30 while the average number of years of life lost from a fatal radiation-induced cancer is 10. The shorter loss of life expectancy is due to the delayed onset of cancer.

It is important to realize that these risk numbers are only estimates. Many difficulties are involved in designing research studies that can accurately measure the small increases in cancer cases due to low exposures to radiation as compared to the normal rate of cancer. There is still uncertainty and a great deal of controversy with regard to estimates of radiation risk. The numbers used here result from studies involving high doses and high dose rates, and they may not apply to doses at the lower occupational levels of exposure. The NRC and other agencies both in the United States and abroad are continuing extensive long-range research programs on radiation risk.

Some members of the National Academy of Sciences BEIR Advisory Committee and others feel that risk estimates in Table 1 are higher than would actually occur and represent an upper limit on the risk. Other scientists believe that the estimates are low and that the risk could be higher. However, these estimates are considered by the NRC staff to be the best available that the worker can use to make an informed decision concerning acceptance of the risks associated with exposure to radiation. A worker who decides to accept this risk should make every effort to keep exposure to radiation ALARA to avoid unnecessary risk. The worker, after all, has the first line responsibility for protecting himself from radiation hazards.

10. *How can we compare radiation risk to other kinds of health risks?*

Perhaps the most useful unit for comparison among health risks is the average number of days of life expectancy lost per unit of exposure to each particular health risk. Estimates are calculated by looking at a large number of persons, recording the age when death occurs from apparent causes, and estimating the number of days of life lost as a result of these early deaths. The total number of days of life lost is then averaged over the total group observed.

Several studies have compared the projected loss of life expectancy resulting from exposure to radiation with other health risks. Some representative numbers are presented in Table 2.

These estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with many other events or activities we encounter and accept in normal day-to-day activities.

TABLE 2

Estimated Loss of Life Expectancy from Health Risks[a]

Health Risk	Estimates of Days of Life Expectancy Lost, Average
Smoking 20 cigarettes/day	2370 (6.5 years)
Overweight (by 20%)	985 (2.7 years)
All accidents combined	435 (1.2 years)
Auto accidents	200
Alcohol consumption (U.S. average)	130
Home accidents	95
Drowning	41
Natural background radiation, calculated	8
Medical diagnostic x-rays (U.S. average), calculated	6
All catastrophes (earthquake, etc.)	3.5
1 rem occupational radiation dose, calculated (industry average for the higher-dose job categories is 0.65 rem/yr)	1
1 rem/yr for 30 years, calculated	30

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[a] Adapted from Cohen and Lee, "A Catalogue of Risks," *Health Physics*, Vol. 36, June 1979.

A second useful comparison is to look at estimates of the average number of days of life expectancy lost from exposure to radiation and from common industrial accidents at radiation-related facilities and to compare this number with days lost from other occupational accidents. Table 3 shows average days of life expectancy lost as a result of fatal work-related accidents. Note that the data for occupations other than radiation related do not include death risks from other possible hazards such as exposure to toxic chemicals, dusts, or unusual temperatures. Note also that the unlikely occupational exposure at 5 rems per year for 50 years, the maximum allowable risk level, may result in a risk comparable to the average risks in mining and heavy construction.

Industrial accident rates in the nuclear industry and related occupational areas have been relatively low during the entire history of the industry (see Table 4). This is believed to be due to the early and continuing emphasis on tight safety controls. The relative safety of various occupational areas can be seen by comparing the probability of death by accident per 10,000 workers over a 40-year working lifetime. These figures do not include death from possible causes such as exposure to toxic chemicals or radiation.

11. *Can a worker become sterile or impotent from occupational radiation exposure?*

Observation of radiation therapy patients who receive localized exposures, usually spread over a few weeks, has

TABLE 3

Estimated Loss of Life Expectancy from Industrial Hazards[a]

Industry Type	Estimates of Days of Life Expectancy Lost, Average
All industry	74
Trade	30
Manufacturing	43
Service	47
Government	55
Transportation and utilities	164
Agriculture	277
Construction	302
Mining and quarrying	328
Radiation accidents, death from exposure	<1
Radiation dose of 0.65 rem/yr (industry average) for 30 years, calculated	20
Radiation dose of 5 rems/yr for 50 years	250
Industrial accidents at nuclear facilities (nonradiation)	58

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[a] Adapted from Cohen and Lee, "A Catalogue of Risk," *Health Physics*, Vol. 36, June 1979; and World Health Organization, *Health Implications of Nuclear Power Production*, December 1975.

TABLE 4

Probability of Accidental Death by Type of Occupation[a]

Occupation	Number of Accidental Deaths for 10,000 Workers for 40 Years
Mining	252
Construction	228
Agriculture	216
Transportation and public utilities	116
All industries	56
Government	44
Nuclear industry (1975 data excluding construction)	40
Manufacturing	36
Services	28
Wholesale and trade	24

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[a] Adapted from National Safety Council, *Accident Facts*, 1979; and Atomic Energy Commission, *Operational Accidents and Radiation Exposure Experience*, WASH-1192, 1975.

shown that a dose of 500-800 rems to the gonads can produce permanent sterility in males or females (an acute whole-body dose of this magnitude would probably result in death within 60 days). An acute dose of 20 rems to the testes can result in a measurable but temporary reduction in sperm count. Such high exposures on the job could result only from serious and unlikely radiation accidents. Although high doses of radiation can affect fertility, they have no effect on the ability to function sexually. Likewise, exposure to permitted occupational levels of radiation has no observed effect on fertility and also has no effect on the ability to function sexually.

12. What are the NRC external radiation dose limits?

Federal regulations currently limit occupational external whole-body radiation dose to 1¼ rems in any calendar quarter or specified 3-month period. However, when there is documented evidence that a worker's previous occupational dose is low enough, a licensee may permit a dose of up to 3 rems per quarter or 12 rems per year. The accumulated dose may not exceed 5(N - 18) rems[6] where N is the person's age in years, i.e., the lifetime occupational dose may not exceed an average of 5 rems for each year above the age of 18.

An additional whole-body dose of approximately 5 rems per year is permitted from internal exposure. (See Question 28.)

13. What is meant by ALARA?

In addition to [illegible]ding an upper limit on a person's permissible radiatio[illegible]sure, the NRC also requires that its licensees maint[illegible]upational exposures as far below the limit as is reason[illegible] achievable (ALARA). This means that every activity a[illegible] nuclear facility involving exposure to radiation should be planned so as to minimize unnecessary exposure to individual workers and also to the worker population. A job that involves exposure to radiation should be scheduled only when it is clear that the benefit justifies the risks assumed. All design, construction, and operating procedures should be reviewed with the objective of reducing unnecessary exposures.

14. Has the ALARA concept been applied if, instead of reaching dose limits during the first week of a quarter, the worker's dose is spread out over the whole quarter?

No. For radiation protection purposes, the risk of cancer from low doses is assumed to be proportional to the amount of exposure, not the rate at which it is received. Thus it is assumed that spreading the dose out over time or over larger numbers of people does not reduce the overall risk. The ALARA concept has been followed only when the individual and collective doses are reduced by reducing the time of exposure or decreasing radiation levels in the

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[6] The NRC has published a proposed rule change for public comment that would eliminate the 5(N-18) formula. This proposal is currently under consideration by a task force reviewing all of 10 CFR Part 20. Recent EPA guidance recommends eliminating the 5(N-18) formula. If adopted, the maximum allowed annual dose will be 5 rems rather than 12.

individual and collective doses are reduced by reducing the time of exposure or decreasing radiation levels in the working environment.

15. *What is meant by collective dose and why should it be maintained ALARA?*

Nuclear industry activities expose an increasing number of people to occupational radiation in addition to the radiation doses they receive from natural background radiation and medical radiation exposures. The collective occupational dose (person-rems) is the sum of all occupational radiation exposure received by all the workers in an entire worker population. For example, if 100 workers each receive 2 rems, the individual dose is 2 rems and the collective dose is 200 person-rems. The total additional risk of cancer and genetic effects in an exposed population is assumed to depend on the collective dose.

It should be noted that, from the viewpoint of risk to a total population, it is the collective dose that must be controlled. For a given collective dose, the number of health effects is assumed to be the same even if a larger number of people share the dose. Therefore, spreading the dose out may reduce the individual risk, but not that of the population.

Efforts should be made to maintain the collective dose ALARA so as not to unnecessarily increase the overall population incidence of cancer and genetic effects.

16. *Is the use of extra workers a good way to reduce risks?*

There is a "yes" answer to this question and a "no" answer. For a given job involving exposure to radiation, the more people who share the work, the lower the average dose to an individual. The lower the dose, the lower the risk. So, for you as an individual, the answer is "yes."

But how about the risk to the entire group of workers? Under assumptions used by the NRC for purposes of protection, the risk of cancer depends on the total amount of radiation energy absorbed by human tissue, not on the number of people to whom this tissue belongs. Therefore, if 30 workers are used to do a job instead of 10, and if both groups get the same collective dose (person-rems), the total cancer risk is the same, and nothing was gained for the group by using 30 workers. From this viewpoint the answer is "no." The risk was not reduced but simply spread around among a larger number of persons.

Unfortunately, spreading the risk around often results in a larger collective dose for the job. Workers are exposed as they approach a job, while they are getting oriented to do the job, and as they withdraw from the job. The dose received during these actions is called nonproductive. If several crew changes are required, the nonproductive dose can become very large. Thus it can be seen that the use of extra workers may actually increase the total occupational dose and the resulting collective risks.

The use of extra workers to comply with NRC dose limits is not the way to reduce the risk of radiation-induced cancer for the worker population. At best, the total risk remains the same, and it may even be increased. The only way to reduce the risk is to reduce the collective dose; that can be done only by reducing the radiation levels, the working times, or both.

17. *Why doesn't the NRC impose collective dose limits?*

Compliance with individual dose limits can be achieved simply by using extra workers. However, compliance with a collective dose limit (such as 100 person-rems per year for a licensee) would require reduction of radiation levels, working times, or both. But there are many problems associated with setting appropriate collective dose limits.

For example, we might consider applying a single collective dose limit to all licensees. The selection of such a collective dose limit would be almost impossible because of the wide variations in collective doses among licensees. A power reactor could reasonably be expected to have an average annual collective dose of several hundred person-rems. However, a small industrial radiography licensee could very well have a collective dose of only a few person-rems in a year.

Even choosing a collective dose limit for a group of similar licensees would be almost as difficult. Radiography licensees as a group had an average collective dose in 1977 of 9 person-rems. However, the smallest collective dose for a radiography licensee was less than 1 person-rem, and the largest was 401 person-rems.

Setting a reasonable collective dose limit for each individual licensee would also be very difficult. It would require a record of all past collective doses on which to base such limits. Setting an annual collective dose limit would then amount to an attempt to predict a reasonable collective dose for each future year. In order to do this, it would be necessary to be able to predict changes in each licensed activity that would increase or decrease the collective dose. In addition, annual collective doses vary significantly from year to year according to the kind and amount of maintenance required, which cannot generally be predicted in advance. Following all such changes and revising limits up and down would be very difficult if not impossible. However, these efforts would be necessary if a collective dose limit were to be reasonable and help minimize doses and risks.

18. *How are radiation dose limits established?*

The NRC establishes occupational radiation dose limits based on guidance to Federal agencies from the Environmental Protection Agency (EPA) and, in addition, considers NCRP and ICRP recommendations. Scientific reviews of research data on biological effects such as the BEIR report are also considered.

For example, recent EPA guidance recommended that the annual whole-body dose limit be established at 5 rems per year and indicated that exposure, year after year, to 5 rems would involve a risk to a worker comparable to the average risks incurred by workers in the higher risk jobs such as mining. In fact, few workers ever reach such a limit, much less year after year, and the risks associated with actual exposures are considered by the EPA to be comparable to the safer job categories. A 5-rem-per-year limit would allow occasional high dose jobs to be done without excessive risk.

19. *What are the typical radiation doses received by workers?*

The NRC requires that certain categories of licensees report data on annual worker doses and doses for all workers who leave employment with licensees. Data were received on the occupational doses in 1977 of approximately 100,000 workers in power reactors, industrial radiography, fuel processing and fabrication facilities, and manufacturing and distribution facilities. Of this total group, 85 percent received an annual dose of less than 1 rem; 95 percent received less than 2 rems; fewer than 1 percent exceeded 5 rems in 1 year. The average annual dose of those workers who were monitored and had measurable exposures was about 0.65 rem. A study completed by the EPA, using 1975 exposure data for 1,260,000 workers, indicated that the average annual dose for all workers who received a measurable dose was 0.34 rem.

Table 5 lists average occupational exposures for workers (persons who had measurable exposure above background levels) in various occupations, based on the 1975 data.

TABLE 5

U.S. Occupational Exposure Estimates[a]

Occupational Subgroup	Average Whole-Body Dose (millirems)	Collective Dose (person-rems)
Medicine	320	51,400
Industrial Radiography	580	5,700
Source Manufacturing	630	2,500
Power Reactors	760	21,400
Fuel Fabrication and Reprocessing	560	3,100
Uranium Enrichment	70	400
Nuclear Waste Disposal	920	100
Uranium Mills	380	760
Department of Energy Facilities	300	11,800
Department of Defense Facilities	180	10,100
Educational Institutions	206	1,500
Transportation	200	2,300

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[a] Adapted from Cook and Nelson, *Occupational Exposures to Ionizing Radiation in the United States: A Comprehensive Summary for 1975*, Draft, Environmental Protection Agency.

20. *What happens if a worker exceeds the quarterly exposure limit?*

Radiation protection limits, such as 3 rems in 3 months, are not absolute limits below which it is safe and above which there is danger. Exceeding a limit does not imply that you have suffered an injury. A good comparison is with the highway speed limit, which is selected to limit accident risk and still allow you to get somewhere. If you drive at 75 mph, you increase your risk of an auto accident to levels that are not considered acceptable by the people who set speed limits, even though you may not actually have an accident. If a worker's radiation dose repeatedly exceeds 3 rems in a quarter, the risk of health effects could eventually increase to a level that is not considered acceptable to the NRC. Exceeding an NRC protection limit does not mean that any adverse health effects are going to occur. It does mean that a licensee's safety program has failed in some respect and that the NRC and the licensee should investigate to make sure the problems are corrected.

If an overexposure occurs, the regulations prohibit any additional occupational exposure to that person during the remainder of the calendar quarter in which the overexposure occurred. The licensee is required to file an overexposure report to the NRC and may possibly be subject to a fine, just as you are subject to a traffic fine for exceeding the speed limit. In both cases, the fines and, in some serious or repetitive cases, suspension of license are intended to encourage efforts to operate within the limits. The safest limits would be 0 mph and 0 rem per quarter. But then we wouldn't get anywhere.

21. *Why do some facilities establish administrative limits that are below the NRC limits?*

There are two reasons. First, the NRC regulations state that licensees should keep exposures to radiation ALARA. By requiring specific approval for worker doses in excess of set levels, more careful risk-benefit analysis can be made as each additional increment of dose is approved for a worker. Secondly, a facility administrative limit that is set lower than the quarterly NRC limit provides a safety margin designed to help the licensee avoid overexposures.

22. *Several scientists have suggested that NRC limits are too high and should be lowered. What are the arguments for lowering the limits?*

In general, those critical of present dose limits say that the individual risk is higher than is estimated by the BEIR Committee, the ICRP, and UNSCEAR. Based on studies of low-level exposures to large groups, some researchers have concluded that a given dose of radiation may be more likely to cause biological effects than previously thought. Some of these studies are listed in the bibliography (Mancuso, Archer) and the BEIR-80 report includes a section analyzing the findings of these and other studies. Scientific opinion differs on the validity of the research methods used and the methods of statistical analysis. The problem is that the expected additional incidence of radiation-caused effects such as cancer is difficult to detect in comparison with the much larger normal incidence. It cannot be shown without question that these effects were more frequent in the exposed study group than in the unexposed group used for comparison, or that the observed effects were caused by radiation. The BEIR committee concluded that claims of higher risk had "no substance."

The NRC staff continually reviews the results of research on radiation risks. With respect to large-scale studies of radiation-induced health effects in human populations exposed to low-level ionizing radiation, the NRC and EPA have recently concluded that there is no one population group available for which such a study could be expected to provide a more meaningful estimate of the low-level radiation risk. This is due, in large part, to the observed and estimated low incidence of radiation health effects from low doses. However, the results of ongoing studies, such as that on nuclear shipyard workers, will be carefully reviewed and the development of a radiation-worker registry is being considered as a possible data base for future studies.

23. What are the reasons for not lowering the NRC dose limits?

Assuming that the 5-rem-per-year limit is adopted, there are three reasons:

a. Health risks are already low.

The estimated health risks associated with current average occupational radiation doses (e.g., 0.5 rem/yr for 50 years) are comparable to or less than risk levels in other occupational areas considered to be among the safest. If a person were exposed to the maximum of 5 rems per year for 50 years, which virtually never occurs, he or she might incur a risk comparable to the average risks in mining and heavy construction. An occasional 5-rem annual dose might be necessary to allow some jobs to be done without a significant increase in the collective dose. If the dose limits were lowered significantly, the number of people required to complete many jobs would increase. The collective dose would then increase since more individuals would be receiving nonproductive exposure while entering and leaving the work area and preparing for the job. The total number of health effects might go up as the collective dose increased.

b. The current regulations are considered sound.

The regulatory standards for dose limits are based on the recommendations of the Federal Radiation Council. At the time these standards were developed, about 1960, it was considered unlikely that exposure to these levels during a working lifetime would result in clinical evidence of injury or disease different from that occurring in the unexposed population. The scientific data base for the standards consisted primarily of human experience (x-ray exposures to medical practitioners and patients, ingestion of radium by watch dial painters, early effects observed in Japanese atomic bomb survivors, radon exposures of uranium miners, occupational radiation accidents) involving very large doses delivered at high dose rates. The data base also included the results of a large number of animal experiments involving high doses and dose rates. The animal experiments were particularly useful in the evaluation of genetic effects. The observed effects were related to low-level radiation according to the linear model explained in Question 7. Based on this approach, the regulations in 10 CFR Part 20, "Standards for Protection Against Radiation," also state that licensees should maintain all radiation exposures, and releases of radioactive materials in effluents, as low as is reasonably achievable. More recent scientific reviews of the large body of experimental data, such as the BEIR-80 and the recent EPA guidance, continue to support the view that use of a 5-rem-per-year limit is acceptable in practice. Experience has shown that, under this limit, the average dose to workers is near 0.5 rem/yr with very few workers consistently approaching the limit.

c. There is little to gain.

Reducing the dose limits, for example, to 0.5 rem/yr has been analyzed by the NRC staff. An estimated 2.6 million person-rems could be saved from 1980 through the year 2000 by nuclear power plant licensees if compliance with the new limit were achieved by lowering the radiation levels, working times, or both, rather than by using extra workers. It is estimated that something like $23 billion would be spent toward this purpose. Spending $23 billion to save 2.6 million person-rems would amount to spending $30 to $90 million to prevent each potential radiation-induced premature cancer death. Society considers this cost unacceptably high for individual protection.

24. Are there any areas of concern about radiation risks that might result in changing the NRC dose limits?

Yes. Three areas of concern to the NRC staff are specifically identified below:

a. An independent study by Rossi and Mays and other biological research have indicated that a given dose of neutron radiation may be more likely to cause biological effects than was previously thought. Other recent studies cast doubt on the issue. The NCRP is currently studying the data related to the neutron radiation question and is expected to make recommendations as to whether neutron dose limits should be changed. Although the scientific community has not yet come to agreement on this question, workers should be advised of the possibility of higher risk when entering areas where exposure to neutrons will occur.

b. It has been known for some time that rapidly growing living tissue is more sensitive to injury from radiation than tissue in which the cells are not reproducing rapidly. Thus the embryo or fetus is more sensitive to radiation injury than an adult. The NCRP recommended in Report No. 39 that special precautions be taken when an occupationally exposed woman could be pregnant in order to protect the embryo or fetus. In 1975, the NRC issued Regulatory Guide 8.13, "Instruction Concerning Prenatal Radiation Exposure," in which it is recommended that licensees instruct workers concerning this special risk. The guide recommends that all workers be advised that the NCRP recommended that the maximum permissible dose to the embryo or fetus from occupational exposure of the mother should not exceed 0.5 rem for the full 9-month pregnancy period. In addition, the guide suggests options available to the female employee who chooses not to expose her embryo or fetus to this additional risk.

The United States Department of Health and Human Services is similarly concerned about prenatal exposure from medical x-rays. In 1979 they published proposed guidelines for physicians concerning abdominal x-rays for possibly pregnant women. The guidelines in effect encourage the x-ray staff to make efforts to determine whether a female patient is pregnant and to defer x-rays if possible until after the child is born.

c. Also of special interest is the indication that female workers are subject to more risk of cancer incidence than male workers. In terms of all types of cancer except leukemia, the BEIR-80 analysis indicates that female workers have a risk of developing radiation-induced cancer that is approximately one and one-half times that for males. This increased risk is primarily due to the incidence of breast and thyroid cancer in women. These types of cancer, however, have a high cure rate. Thus the difference between men and women in cancer mortality is not great. Incidence of radiation-induced leukemia is about the same for both sexes. Female workers should be aware of this difference in the risks of radiation-induced cancer in deciding whether or not to seek work involving exposure to radiation.

25. *How much radiation does the average person who does not work in the nuclear industry receive?*

We are all exposed from the moment of conception to ionizing radiation from several sources. Our environment, and even the human body, contains naturally occurring radioactive materials that contribute some of the background radiation we receive. Cosmic radiation originating in space and in the sun contributes additional exposure. The use of x-rays and radioactive materials in medicine and dentistry adds considerably to our population exposure.

Table 6 shows estimated average individual exposure in millirems from natural background and other sources.

TABLE 6

U.S. General Population Exposure Estimates (1978)[8]

Source	Average Individual Dose (mrem/yr)
Natural background (average in U.S.)	100
Release of radioactive material in natural gas, mining, milling, etc.	5
Medical (whole-body equivalent)	90
Nuclear weapons (primarily fallout)	5-8
Nuclear energy	0.28
Consumer products	0.03
Total	~200 mrem/yr

Thus, the average individual in the general population receives about 0.2 rem of radiation exposure each year from sources that are a part of our natural and man-made environment. By the age of 20 years, an individual has accumulated about 4 rems. The most likely target for reduction of population exposure is medical uses.

26. *Why aren't medical exposures considered as part of a worker's allowed dose?*

Equal doses of medical and occupational radiation have equal risks.[7] Medical exposure to radiation should be justified for reasons quite different, however, from those applicable to occupational exposure. A physician prescribing an x-ray should be convinced that the benefit to the patient of the resulting medical information justifies the risk associated with the radiation. Each worker must decide on the acceptance of occupational radiation risk just as each worker must decide on the acceptability of any other occupational hazard.

For another point of view, consider a worker who receives a dose of 2 rems from a series of x-rays or a radioactive medicine in connection with an injury or illness. This dose and the implied risk should be justified on medical grounds. If the worker had also received a dose of 2 rems on the job, the combined dose of 4 rems would not incapacitate the worker. A dose of 4 rems is not especially dangerous and is not large compared to the cumulative lifetime dose. Restricting the worker from additional job exposure during the remainder of the quarter would have no effect one way or the other on the risk from the 2 rems already received from medical exposure. If the individual worker accepts the risks associated with the x-rays on the basis of the medical benefits and the risks associated with job-related exposure on the basis of employment benefits, it would be unfair to restrict the individual from employment in radiation areas for the remainder of the quarter.

Some therapeutic medical doses such as those received from cobalt-60 treatment can range as high as 6000 rems to a small part of the body, spread over a period of several weeks or months.

27. *What is meant by internal exposure?*

The total radiation dose to the worker is the external dose (measured by the film badge and reported as "whole-body dose") plus the dose from internal emitters. The monitoring of the additional internal dose is difficult. Because there is the possibility of internal doses occurring, a good air-monitoring program should be established when warranted.

The uptake of radioactive materials by workers is generally due to breathing contaminated air. Radioactive materials may be present as fine dust or gases in the workplace atmosphere. The surfaces of equipment and workbenches

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[8] Adapted from a report by the Interagency Task Force on the Health Effects of Ionizing Radiation published by the Department of Health, Education, and Welfare.

[7] It is likely that a significant portion of reported medical x-ray exposure is to parts of the body only. An exposure of 100 mrem to the whole body is more significant than a 100-mrem chest x-ray.

may be contaminated. Radioactive materials may enter the body by being breathed in, taken in with food or drink, or being absorbed through the skin, particularly if the skin is broken.

After entering the body, the radioactive material will migrate to particular organs or particular parts of the body depending on the biochemistry of the material. For example, uranium will tend to deposit in the bones where it will remain for a long time. It is slowly eliminated from the body, mostly by way of the kidneys. Radium will also tend to deposit in the bones. Radioactive iodine will seek out the thyroid glands (located in the neck) and deposit there.

The dose from these internal emitters cannot be measured either by the film badge or by other ordinary dosimeters carried by the worker. This means that the internal radiation dose must be separately monitored using other detection methods.

Internal exposure can be estimated by measuring the radiation emitted from the body or by measuring the radioactive materials contained in biological samples such as urine or feces. Dose estimates can also be made if one knows how much radioactive material is in the air and the length of time during which the air was breathed.

28. *How are the limits for internal exposure set?*

Standards have been established for the maximum permissible amount of each radionuclide that may be accumulated in the critical organs[8] of the worker's body.

Calculations are made to determine the quantity of radioactive material that has been taken into the body and the total dose that would result. Then, based on limits established for particular body organs similar to 1¼ rems in a calendar quarter for whole-body exposure, the regulations specify maximum permissible concentrations of radioactive material in the air to which a worker can be exposed for 40 hours per week over 13 weeks or 1 calendar quarter. The regulations also require that efforts be made to keep internal exposure ALARA.

Internal exposure is controlled by limiting the release of radioactive material into the air and by carefully monitoring the work area for airborne radioactivity and surface contamination. Protective clothing and respiratory (breathing) protection should be used whenever the possibility of contact with loose radioactive material cannot be prevented.

29. *Is the dose a person received from internal exposure added to that received from external exposure?*

Exposure to radiation that results from radioactive materials taken into the body is measured, recorded, and reported to the worker separately from external dose. The internal dose to the whole body or to specific organs does not at this time count against the 3-rem-per-calendar-quarter limit. ICRP recommends that the internal and external doses should be appropriately added. This recommendation is currently under study by the staffs of the NRC, the EPA, and the Occupational Safety and Health Administration (OSHA).

30. *How is a worker's external radiation dose determined?*

A worker may wear three types of radiation-measuring devices. A self-reading pocket dosimeter records the exposure to incident radiation and can be read out immediately upon finishing a job involving external exposure to radiation. A film badge or TLD badge records radiation dose, either by the amount of darkening of the film or by storing energy in the TLD crystal. Both these devices require processing to determine the dose but are considered more reliable than the pocket dosimeter. A worker's official report of dose received is normally based on film or TLD badge readings, which provide a cumulative total and are more accurate.

31. *What are my options if I decide not to accept the risks associated with occupational radiation exposure?*

If the risks from exposure to radiation that may be expected to occur during your work are unacceptable to you, you could request a transfer to a job that does not involve exposure to radiation. However, the risks associated with exposure to radiation that workers, on the average, actually receive are considered acceptable, compared to other occupational risks, by virtually all the scientific groups that have studied them. Your employer is probably not obligated to guarantee you a transfer if you decide not to accept an assignment requiring exposure to radiation.

You also have the option of seeking other employment in a nonradiation occupation. However, the studies that have compared occupational risks in the nuclear industry to those in other job areas indicate that nuclear work is relatively safe. Thus, you will not necessarily find significantly lower risks in another job.

A third option would be to practice the most effective work procedures so as to keep your exposure ALARA. Be aware that reducing time of exposure, maintaining distance from radiation sources, and using shielding can all lower your exposure. Plan radiation jobs carefully to increase efficiency while in the radiation area. Learn the most effective methods of using protective clothing to avoid contamination. Discuss your job with the radiation protection personnel who can suggest additional ways to reduce your exposure.

32. *Where can I get additional information on radiation risk?*

The following list suggests sources of useful information on radiation risk.

a. Your Employer

The radiation protection or health physics office in the facility where you are employed.

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[8] Critical organ refers to those parts of the body vulnerable to radiation damage such as bone, lungs, thyroid, and other systems where certain radioactive materials will concentrate if taken into the body.

b. Nuclear Regulatory Commission

Regional Offices

King of Prussia, PA 19406	215-337-5000
Atlanta, GA 30303	404-221-4503
Glen Ellyn, IL 60137	312-932-2500
Arlington, TX 76012	817-334-2841
Walnut Creek, CA 94596	415-943-3700

Headquarters

Occupational Radiation Protection Branch
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Telephone: 301-443-5970

c. Department of Health and Human Services

Office of the Director
Bureau of Radiological Health (HFX-1)
Department of Health and Human Services
5600 Fishers Lane
Rockville, MD 20857

Telephone: 301-443-4690

d. Environmental Protection Agency

Office of Radiation Programs
U.S. Environmental Protection Agency
401 M Street, SW
Washington, D.C. 20460

Telephone: 703-557-9710