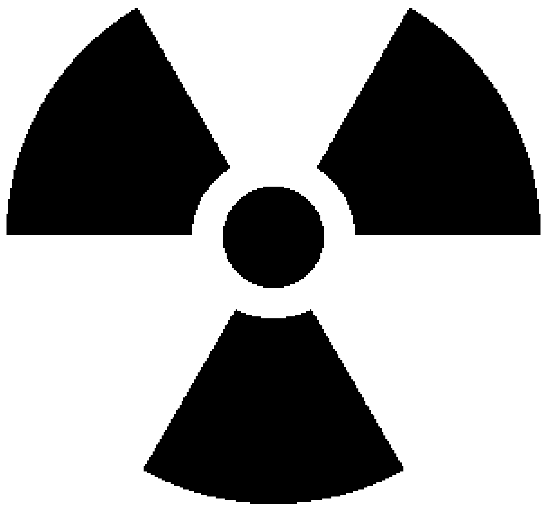
CALIFORNIA INSTITUTE OF TECHNOLOGY

RADIATION SAFETY



TRAINING AND REFERENCE MANUAL

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1. INTRODUCTION

RADIATION SAFETY MANUAL

This manual is a companion to the *Radiation Safety Manual (RSM)*. The RSM describes the radiation protection program at Caltech. The policies and procedures contained in the RSM have been approved by the Radiation Safety Committee (RSC), and submitted to the California Department of Health Services as part of our Radioactive Materials License.

TRAINING AND REFERENCE MANUAL

This *Training and Reference Manual (TRM)* presents the information necessary for users of radioactive materials and radiation producing machines to properly understand and follow the policies and procedures in the RSM. Some of the topics covered are:

The nature of radiation and its interaction with matter.

Definitions of units and terms used to describe radiation and radioactive material.

Methods of calculating and measuring radiation levels for a variety of sources.

The biological effects of ionizing radiation.

Additional information on some of the policies and procedures in the RSM (e.g. dosimetry, waste disposal, and radionuclide handling).

Safety precautions for the use of radiation producing machines.

ORIENTATION AND TRAINING

In addition to receiving the two manuals, each user of radioactive materials or radiation producing machines will attend an orientation with one of the Health Physicists in the Radiation Safety Office. This is usually a one-on-one meeting and the topics covered depend on the experience and knowledge of the new user.

Those without extensive prior experience must complete a quiz on the material presented in the two manuals and the orientation.

Training for each user is also provided in the laboratory by the Principal Investigator (PI) or an experienced user designated by the PI. Topics covered during this training include, as appropriate:

Safe use of laboratory equipment and materials, including protective clothing.

Experiment procedures and protocols, including operating procedures for radiation producing machines.

Safe handling, storage, and disposal of radioactive materials.

Methods to control and measure radiation levels and contamination.

Proper maintenance of required records.

Emergency procedures.

Annual refresher training, usually presented at a meeting of each research group, keeps users up-to-date with the latest regulations and Institute policies.

RADIATION SAFETY OFFICE

The Radiation Safety staff is available for consultation and to answer questions on the safe use of radioactive materials and radiation producing machines. Radiation Safety also will keep Principal Investigators informed of changes in government regulations or Institute policies.

2. RADIATION FUNDAMENTALS

INTRODUCTION

For the purposes of this manual, we can use a simplistic model of an atom. The atom can be thought of as a system containing a positively charged nucleus and negatively charged electrons which are in orbit around the nucleus.

The nucleus is the central core of the atom and is composed of two types of particles, protons which are positively charged and neutrons which have a neutral charge. Each of these particles has a mass of approximately one atomic mass unit (amu). (1 amu $\approx$ 1.66 x 10^{-24} g)

Electrons surround the nucleus in orbitals of various energies. (In simple terms, the farther an electron is from the nucleus, the less energy is required to free it from the atom.) Electrons are very light compared to protons and neutrons. Each electron has a mass of approximately 5.5 x 10^{-4} amu.

A *nuclide* is an atom described by its *atomic number (Z)* and its *mass number (A)*. The Z number is equal to the charge (number of protons) in the nucleus, which is a characteristic of the element. The A number is equal to the total number of protons and neutrons in the nucleus. Nuclides with the same number of protons but with different numbers of neutrons are called *isotopes*. For example, deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) are isotopes of hydrogen with mass numbers two and three, respectively. There are on the order of 200 stable nuclides and over 1100 unstable (radioactive) nuclides. Radioactive nuclides can generally be described as those which have an excess or deficiency of neutrons in the nucleus.

RADIOACTIVE DECAY

Radioactive nuclides (also called *radionuclides*) can regain stability by nuclear transformation (*radioactive decay*) emitting radiation in the process. The radiation emitted can be particulate or electromagnetic or both. The various types of radiation and examples of decay are shown below.

ALPHA (α)

Alpha particles have a mass and charge equal to those of helium nuclei (2 protons + 2 neutrons). Alpha particles are emitted from the nucleus during the decay of some very heavy nuclides (Z > 83).

$${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}\alpha$$

BETA (β^-, β^+)

Beta particles are emitted from the nucleus and have a mass equal to that of electrons. Betas can have either a negative charge or a positive charge. Negatively charged betas are equivalent to electrons and are emitted during the decay of neutron rich nuclides.

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta + \nu$$

(See page 8 for a discussion of the neutrino (ν).)

Positively charged betas (positrons) are emitted during the decay of proton rich nuclides.

$${}^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + {}^{0}_{1}\beta + \gamma$$

GAMMA (γ)

Gammas (also called gamma rays) are electromagnetic radiation (photons). Gammas are emitted during energy level transitions in the nucleus. They may also be emitted during other modes of decay.

$${}^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc + \gamma$$

ELECTRON CAPTURE

In certain neutron deficient nuclides, the nucleus will capture an orbital electron resulting in conversion of a proton into a neutron. This type of decay also involves gamma emission as well as x-ray emission as other electrons fall into the orbital vacated by the captured electrons.

$$^{125}_{53}I + ^{0}_{-1}e \rightarrow ^{125}_{52}Te + \gamma$$

FISSION

Fission is the splitting of an atomic nucleus into two smaller nuclei and usually two or three neutrons. This process also releases a large amount of energy in the form of gammas and kinetic energy of the fission fragments and neutrons.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{93}_{37}Rb + ^{141}_{55}Cs + 2(^{1}_{0}n) + \gamma$$

NEUTRONS

For a few radionuclides, a neutron can be emitted during the decay process.

$$^{17}_{7}N \rightarrow ^{17}_{8}O^{*} + ^{0}_{-1}\beta \qquad (^{*}\text{excited state})$$

$$^{17}_{8}O^{*} \rightarrow ^{16}_{8}O + ^{1}_{0}n$$

X-RAYS

X-rays are photons emitted during energy level transitions of orbital electrons.

Bremsstrahlung x-rays (braking radiation) are emitted as energetic electrons (betas) are decelerated when passing close to a nucleus. Bremsstrahlung must be considered when using large activities of high energy beta emitters such as P-32 and Sr-90.

CHARACTERISTICS OF RADIOACTIVE DECAY

In addition to the type of radiation emitted, the decay of a radionuclide can be described by the following characteristics.

HALF-LIFE

The half-life of a radionuclide is the time required for one-half of a collection of atoms of that nuclide to decay. Decay is a random process which follows an exponential curve. The number of radioactive nuclei remaining after time (t) is given by:

$$N_t = N_0 e^{-(0.693t/T)}$$

where N_0 = original number of atoms
N_t = number remaining at time t
t = decay time
T = half-life

ENERGY

The basic unit used to describe the energy of a radiated particle or photon is the electron volt (eV). An electron volt is equal to the amount of energy gained by an electron passing through a potential difference of one volt. The energy of the radiation emitted is a characteristic of the radionuclide. For example, the energy of the alpha emitted by Cm-238 will always be 6.52 MeV, and the gamma emitted by Ba-135m will always be 268 keV. Many radionuclides have more than one decay route. That is, there may be different possible energies that the radiation may have, but they are discreet possibilities. However, when a beta particle is emitted, the energy is divided between the beta and a neutrino. (A neutrino is a particle with no charge and infinitesimally small mass.) Consequently, a beta particle may be emitted with an energy varying in a continuous spectrum from zero to a maximum energy (E_{max}) which is characteristic of the radionuclide. The average energy is generally around forty percent of the maximum.

Figure 2.1 Typical Beta Spectrum

3. INTERACTION OF RADIATION WITH MATTER

ENERGY ABSORPTION

The transfer of energy from the emitted particle or photon to an absorbing medium has several mechanisms. These mechanisms result in ionization and excitation of atoms or molecules in the absorber. The transferred energy is eventually dissipated as heat.

Ionization is the removal of an orbital electron from an atom or molecule, creating a positively charged ion. In order to cause an ionization, the radiation must transfer enough energy to the electron to overcome the binding force on the electron. The ejection of an electron from a molecule can cause dissociation of the molecule.

Excitation is the addition of energy to an orbital electron, thereby transferring the atom or molecule from the ground state to an excited state.

ALPHA PARTICLES

Interactions between the electric field of an alpha and orbital electrons in the absorber cause ionization and excitation events. Because of their double charge and low velocity (due to their large mass), alpha particles lose their energy over a relatively short range. One alpha will cause tens of thousands of ionizations per centimeter in air. The range in air of the most energetic alpha particles commonly encountered is about 10 centimeters (4 inches). In denser materials, the range is much less. Alpha particles are easily stopped by a sheet of paper or the protective (dead) layers of skin.

BETA PARTICLES

Normally, a beta particle loses its energy in a large number of ionization and excitation events. Due to the smaller mass, higher velocity and single charge of the beta particle, the range of a beta is considerably greater than that of an alpha of comparable energy. The maximum ranges of beta particles in various absorbing media are shown in Figure 3.1. Since its mass is equal to that of an electron, a large deflection can occur with each interaction, resulting in many path changes in an absorbing medium.

If a beta particle passes close to a nucleus, it decreases in velocity due to interaction with the positive charge of the nucleus, emitting x-rays (bremsstrahlung). The energy of the bremsstrahlung x-rays has a continuous spectrum up to a maximum equal to the maximum kinetic energy of the betas. The production of bremsstrahlung increases with the atomic number of the absorber and the energy of the beta. Therefore, low Z materials are used as beta shields.

A positron will lose its kinetic energy through ionizations and excitations in a similar fashion to a negative beta particle. However, the positron will then combine with an electron. The two particles are annihilated, producing two 511 keV photons called annihilation radiation.

PHOTONS

Gammas and x-rays differ only in their origin. Both are electromagnetic radiation, and differ only from radio waves and visible light in having much shorter wavelengths. They have zero rest mass and travel with the speed of light. They are basically distortions in the electromagnetic field of space, and interact electrically with atoms even though they have no net electrical charge. While alphas and betas have a finite maximum range and can therefore be completely stopped with a sufficient thickness of absorber, photons interact in a probabilistic manner. This means that an individual photon has no definite maximum range. However, the total fraction of photons passing through an absorber decreases exponentially with the thickness of the absorber. There are three mechanisms by which gammas and x-rays lose energy.

The *photoelectric effect* is one in which the photon imparts all its energy to an orbital electron. The photon simply vanishes, and the absorbing atom becomes ionized as an electron (photoelectron) is ejected. This effect has the highest probability with low energy photons (< 50 keV) and high Z absorbers.

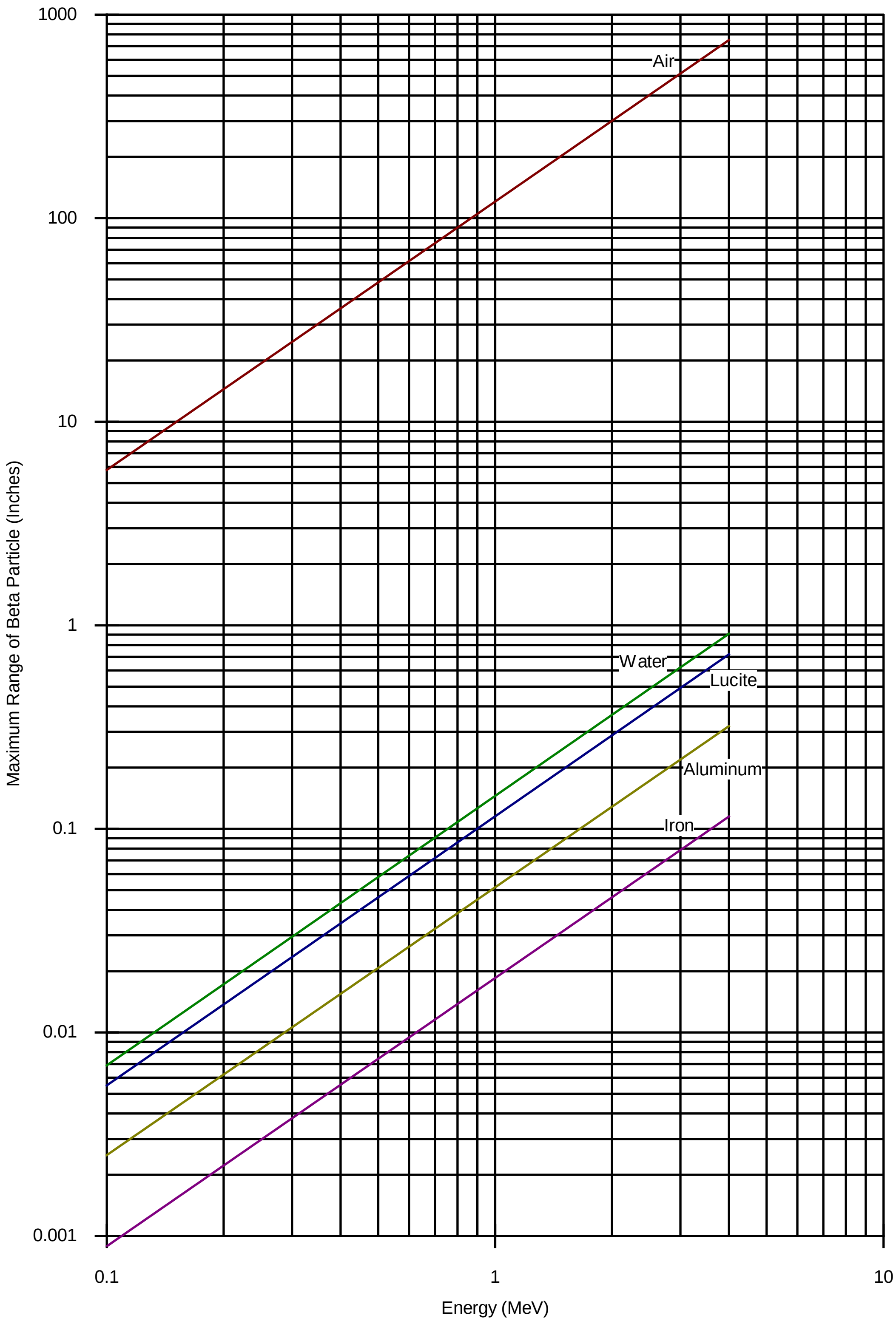
Compton scattering provides a means for partial absorption of photon energy by interaction with a "free" (loosely bound) electron. The electron is ejected, and the photon continues on to lose more energy in other interactions. In this mechanism of interaction, the photons in a beam are scattered, so that radiation may appear around corners and in front of shields.

Pair production occurs only when the photon energy exceeds 1.02 MeV. In pair production the photon simply disappears in the electric field of a nucleus, and in its place two electrons, a negatron and a positron, are produced from the energy of the photon. The positron will eventually encounter a free electron in the absorbing medium. The two particles annihilate each other and their mass is converted into energy. Two photons are produced each of 0.511 MeV. The ultimate fate of these two photons is energy loss by Compton scattering or the photoelectric effect.

SECONDARY IONIZATIONS

The electrons from ionizations and pair production will themselves go on to cause more ionization and excitation events in the same way as described for betas.

Figure 3.1 Penetration Ability of Beta Radiation



4. ACTIVITY, EXPOSURE, AND DOSE

DEFINITIONS

Activity is the rate of decay (disintegrations/time) of a given amount of radioactive material.

Dose is a measure of energy deposited by radiation in a material, or of the relative biological damage produced by that amount of energy given the nature of the radiation.

Exposure is a measure of the ionizations produced in air by x-ray or gamma radiation. The term exposure (with its "normal" definition) is sometimes used to mean dose. (e.g. "He received a radiation exposure to his hand.")

UNITS

ACTIVITY

1 *Curie (Ci)* = 3.7 x 10^{10} disintegrations per sec (dps). The *Becquerel (Bq)* is also coming into use as the *International System of Units (SI)* measure of disintegration rate. 1 Bq = 1 dps, 3.7 x 10^{10} Bq = 1 Ci, and 1 mCi = 37 MBq.

EXPOSURE

The unit of radiation exposure in air is the *roentgen (R)*. It is defined as that quantity of gamma or x-radiation causing ionization in air equal to 2.58 x 10^{-4} coulombs per kilogram. Exposure applies only to absorption of gammas and x-rays in air.

DOSE

The *rad* is a unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram. (1 erg = 6.24 x 10^{11} eV) The SI unit of absorbed dose is the *Gray (Gy)*. 1 Gy = 1 joule/kilogram = 100 rad. An exposure of 1 R results in an absorbed dose of 0.87 rad.

A *quality factor (Q)* is used to compare the biological damage producing potential of various types of radiation, given equal absorbed doses. The effectiveness of radiation in producing damage is related to the energy loss of the radiation per unit path length. The term used to express this is *linear energy transfer (LET)*. Generally, the greater the LET in tissue, the more effective the radiation is in producing damage. The quality factors for radiations frequently encountered are:

Radiation	Q
Gammas and x-rays	1
Beta particles & electrons	1
Alpha particles & fission fragments	20
Neutrons	10

The *rem* is a unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by the quality factor. Dose equivalent determinations for internally deposited radioactive materials also take into account other factors such as the non-uniform distribution of some radionuclides (e.g. I-125 in the thyroid). The SI unit for dose equivalent is the Sievert (Sv). 1 Sv = 100 rem.

CALCULATION OF ACTIVITIES

The half-life of a radionuclide is the time required for one-half of a collection of atoms of that nuclide to decay. This is the same as saying it is the time required for the activity of a sample to be reduced to one-half the original activity. The equation on page 7 can be rewritten as:

$$A_t = A_0 \, e^{-(0.693t/T)}$$

where A_0 = original activity, A_t = activity at time t
t = decay time, T = half-life

EXAMPLE

P-32 has a half-life of 14.3 days. On January 10, the activity of a P-32 sample was 10 μCi. What will the activity be on February 6? February 6 is 27 days after January 10 so

$$A_{2/6} = A_{1/10} \, e^{-[0.693(27/14.3)]} = 2.7 \, \mu\text{Ci}$$

A quick estimate could also have been made by noting that 27 days is about two half-lives. So the new activity would be about one-half of one-half (i.e. one-fourth) of the original activity.

CALCULATION OF EXPOSURE RATES

Gamma exposure constants (Γ) for many radionuclides are given in Table 4.1. Γ is the exposure rate in R/hr at 1 cm from a 1 mCi point source.

An empirical rule which may also be used is:
6 x Ci x n x E = R/hr @ 1 foot,

where Ci = source strength in curies.
E = energy of the emitted photons in MeV.
n = fraction of decays resulting in photons with an energy of E.

It should be noted that this formula and the gamma constants are for exposure rates from gammas and x-rays only. Any dose calculations would also have to include the contribution from any particulate radiation that may be emitted.

INVERSE SQUARE LAW

Exposure rate varies inversely with the square of the distance from a point source of radiation. This is often referred to as the inverse square law (or $1/r^2$ rule).

$$ER_2 = ER_1 \times (d_1/d_2)^2$$

where ER_2 = exposure rate at distance 2
ER_1 = exposure rate at distance 1
d_1 = distance 1
d_2 = distance 2

For example, from Table 4.1, the Γ for Co-60 is 13.2. Therefore, the exposure rate at 1 cm from a 1 mCi source would be 13.2 R/hr. At 30 cm from the same source, the exposure rate would be $(13.2 \text{ R/hr})(1/30)^2 = 0.0147$ R/hr = 14.7 mR/hr.

BETA DOSE RATES

For a beta emitter point source, the dose rate can be calculated using the empirical equation

300 x Ci = rad/hr @ 1 foot, where Ci = source strength in curies.

This calculation neglects any shielding provided by the air, which can be significant. For example, the maximum range in air for a beta from S-35 is less than one foot, so the dose rate at one foot is zero for any size S-35 source.

SKIN DOSE

For energies above 0.6 MeV, the dose rate to the skin from a uniform deposition of 1 $\mu Ci/cm^2$ of a beta emitter on the skin is about 9 rem/hr.

INTERNAL DOSE CALCULATIONS

See Appendix A for methods and examples of internal dose calculations.

Table 4.1. Gamma exposure constants (Γ)

Nuclide	Γ	Nuclide	Γ	Nuclide	Γ
Actinium-227	2.2	Gold-198	2.3	Potassium-43	5.6
Antimony-122	2.4	Gold-199	0.9	Radium-226	8.25
Antimony-124	9.8	Hafnium-175	2.1	Radium-228	5.1
Antimony-125	2.7	Hafnium-181	3.1	Rhenium-186	0.2
Arsenic-72	10.1	Indium-114m	0.2	Rubidium-86	0.5
Arsenic-74	4.4	Iodine-124	7.2	Ruthenium-106	1.7
Arsenic-76	2.4	Iodine-125	1.5	Scandium-46	10.9
Barium-131	3.0	Iodine-126	2.5	Scandium-47	0.56
Barium-133	2.4	Iodine-130	12.2	Selenium-75	2.0
Barium-140	12.4	Iodine-131	2.2	Silver-110m	14.3
Beryllium-7	0.3	Iodine-132	11.8	Silver-111	0.2
Bromine-82	14.6	Iridium-192	4.8	Sodium-22	12.0
Cadmium-115m	0.2	Iridium-194	1.5	Sodium-24	18.4
Calcium-47	5.7	Iron-59	6.4	Strontium-85	3.0
Carbon-11	5.9	Krypton-85	0.04	Tantalum-182	6.8
Cerium-141	0.35	Lanthanum-140	11.3	Tellurium-121	3.3
Cerium-144	0.4	Lutecium-177	0.09	Tellurium-132	2.2
Cesium-134	8.7	Magnesium-28	15.7	Thulium-170	0.025
Cesium-137	3.3	Manganese-52	18.6	Tin-113	1.7
Chlorine-38	8.8	Manganese-54	4.7	Tungsten-185	0.5
Chromium-51	0.16	Manganese-56	8.3	Tungsten-187	3.0
Colbalt-56	17.6	Mercury-197	0.4	Uranium-234	0.1
Colbalt-57	0.9	Mercury-203	1.3	Vanadium-48	15.6
Colbalt-58	5.5	Molybdenum-99	1.8	Xenon-133	0.1
Colbalt-60	13.2	Neodymium-147	0.8	Ytterbium-88	0.4
Colbalt-64	1.2	Nickel-65	3.1	Yttrium-88	14.1
Europium-152	5.8	Niobium-95	4.2	Yttrium-91	0.01
Europium-154	6.2	Osmium-191	0.6	Zinc-65	2.7
Europium-155	0.3	Palladium-109	0.03	Zirconium-95	4.1
Gallium-67	1.1	Platinum-197	0.5		
Gallium-72	11.6	Potassium-42	1.4		

Γ = exposure rate in R/hr at 1 cm from a 1 mCi point source

Γ/10 = exposure rate in mR/hr at 1 meter from a 1 mCi point source

5. BIOLOGICAL EFFECTS OF IONIZING RADIATION

RADIATION HAZARDS

The hazards associated with the absorption of radiation in mammalian systems and tissue are related to both the type of radiation and the nature of the absorbing tissue or organ system.

ALPHA

Alpha particles will be stopped by the dead layers of skin, so they are not an external hazard. However, many alpha emitters or their daughters also emit gammas which are penetrating and therefore may present an external hazard. Internally, alphas can be very damaging due to their high linear energy transfer (LET). That is, they deposit all of their energy in a very small area. Based on their chemical properties, alpha emitters can be concentrated in specific tissues or organs.

BETA

Externally, beta particles can deliver a dose to the skin or the tissues of the eye. Many beta emitters also emit gammas. A large activity of a high energy beta emitter can create a significant exposure from bremsstrahlung x-rays produced in shielding material. Internally, betas can be more damaging, especially when concentrated in specific tissues or organs.

PHOTONS

Externally, the hazard from low energy (< 30 keV) gammas and x-rays is primarily to the skin or the tissues of the eye. Higher energies are more penetrating and therefore a whole body hazard. Internally, gamma emitters can effect not only the tissues or organs in which they are deposited, but also surrounding tissues.

MECHANISMS OF DAMAGE

As discussed earlier, radiation causes atoms and molecules to become ionized or excited. These ionizations and excitations can result in:

Production of free radicals.

Breakage of chemical bonds.

Production of new chemical bonds and cross-linkage between macromolecules.

Damage to molecules which regulate vital cell processes (e.g. DNA, RNA, proteins).

TISSUE SENSITIVITY

In general, the radiation sensitivity of a tissue varies directly with the rate of proliferation of its cells and inversely with the degree of differentiation.

EFFECTS OF ACUTE HIGH RADIATION DOSES

A whole body radiation dose of greater than 25 to 50 rem received in a short time results in the clinical "acute radiation syndrome." This syndrome, which is dose related, can result in disruption of the functions of the bone marrow system (>25 rem), the gastro-intestinal system (>500 rem), and the central nervous system (>2000 rem). An acute dose over 300 rem can be lethal.

EFFECTS OF LOW RADIATION DOSES

There is no disease uniquely associated with low radiation doses.

Immediate effects are not seen below doses of 25 rem. Latent effects may appear years after a dose is received. The effect of greatest concern is the development of some form of cancer.

The National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (BEIR) issued a report in 1990 entitled "Health Effects of Exposure to Low Levels of Ionizing Radiation," also known as BEIR V. The following is an excerpt from the Executive Summary of the report:

> On the basis of the available evidence, the population-weighted average lifetime risk of death from cancer following an acute dose equivalent to all body organs of 0.1 Sv (0.1 Gy of low-LET radiation) is estimated to be 0.8%, although the lifetime risk varies considerably with age at the time of exposure. For low LET radiation, accumulation of the same dose over weeks or months, however, is expected to reduce the lifetime risk appreciably, possibly by a factor of 2 or more. The Committee's estimated risks for males and females are similar. The risk from exposure during childhood is estimated to be about twice as large as the risk for adults, but such estimates of lifetime risk are still highly uncertain due to the limited follow-up of this age group.
>
> . . . . .
>
> The Committee examined in some detail the sources of uncertainty in its risk estimates and concluded that uncertainties due to chance sampling variation in the available epidemiological data are large and more important than potential biases such as those due to differences between various exposed ethnic groups. Due to sampling variation alone, the 90% confidence limits for the Committee's preferred risk models, of increased cancer mortality due to an acute whole body dose of 0.1 Sv to 100,000 males of all ages range from about 500 to 1200 (mean 760); for 100,000 females of all ages, from about 600 to 1200 (mean 810). This increase in lifetime risk is about 4% of the current baseline risk of death due to cancer in the United States. The Committee also estimated lifetime risks with a number of other plausible linear models which were consistent with the mortality data. The estimated lifetime risks projected by these models were within the range of uncertainty given above. The committee recognizes that its risk estimates become more uncertain when applied to very low doses. Departures from a linear model at low doses, however, could either increase or decrease the risk per unit dose.

Caltech's whole body dose limit for planned exposures is 500 mrem/year (5 mSv/yr). If a Caltech worker were to receive the maximum allowable planned dose each year for twenty years, the total dose received would be 10 rem (0.1 Sv). According to the BEIR V report, the worker's chance of death from cancer would increase by approximately 0.4%. This is fairly small compared to the normal chance of death from cancer in the U. S. of about 20%.

6. RADIATION DOSIMETRY PROGRAM

EXTERNAL DOSIMETRY

Caltech currently uses film badge dosimeters and thermoluminescent dosimeters (TLDs) supplied and processed by an independent outside company.

FILM BADGE

The film badge is used to measure whole body dose and shallow dose. It consists of a film packet and a holder. The film is similar to ordinary photographic film but will be exposed by radiation. (It will also be exposed by light, so if the packet is opened or damaged, the reading will be invalid.) The holder has several filters which help in determining the type and energy of radiation. The badge will detect gamma and x-rays, high energy beta particles, and in certain special cases, neutrons. It does not register radiation from low energy beta emitters such as ^{3}H, ^{14}C, and ^{35}S, since their betas will not penetrate the paper covering on the film packet.

The badge is usually worn at the collar or chest level to measure the radiation dose received by the trunk of the body. When not in use, the badge should be left in a safe place on campus away from any radiation sources. (Use the film badge rack if one is provided.) Be sure the badge is available for the film packet exchange which is done monthly.

TLD RING

The TLD ring is used to measure dose to the hand. They are issued to individuals who may use millicurie amounts of a gamma or high energy beta emitter. The TLD is a small crystal which absorbs the energy from radiation. When heated, it releases the stored energy in the form of visible light. The crystal is mounted in a ring which should be worn on the hand which is expected to receive the larger dose. Wear the ring inside your glove with the label facing towards your palm.

PRECAUTIONS

The radiation doses recorded by your dosimeters become part of your occupational radiation dose record. Make sure that this record is valid and accurate by observing the following precautions:

> Always wear your badge when using radioactive materials or radiation producing machines. Wear your ring when using gamma or high energy beta emitters.
>
> Keep your dosimeters away from radiation sources when not in use. Do not deliberately expose a dosimeter to radiation or wear your badge when receiving medical or dental x-rays.
>
> Do not tamper with the film packet or remove it from the holder.
>
> Never wear someone else's dosimeter or let someone else wear yours.
>
> Avoid subjecting the badge to high temperatures or getting it wet.

Notify the Safety Office if your badge or ring has been damaged or lost, or if you have reason to believe that you or your dosimeter has received an accidental high dose.

STATE NOTIFICATION

The dosimeter vendor and Caltech are required by law to report to the California Department of Health Services (DHS) any personnel dosimeter which shows a dose higher than the occupational dose limits. It is a violation of the California Radiation Control Regulations and the conditions of our Radioactive Material License to deliberately expose a personnel dosimeter to a radiation source (except when being used as intended). The dose recorded by the dosimeter will become part of the dose record of the individual to whom it was issued unless it can be proven to DHS that the individual did not actually receive the dose.

INTERNAL DOSIMETRY

Caltech's license requires that persons authorized to use unsealed radionuclides be included in a bioassay program. On a bi-monthly basis, you may be sent a "Bioassay Information Form" which asks your radionuclide use. Whether or not you receive the form depends on the material you are authorized to use. You must complete and sign the information request, even if you have not used radioactive material during the period in question.

Whether or not a bioassay (usually urinalysis or thyroid assay) is requested by the Safety Office depends on your response. Urine specimen aliquots are counted in the Safety Office liquid scintillation counter and then disposed of. Thyroid assays are done using a calibrated gamma detector in the Safety Office lab.

7. RADIOACTIVE MATERIAL HANDLING AND LABORATORY SAFETY

REDUCTION OF DOSE TO PERSONNEL	The following are ways in which radiation doses can be reduced.
TIME	Carefully plan your activities in order to minimize the time spent handling or in the vicinity of radiation sources.
DISTANCE	Increasing the distance from a radiation source by the use of handling devices will reduce the dose received, since exposure rate decreases as $1/r^2$, where r is the distance from a point source. For example: At 10 cm, a 5 mCi I-125 source has an exposure rate of 75 mR/hr. Moving to 30cm would reduce the exposure rate to $(75 \text{ mR/hr})(10/30)^2 = 8.3 \text{ mR/hr}$ Note: The $1/r^2$ formula (also known as the inverse square law) does not take into account shielding provided by air. This can be significant for particulate radiation. Even the most energetic alpha particles commonly encountered have a range in air of about 4 inches. A beta from the decay of S-35 has a maximum range in air of about 12 inches.
SHIELDING	As gammas and x-rays pass through an absorber their decrease in number (by the processes discussed in chapter 3) is governed by the energy of the radiation, the density of the absorber medium, and the thickness of the absorber. This can be expressed approximately as

$$I = I_o e^{-\mu x}$$

where I_o is the intensity (number of photons per unit area) of the initial radiation,
I is the radiation intensity after it has passed through the absorber,
μ is a factor called the linear absorption coefficient. (The value of u depends on the energy of the incident radiation and the density of the absorbing medium.), and
x is the thickness of the absorber.

TVL & HVL

The thicknesses of an absorber needed to reduce the radiation intensity by a factor of two and by a factor of ten are called the *half-value layer (HVL)* and the *tenth-value layer (TVL)*, respectively. Approximate lead TVL's, HVL's and linear attenuation coefficients for some radionuclides are listed below.

Nuclide	γ Energy (MeV)	HVL (mm)	TVL (mm)	μ (cm^{-1})
I-125	0.035	0.05	0.16	150
Am-241	0.060	0.14	0.45	51
Co-57	0.122	2.0	6.7	3.4
Cs-137	0.662	6.5	21	1.1
Na-22	1.28	9.6	32	0.72
Co-60	1.17 & 1.33	12	40	0.58

EXAMPLE

At 30 cm, a 10 mCi Co-60 source produces an exposure rate of about 150 mR/hr. How much lead shielding is needed to reduce the rate to 4 mR/hr?

40 mm (one TVL) will reduce the rate to 15 mR/hr. Adding 12 mm (one HVL) will make it 7.5 mR/hr. One more HVL will put the rate at about 4 mR/hr. So the total lead shielding needed is 40 + 12 + 12 = 64 mm.

SHIELDING CONCERNS

When designing shielding there are several points to be kept in mind.

Persons outside the shadow cast by the shield are not necessarily protected.

A wall or partition may not be a safe shield for people on the other side.

Radiation can be "scattered" around corners.

BREMSSTRAHLUNG

The absorption of high energy beta radiation (e.g. ^{32}P and ^{90}Sr) in high Z materials such as lead and tungsten may result in the production of electromagnetic radiation (bremsstrahlung) which is more penetrating than the beta radiation that produced it. Low Z materials such as plastics and glass minimize the production of bremsstrahlung.

HANDLING PRECAUTIONS

Here are some of the radiological characteristics of and special precautions associated with some radionuclides commonly used on campus. In addition to the specific precautions for each nuclide, the following general precautions should always be followed when applicable to your work.

Whenever practical, designate specific areas for radioactive material handling and use. Clearly label the area and all containers. Minimize and confine contamination by using absorbent paper and spill trays. Handle potentially volatile materials in certified fume hoods.

Do not smoke, eat, or drink in rooms where radioactive materials are used. Do not store food or drink in refrigerators, freezers, or cold rooms used for radioactive material storage.

Use an appropriate instrument to detect radioactive contamination. Regularly monitor the work area. Always monitor yourself, the work area, and equipment for contamination when your experiment or operation is completed. Decontaminate when necessary.

Use appropriate shielding when handling millicurie or greater amounts of gamma emitters or high energy beta emitters.

Wear the dosimeters issued to you while using radioactive materials.

Wash your hands before leaving the lab, using a telephone, or handling food.

P-32 INFORMATION

Radioactive half-life	14.3 days
Decay mechanism	Beta emission
Energy	E_{max} = 1.709 MeV
Contamination monitoring	Thin window Geiger-Mueller detector
Shielding	1 cm lucite
Dosimetry	Film badge, TLD ring, urinalysis

P-32 Decay Table

days	0	1	2	3	4	5	6
0	1000	953	908	865	824	785	748
7	712	679	646	616	587	559	533
14	507	483	460	439	418	398	379
21	361	344	328	312	298	284	270
28	257	245	234	223	212	202	192
35	183	175	166	159	151	144	137
42	131	124	119	113	108	102	98
49	93	89	84	80	77	73	70
56	66	63	60	57	55	52	50

1. The dose rate on contact on the side of a 1 mCi delivery vial can be on the order of 1000 mrem/hr. If possible, avoid direct hand contact with vials and sources. When working with 100 μCi or more of P-32, work should be done behind a 1 cm lucite shield.

2. One microcurie of P-32 in direct contact with 1 cm^2 of bare skin gives a dose rate to the skin of about 9 rem/hr. Always protect your skin and eyes when handling unsealed materials. Wear gloves, lab coats, safety glasses, and shoes.

3. A thin window G-M survey meter should always be available. A survey should be made immediately after use and any "hot spots" should be decontaminated.

4. Film badges must be worn for all P-32 work. TLD rings should be worn for all P-32 work, and are required when

handling 1 millicurie or more.

5. Handle and store your radioactive waste carefully. The one gallon polyethylene bottles for liquid waste should be placed in a secondary container (e.g. a bucket or tray) to contain spills or leaks. When more than a millicurie is involved, place 1 cm lucite in front of the container for shielding. The metal barrels for dry waste provide sufficient shielding but be sure to keep the lid on.

S-35 INFORMATION

Radioactive half-life	87.4 days
Decay mechanism	Beta emission
Energy	E_{max} = 0.167 MeV
Contamination monitoring	Thin window Geiger-Mueller detector, liquid scintillation counter for wipe surveys
Dosimetry	Urinalysis

S-35 Decay Table

days	0	1	2	3	4	5	6
0	1000	992	984	976	969	961	954
7	946	939	931	924	916	909	902
14	895	888	881	874	867	860	853
21	847	840	833	827	820	814	807
28	801	795	788	782	776	770	764
35	758	752	746	740	734	728	722
42	717	711	705	700	694	689	683
49	678	673	667	662	657	652	646
56	641	636	631	626	621	616	612

1. Radiolysis of S-35 labelled amino acids may lead to the release of S-35 labelled volatile impurities. Delivery vials should therefore be opened in a fume hood.

2. The addition of stabilizers (buffers) will reduce, but not eliminate, the evolution of S-35 volatiles from tissue culture media. Incubators should be checked for contamination after using S-35 methionine or other volatile compounds.

3. S-35 may be difficult to distinguish from C-14. If both nuclides are being used in the same laboratory, establish controls to ensure they are kept separate. If "unknown" contamination is found, treat it as C-14.

I-125 INFORMATION

Radioactive half-life	59.6 days
Decay mechanism	Electron capture (gamma and x-ray emission)
Energy	27-35 keV
Contamination monitoring	Thin crystal NaI detector, liquid scintillation counter for wipe surveys
Shielding	Thin lead
Dosimetry	Film badge, TLD ring, thyroid scan

I-125 Decay Table

days	0	1	2	3	4	5	6
0	1000	988	977	966	955	944	933
7	922	911	901	890	880	870	860
14	850	840	830	821	811	802	792
21	783	774	765	756	748	739	731
28	722	714	705	697	689	681	673
35	666	658	650	643	635	628	621
42	614	606	599	593	586	579	572
49	566	559	553	546	540	534	527
56	521	515	509	504	498	492	486

1. The dose rate at 1 cm from a 1 mCi point source is about 1.5 rem/hr The dose rate is inversely related to the square of the distance from the source. Thus while a small amount of I-125 held for a short time can result in a significant dose to the hands, a relatively short separation distance reduces the dose rate to an acceptable level.

2. The volatility of iodine requires special handling techniques to minimize radiation doses. Solutions containing iodide ions (such as NaI) should not be made acidic or be frozen. Both lead to formation of volatile elemental iodine. Once bound to a protein, the volatility of the radioiodine is tremendously reduced.

3. Always work in a fume hood with a minimum face velocity of at least 125 linear feet per minute when working with NaI. The sash should be below the breathing zone.

4. Use shoulder length veterinary gloves with short vinyl gloves on top to minimize skin absorption.

5. Avoid opening the septum on delivery vials. It is preferable to remove radioiodine using a hypodermic needle and syringe.

6. A radiation survey instrument should be available in the immediate area. A low energy scintillation detector is preferable to a G-M detector. You should do a wipe survey in your work areas after each use.

7. Film badges must be worn for all radioiodine work, and finger rings are required when handling 1 mCi or more of I-125.

8. Use lead to shield quantities of 1 mCi or more. 1 mm of lead will essentially block all of the radiation emitted from I-125.

9. Call the Safety Office, x6727, to schedule a thyroid assay after using 1mCi or more of NaI, or in cases of suspected accidental contamination.

10. Until waste is picked up by Radiation Safety, it should be kept in the waste containers supplied by Radiation Safety and stored in a fume hood.

H-3 (TRITIUM) INFORMATION

Radioactive half-life	12.4 years
Decay mechanism	Beta emission
Energy	E_{max} = 18.6 keV
Contamination monitoring	Liquid scintillation counter for wipe surveys
Dosimetry	Urinalysis

1. Because the beta emitted has a very low energy, tritium can not be detected with the usual survey meters found in the lab. Therefore, special care is needed to keep the work area from becoming contaminated. Tritium can be detected by doing a wipe survey and counting the wipes in a liquid scintillation counter.

2. Many tritiated compounds readily penetrate gloves and skin. Wearing two pairs of gloves and changing the outer pair every fifteen or twenty minutes will reduce the chances of cross contamination and absorption through the skin.

C-14 INFORMATION

Radioactive half-life	5730 years
Decay mechanism	Beta emission
Energy	E_{max} = 0.156 MeV
Contamination monitoring	Thin window Geiger-Mueller detector, liquid scintillation counter for wipe surveys
Dosimetry	Urinalysis

1. Some C-14 labelled compounds can penetrate gloves and skin. Wearing two pairs of gloves and changing the outer pair every fifteen or twenty minutes will reduce the chances of absorption through the skin.

2. C-14 may be difficult to distinguish from S-35. If both nuclides are being used in the same laboratory, establish controls to ensure they are kept separate. If "unknown" contamination is found, treat it as C-14.

8. RADIATION SURVEY METERS

INTRODUCTION

There are several types of portable radiation survey instruments in use on campus. Various types have different qualities and can therefore have very different detection capabilities.

As a user of radioactive materials or radiation producing machines, you are expected to be able to use the survey meters in your laboratory. During your initial training, you will learn how to operate the instruments in your lab. You should know their capabilities and limitations and be able to interpret the meter readings.

GEIGER-MUELLER DETECTOR

The Geiger-Mueller (G-M) counter is the most common radiation detection instrument on campus. In this type of meter, an ionization in the detector results in a large output pulse that causes meter and audio responses. Because of the inherent characteristics of the detector, all initial ionizing events produce the same size output pulse. Therefore, the meter does not differentiate among types or energies of radiation.

Most G-M detectors have a thin mica film "window" at one end. This window is very fragile. Always use the thin end window for detecting pure beta emitters and low energy photons (e.g. ^{32}P, ^{35}S, ^{14}C, ^{55}Fe, ^{125}I, and x-rays less than 40 keV). The aluminum side wall should be used only for the detection of penetrating x-rays and gamma radiation.

Very low energy beta emitters such as ^{3}H and ^{63}Ni are not detectable since their betas do not have enough energy to penetrate the window. They are best detected by using liquid scintillation counting techniques. ^{14}C and ^{35}S emit betas energetic enough to pass through the thin window. *However, covering the window with plastic wrap or paraffin film will stop most or all of their betas from entering the detector.*

The efficiency of a meter for a specific source of radiation is given by the ratio of the meter count rate to the actual disintegration rate of the source. This means

$$\text{actual rate} = \frac{\text{meter reading}}{\text{efficiency}}$$

Some examples of approximate G-M efficiencies through the end window at 1 inch from a point source are given below:

^{3}H	not detectable
^{14}C, ^{35}S	0.2% - 0.8% *
^{32}P	3% - 8%
^{125}I	0.01% - 0.03%

* Not detectable if the detector window is covered with paraffin film, plastic wrap, or other material.

EXAMPLE

Your G-M counter reads 5000 cpm at one inch from a small spot of P-32 contamination on the bench. What is the total activity of the contamination (assuming a 5% efficiency)?

actual disintegration rate = (5000 cpm)/(0.05 cpm/dpm)
= 100,000 dpm = 1700 dps
= 1700 Bq = 45 nCi

Because of the randomness of radioactive decay, the meter reading at low count rates often fluctuates widely. For this reason, the audio speaker is sometimes a better indicator of small amounts of radioactivity than the meter reading. At higher count rates, the speaker response is often faster than the meter reading. It is better, therefore, to have the speaker on when using a G-M counter.

Very high radiation fields may temporarily overload the detector circuit resulting in a partial or complete loss of meter or audio response. If this happens, remove the meter and yourself from the area and push the reset button or turn the meter off then back on. The meter should resume normal operation. Always turn on a survey meter before entering an area that might have high radiation fields.

SCINTILLATION DETECTOR

Scintillation detectors which incorporate a sodium iodide crystal are used in some laboratories for the detection of low energy gamma emitters such as ^{125}I. Some survey meters allow the use of either a G-M detector or a scintillation detector. The efficiency of a low energy scintillation probe for the detection of ^{125}I is about 5% at one inch — over a hundred times better than a G-M probe.

ION CHAMBER

Ionization chambers are suitable for measuring radiation exposure rate or cumulative radiation exposure at high radiation intensities. They are not especially useful at low radiation intensities or for detecting small quantities of radioactive material.

CALIBRATION

Most survey meters have scales that read in milliRoentgen per hour (mR/hr) and/or counts per minute (cpm) or counts per second (cps). After detector efficiency is taken into consideration, the cpm or cps scales give an indication of the quantity of radioactivity. The mR/hr scales give an indication of the radiation exposure rate. There is an important difference in these measurements. *Exposure rate measurements are only valid for electromagnetic radiation.*

Radiation Safety calibrates all of the portable radiation survey instruments on campus. We use two general types of calibration procedures — one for meters that are used for detection and measurement of particulate radiation, and another for meters used for detection and measurement of penetrating electromagnetic radiation. The two procedures are explained briefly below so that you will know what to expect.

Survey meters used in biology and chemistry research labs are calibrated for the detection and measurement of particulate radiation. These meters are calibrated using a pulse generator so that the cpm or cps scales read correctly (i.e. one pulse in = one meter count). If the meter reads only in cpm or cps, we may place an additional calibration tag on the instrument giving the mR/hr equivalent of the count rate reading for penetrating electromagnetic radiation. If the meter also reads in mR/hr, those readings may not be accurate for the measurement of electromagnetic radiation. We will indicate a correction factor.

Survey meters that are used for radiation exposure measurements are calibrated with a comparable radiation source. The mR/hr scale will read correctly when the detector is exposed to electromagnetic radiation greater than 100 keV.

9. RADIOACTIVE WASTE DISPOSAL

INTRODUCTION

Due to Federal legislation, out-of-state low-level radioactive waste (LLRW) disposal facilities are no longer accepting California generated LLRW. Unfortunately, litigation and other delays have kept California from developing its own LLRW disposal facility. In response to these events, the Radiation Safety Committee has approved storage of radioactive waste by Radiation Safety. The purpose of this storage is to allow time for the decay of short-lived radionuclides and to facilitate the proper disposal of all radioactive waste.

MIXED HAZARDOUS/ RADIOACTIVE WASTE

Radioactive waste containing any hazardous chemicals requires special handling. Radiation Safety must be consulted before any such waste is generated.

WASTE MINIMIZATION

Since all radioactive waste must be stored on campus until it decays or until it can be shipped to an authorized LLRW disposal facility, it is important that the amount of waste generated be kept to a minimum. Radiation Safety has a limited area to store radioactive waste. Some ways to minimize waste are listed below.

Design experiments to use as little radioactive material as possible.

Use proper handling techniques. (See chapter 7.) This will reduce the chance of contamination.

When practical, use techniques which do not involve radioactive materials. There are many new techniques and products available which can be used in place of radioactive materials.

Monitor for contamination and dispose of as little as possible. If there is a spot of contamination on a piece of absorbent paper, cut out that spot and dispose of it rather than the whole piece. Don't automatically place your gloves in the radioactive waste. Monitor them. If there is no detectable contamination, throw them in the regular trash.

Liquid radioactive waste includes the radioactive material and the first rinse of its experimental container. After the first rinse, the container can be washed in the sink.

SEGREGATION BY HALF-LIFE

All radioactive waste must be segregated according to radionuclide half-life. The three categories for segregation are:

Half-life less than 15 days (P-32)

Half-life between 15 and 90 days (S-35, Cr-51, I-125)

Half-life greater than 90 days (H-3, C-14, Ca-45)

Waste containers are marked with the category of waste they are intended for. It is very important that waste is placed in the proper container.

If waste contains two different radionuclides, place it in the container appropriate for the longer half-life.

DISPOSAL TAGS

Radiation Safety will provide a tag for each liquid and solid radioactive waste container. The top portion of the tag must be filled out completely with the following information:

Principal Investigator

Radionuclide disposed

Date, estimated activity, and user for each significant disposal.

PROHIBITED ITEMS	All radioactive labels, markings, and tape must be defaced or removed before being put in a waste container. Solid waste can not be picked up by Radiation Safety if it contains any of the following: Hazardous material (e.g. lead, toxins) Biohazard bags or other hazardous material markings Radioactive markings Sharps (e.g. needles, razor blades) Liquid radioactive waste must be readily soluble or dispersible in water. It must not contain any hazardous materials such as solvents or scintillation fluid.
LEAD PIGS/SHIELDING	Lead shipping containers and other lead shielding should not be disposed of as ordinary trash or placed in solid radioactive waste containers. Lead which is boxed and identified will be picked up by Radiation Safety when requested.
GELS	If a gel is very solid at room temperature, it may be disposed of as solid waste. If it is soft or semi-solid at room temperature, use a solubilizer to liquefy it and dispose of it as liquid waste.
DISPOSAL PROCEDURES	Disposal procedures are described in the Radiation Safety Manual.

APPENDIX A DOSE CONCEPTS

INTRODUCTION

This discussion is provided as an additional source of information to those members of the Caltech community who desire a more in-depth understanding of radiation dose concepts.

Changes to the federal radiation protection regulations took effect in January, 1994. These changes were based on reports and recommendations by the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), and other organizations involved with radiation protection.

TOTAL DOSE CONCEPT

Previously, the radiation doses received from external radiation sources and internally deposited radioactive materials were treated separately. Limits on internal uptake of radioactive materials were based on the dose to a "critical organ" and could not be compared to the "whole body" dose received from an external source.

The external dose number was and still is related to the risk of stochastic effects (primarily cancer). For a stochastic effect, the higher the dose received, the greater the chance of developing the effect. The new regulations have a mechanism for determining the increased risk of stochastic effects from an intake of radioactive material. The dose calculated is based on a variety of factors such as the biological half-life of the material, the distribution of the material in the body, and the type and energy of the radiation. The result is that both the external dose and the internal dose are related to the risk of stochastic effects and thus can be added to obtain a total dose.

ORGAN DOSE

For a few radionuclides, the limits on intake are based on nonstochastic effects rather than stochastic effects. For a nonstochastic effect, the higher the dose received, the more severe the effect. However, unlike stochastic effects, there is a threshold dose, i.e. a certain dose, below which the effect will not occur. Limits on the internal intake of radioactive materials are set to keep organ doses well below the thresholds. Even in these cases, however, the additional risk of stochastic effects must also be determined.

The dose limit for external exposure of the lens of the eye is also based on prevention of a nonstochastic effect (lens opacities).

DEFINITIONS

Absorbed Dose means the energy imparted by ionizing radiation per unit mass of irradiated material.

Dose Equivalent means the product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest.

Deep-dose Equivalent (DDE), which applies to external whole-body exposure, is the dose equivalent at a tissue depth of 1 cm.

Shallow-dose Equivalent, which applies to external exposure of the skin or an extremity, is the dose equivalent at a tissue depth of 0.007 cm.

Eye Dose Equivalent, which applies to the external exposure of the lens of the eye, is the dose equivalent at a tissue depth of 0.3 cm.

Committed Dose Equivalent (CDE) means the dose equivalent to organs or tissues of reference that will be received from an intake of radioactive material by an individual during the fifty-year period following the intake.

Weighting Factor for an organ or tissue is the proportion of the risk of stochastic effects when the whole body is irradiated uniformly.

Committed Effective Dose Equivalent (CEDE) is the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the CDE to these organs or tissues.

Total Effective Dose Equivalent (TEDE) means the sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). TEDE = DDE + CEDE

Total Organ Dose Equivalent (TODE) is the sum of the DDE and the CDE to an organ or tissue.

Annual Limit on Intake (ALI) means the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a CEDE of 5 rem or a CDE of 50 rem to any individual organ or tissue.

EXAMPLE DOSE CALCULATIONS

Fortunately, the NRC has already determined the ALIs for all of the radionuclides and listed them in a table. This makes calculating CEDEs and CDEs fairly simple. Table 2 shows the ALIs for several of the radionuclides used at Caltech.

EXAMPLE 1

P-32 in most chemical forms has an ALI for ingestion of 600 μCi. This is listed as a stochastic ALI, which means that ingesting 600 μCi of P-32 would result in a CEDE of 5 rem.

If a worker accidentally ingests 10 μCi of P-32, the CEDE would be (10 μCi)(5 rem/600 μCi) = 0.083 rem = 83 mrem.

EXAMPLE 2

I-125 has a nonstochastic ALI for inhalation of 60 μCi. This means that inhaling 60 μCi of I-125 would result in a CDE to the thyroid of 50 rem. The stochastic ALI for inhalation of I-125 is 200 μCi.

If a worker accidentally inhales 3 μCi of I-125, the CDE to the thyroid would be (3 μCi)(50 rem/60 μCi) = 2.5 rem. The CEDE would be (3 μCi)(5 rem/200 μCi) = 0.075 rem.

Suppose this worker also received an external dose from working with a high energy gamma emitter. Evaluation of his film badge showed a DDE of 50 mrem. The TEDE would then be 50 mrem + 75 mrem = 125 mrem.

EMBRYO/FETUS DOSE

The dose limit to the embryo/fetus of a declared pregnant woman is 0.5 rem. Efforts must also be made to avoid a dose substantially higher than 0.06 rem in one month. A declared pregnant woman means a woman who has voluntarily informed the Safety Office, in writing, of her pregnancy and the estimated date of conception.

The dose to an embryo/fetus is the sum of the deep-dose equivalent to the declared pregnant woman and the dose from internally deposited radionuclides in the embryo/fetus and in the woman.

DOSE REPORTING

Each worker who is monitored must be advised annually of his or her dose.

DOSE LIMITS

A summary of dose limits set by the revised regulations is shown in Table 1. The Caltech Radiation Safety Committee has established the general policy that planned radiation doses shall not exceed ten percent of the limits for adult radiation workers.

The dose limit for an individual member of the public is 0.1 rem/year TEDE.

Table 1
Revised Occupational Dose Limits

Dose Category	Adult Occupational Dose Limit
Total Effective Dose Equivalent (TEDE)	5 rem/year*
Total Organ Dose Equivalent (TODE)	50 rem/year to any individual organ or tissue except the lens of the eye*
Eye Dose Equivalent	15 rem/year*
Shallow Dose Equivalent	50 rem/year*
Embryo/Fetus Dose	0.5 rem for the entire gestation period

*Occupational dose limit for minors is 10% of the adult limit

Table 2
Annual Limit on Intake (ALI) for Radionuclides Commonly Used at Caltech

Radionuclide	Form	ALI for ingestion (μCi)	ALI for inhalation (μCi)
H-3	gas		8×10^8
	other	8×10^4	8×10^4
C-14	most compounds	2×10^3	2×10^3
P-32	most compounds	6×10^2	9×10^2
P-33	most compounds	6×10^3	8×10^3
S-35	most compounds	8×10^3 stochastic 1×10^4 nonstochastic	2×10^4 stochastic
Ca-45	all compounds	2×10^3	8×10^2
Cr-51	most compounds	4×10^4	5×10^4
I-125	all compounds	4×10^1 nonstochastic 1×10^2 stochastic	6×10^1 nonstochastic 2×10^2 stochastic

APPENDIX B RADIATION RULES OF THUMB

ALPHA PARTICLES	An alpha energy of at least 7.5 MeV is required to penetrate the protective layer of the skin (0.07mm).
BETA PARTICLES	A beta energy of at least 70 keV is required to penetrate the protective layer of the skin (0.07mm). The average energy of a beta-spectrum is approximately one-third the maximum energy. The range of beta particles in air is about 12 ft per MeV. (e.g. The maximum range of P-32 betas is 1.71 MeV x 12 ft/MeV $\approx$ 20 ft). The skin dose rate from a uniform thin deposition of 1 $\mu Ci/cm^2$ is about 9 rem/hr for energies above 0.6 MeV. For a beta emitter point source, the dose rate in rem/hr at one foot is approximately 300 x Ci where Ci is the source strength in curies. This calculation neglects any shielding provided by the air, which can be significant. For example, the maximum range in air for a beta from S-35 is less than one foot, so the dose rate at one foot is zero for any size S-35 source.
GAMMAS AND X-RAYS	For a point source gamma emitter with energies between 0.07 and 2 MeV, the exposure rate in R/hr at 1 foot is approximately 6CEn, where C is the activity in curies; E is the energy in MeV; and n is the number of gammas per disintegration. Gammas and x-rays up to 2 MeV will be attenuated by at least a factor of 10 by 2 inches of lead.

APPENDIX C EXCERPT FROM US NRC 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 about the health risks from occupational exposure to ionizing radiation. Ionizing radiation consists of energy or small particles, such as gamma rays and beta or alpha particles, emitted from radioactive materials, which can cause chemical or physical damage when absorbed by living tissue. A question and answer format is used. Many of the questions or subjects initially were developed by the NRC staff in consultation with workers, union representatives, and licensee representatives experienced in radiation protection training.

This Revision 1 to Regulatory Guide 8.29 updates earlier material on biological effects and risks and on typical occupational exposure. Additionally, it conforms to the revised 10 CFR Part 20, "Standards for Protection Against Radiation," which was required to be implemented by licensees no later than January 1, 1994. The information in this appendix is intended to help develop an attitude of healthy respect for risks associated with radiation, with neither unnecessary fear nor lack of concern. Additional guidance concerning other topics in radiation protection training is provided in other NRC regulatory guides.

1. What is meant by health risk?

A health risk is generally thought of as something that may endanger health. Scientists consider health risk to be the statistical probability or mathematical chance that personal injury, illness, or death may result from some action. Most people do not think about health risks in terms of mathematics. Instead, most of us consider the health risk of a particular action on the basis of whether we believe that particular action will, or will not, cause us some harm. The intent of this appendix is to provide estimates of, and explain the bases for, the possible risk of injury, illness, or death from occupational radiation exposure.

When x-rays, gamma rays, and ionizing particles interact with living materials such as our bodies, they might deposit energy sufficient to cause several different types of damage, such as very small physical displacement of molecules or a change of an atom to a different element, or ionization, which cause electrons to be removed from atoms and molecules. When the energy of these radiations is high enough, biological damage can occur: chemical bonds can be broken and cells can be damaged or killed.

The basic unit for measuring absorbed radiation is the rad (radiation absorbed dose). One rad (0.01 gray in the International System of units) equals the absorption of 100 ergs (a small but measurable amount of energy) in a gram of tissue exposed to radiation. To reflect biological risk, rads must be converted to rems. This conversion accounts for the differences in the effectiveness of different types of radiation to cause damage. The rem is used to estimate biological risk.

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

Potential health effects from exposure to radiation include cancer such as leukemia and bone, breast, and lung cancer. Very high, acute levels of radiation exposure have been known to cause prompt (or early) effects, such as vomiting and diarrhea,[1] skin burns, cataracts, and even death. Radiation exposure has also been linked with the potential for genetic effects in future children of exposed parents. Children who

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[1] These symptoms are early indicators of what is referred to as acute radiation syndrome, which includes damage to the blood-forming organs such as bone marrow, damage to the gastrointestinal system, and at very high doses can include damage to the central nervous system.

were exposed to elevated levels of radiation prior to birth have shown an increased probability of mental retardation. These effects (with the exception of genetic effects) have been observed in studies of medical radiologists, uranium minors, radium workers, radiotherapy patients, and people exposed to radiation from atomic bombs dropped on Japan. In addition, the radiation effects studies with laboratory animals have provided extensive data on radiation-induced health effects, including genetic effects.

The observations and studies mentioned above involve levels of radiation exposure or exposure rates that are generally higher than those received occupationally today. Although studies have not shown a clear cause-and-effect relationship between current levels of occupational exposure and biological effects, it is prudent to assume that some effects do occur.

3. What is meant by early and continuing effects, delayed effects, and genetic effects?

EARLY AND CONTINUING EFFECTS

Early effects, which are also called immediate or prompt effects, are those that occur shortly after an exposure, within hours to a few days. They are observable after receiving a very large dose in a short period of time -- for example, 300 rems (3 Sv) received within a few minutes to a few days. Early effects are not caused at the levels of radiation exposure allowed under the NRC's occupational limits.

Early effects occur when the radiation dose is large enough to cause extensive biological damage to cells; a large number of cells within a specific organ or the whole body will have been killed. For prompt effects to occur, this radiation dose must be received within a short time period. This type of dose is called an acute dose or acute exposure. The same dose received over a long time period would not necessarily cause the same effect. Our body's natural biological process is constantly repairing damaged cells and replacing dead cells; if the cell damage is not severe, our body is capable of repairing and replacing the damaged cells without any observable adverse conditions.

For example, a whole body dose of about 300 rems (3 Sv), 60 times the annual occupational dose limit, if received within a short time period (e.g., a few hours) 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 without medical treatment. These effects would not occur if the dose 300 rems (3 Sv) were accumulated gradually over many years (Refs. 1 and 2).

It is important to distinguish between whole body and partial body exposure. A localized dose to a small area of the body would not produce the same effect as a whole body dose of the same magnitude. For example, f only the hand were exposed, the effect would mainly be limited to a portion of the skin and underlying tissue of the hand. An acute dose of 600 rem (6 Sv) to the hand would cause skin reddening; recovery would occur over the following months and no long-term damage would be expected. An acute dose of this magnitude to the whole body could cause death within a short time without medical treatment. Medical treatment would lessen the magnitude of the effects and the chance of death; however, it would not totally eliminate the effects or chance of death.

Cataracts are also considered early and continuing effects. A certain level of dose to the lens of the eye is required before any observable visual impairment is observed and the impairment remains after the exposure is stopped. The threshold for cataract development is an acute dose on the order of 100 rem (1 Sv). Further, a cumulative dose of 800 rems (8 Sv) from protracted exposures over many years to the lens of the eye has also been linked to some level of visual impairment. This dose exceeds the amount that can be accumulated by the lens for normal occupational exposure (Refs. 1 and 3).

DELAYED EFFECTS

Delayed effects may occur years after exposure. These effects are not the immediate, direct result of biological damage to the cells of the body but are caused indirectly when the radiation causes the cells in the body to change, thereby causing the normal function of the cell to change -- for example, turning normal healthy cells into cancer cells. The potential for these delayed health effects is one of the main concerns addressed when setting limits for occupational doses.

GENETIC EFFECTS

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. However, excess genetic effects clearly caused by radiation have not been observed in human populations exposed to radiation. Continuing evaluations of the atomic bomb survivors (Hiroshima and Nagasaki) have not shown any significant radiation-related increases in genetic defects (Ref. 4). Effects have been observed in animal studies conducted at very high levels of exposure and it is known that radiation can cause changes in the genes in cells of the human body. Therefore, it is prudent to assume that radiation exposures, even at the levels allowed under NRC's limits, do pose some risk of genetic effects. Teratogenic effects, or effects that are observable in children who were exposed during fetal and embryonic stages of development, are discussed in Question 5.

4. What is the difference between the effects of acute and chronic radiation exposure?

Acute radiation doses usually refer to a large dose of radiation received in a short period of time. Chronic exposure refers to small doses received repeatedly over long time periods, for example, 20 to 100 mrem (or millirem, which is one-thousandth of a rem) (0.2 to 1 mSv) per week every week for several years. It is assumed that any radiation exposure, either acute or chronic, has a potential for causing delayed effects. However, only acute doses cause early effects; chronic doses do not cause early effects. Since the NRC limits are set to prevent all early effects, concern with occupational radiation risk is primarily focused on chronic exposure to low levels of radiation over long time periods for which the delayed effects such as cancer are of concern. The difference between acute and chronic radiation exposure can also be shown by a comparison with exposure to the sun's rays. An intense exposure to the sun can result in painful burning, peeling, and growing of new skin. However, repeated short exposures provide time for the skin to repair between exposures. Whether exposure to the sun's rays is long term or spread over short periods, some of the injury may not be repaired and may eventually result in skin cancer.

5. What are the health risks from radiation exposure to the embryo/fetus?

During certain stages of development, the embryo/fetus is much more sensitive to radiation than adults are. Studies of atomic bomb survivors exposed to high radiation doses during pregnancy show that children born after these exposures have a higher risk of mental retardation or lower IQ scores. Other studies suggest that an association exists between exposure to diagnostic x-rays before birth and carcinogenic effects in adult life; the magnitude of the risk, however, is uncertain. In recognition of this increased radiation sensitivity, a more restrictive dose limit has been established for the embryo/fetus of a declared pregnant radiation worker. Guidance in conformance with the revised 10 CFR Part 20 is being developed as a proposed Revision 3 to Regulatory Guide 8.13; it has been published as Draft Regulatory Guide DG-8014, "Instruction Concerning Prenatal Radiation Exposure."

If an occupationally exposed woman declares her pregnancy to the licensee, she is subject to the more restrictive dose limits for the embryo/fetus during the remainder of the pregnancy. The dose limit of 500 mrem (5 mSv) for the total gestation period applies to the embryo/fetus and is controlled by restricting the exposure to the declared pregnant woman. Restricting the woman's occupational exposure, if she declares her pregnancy, raises questions about individual privacy rights, equal employment opportunities, and possible loss of income. Because of these concerns, the declaration of pregnancy by a woman radiation worker is voluntary. Also, the declaration of pregnancy can be withdrawn, for example, if the woman reconsiders and feels that her benefits from receiving the occupational exposure would outweigh the increased risk to her embryo/fetus from the radiation exposure.

6. Can a worker become sterile or impotent from normal occupational radiation exposure?

No. Temporary or permanent sterility can be caused by radiation but not at the levels allowed under NRC's occupational limits. Sterility is an early radiation effect. There is a threshold below which these effects would not occur. Doses on the order of 10 rem (0.1 Sv) to the testes can result in a measurable but temporary reduction in sperm count. Temporary sterility (suppression of ovulation) has been observed in women who have received acute doses of 150 rem (1.5 Sv). The estimated threshold (acute) radiation dose for induction of permanent sterility is about 200 rem (2 Sv) for men and about 350 rem (3.5 Sv) for women (Refs. 1 and 3).

Although high, acute doses can affect fertility, they have no direct effect on the ability to function sexually. No evidence exists that exposures within NRC's occupational limits have any direct effect on the ability to function sexually.

7. What is meant by external and internal exposure?

A worker's occupational dose may be caused by exposure to radiation that originates outside the body, called "external exposure," or by exposure to radiation from radioactive material that has been taken into the body, called "internal exposure." It is the current scientific consensus that a rem of radiation dose has the same biological risk regardless of whether it is from an external or an internal source. The NRC requires that dose for external exposure and dose for internal exposure be added together to determine compliance with the occupational limits. The sum of external and internal dose is called the Total Effective Dose Equivalent (TEDE).

Radioactive materials may enter the body through breathing, eating, or drinking, or they may be absorbed through the skin, particularly if the skin is broken. The intake 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 may be contaminated and these materials can be resuspended in air during work activities.

After entering the body, the radioactive material goes to particular organs, depending on the biochemistry of the material. For example, certain chemical forms of uranium tend to deposit in the bones, where they remain for a long time. These forms of uranium are slowly eliminated from the body, mostly by way of the kidneys. Radioactive iodine is preferentially deposited in the thyroid gland, which is located in the neck.

To limit risk to specific organs and the total body, standards have been established for the annual limit of intake (ALI) for each radionuclide. When more than one radionuclide is involved, the intake amounts of each are reduced proportionally. NRC regulations specify the concentrations of radioactive material in the air to which a worker can be continuously exposed for the entire 2,000 working hours in a year. These concentrations are termed the derived air concentrations (DACs).[2] These limits are the total amounts allowed if no external radiation is received. The resulting dose from the internal radiation sources is the maximum allowed to the organ or to the worker's whole body.

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[2] The DAC in the revised 10 CFR Part 20, which all licensees were required to implement no later than January 1, 1994, replaces the maximum permissible concentrations (MPCs) that were formerly in 10 CFR Part 20.

8. How does radiation cause cancer?

When radiation interacts with the cells of our bodies, a number of events can occur. The damaged cells can repair themselves; no resulting damage is caused. The cells can die, much like the millions of cells that die every day in our bodies, and may be replaced through the normal biological process. Or a change can occur in the cell's reproductive structure -- the cells can mutate and subsequently be repaired with no effect, or they can form precancerous cell, which may become cancerous.

Radiobiologists have studied the relationship between radiation and cancer. These studies indicate that radiation damage to chromosomes in the cell nucleus is the main cause of cancer. Chromosome damage may occur directly through the interaction of the ionizing radiation in the cell or indirectly through reactions of chemical products produced by radiation interactions. Cells are able to repair most damage within hours; however, misrepair may occur. Such misrepaired damage is thought to be the origin of cancer, but misrepair does not always cause cancer. Benign changes in the cell can occur or the cell can die; these changes do not lead to cancer.

Many factors can affect susceptibility to the cancer-causing effects of radiation, such as general health, inherited traits, sex, as well as exposure to other cancer-causing agents such as cigarette smoke. However, most diseases are caused by the interaction of several factors. Other detrimental conditions such as smoking appear to increase the susceptibility.

9. If I receive a radiation dose, will it cause me to get cancer?
Probably not. Radiation is like most substances that cause cancer in that the effects can be seen clearly only at high doses. Assessment of the cancer risks that may be associated with low doses of radiation are projected from data available at doses larger than 10 rad (0.1 gray) (Ref. 3). Generally, for radiation protection purposes, these estimates are made using the straight line portion of the linear quadratic model (Curve 2 in Figure 1). We have data on cancer probabilities for high doses as shown by the solid line inFigure 1. Only in the studies of radiation above occupational limits are there dependable measurements of risk of cancer, primarily because below the limits the effect is small compared to differences in the normal cancer incidence from year to year and place to place. Most scientists believe that there is some 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 the linear quadratic model (Curve 2).

For regulatory purposes, the NRC uses the straight line portion of the linear quadratic model (Curve 2), which shows the number of effects decreasing as the dose decreases. It is prudent to assume that even small doses have some chance of causing cancer. This is as true for natural carcinogens such as sunlight and natural radiation as it is for those that are man-made such ascigarette smoke, smog, and man-made radiation. Thus, a principle of radiation protection is to do more than merely meet the allowed regulatory limits; doses should be kept as low as is reasonably achievable (ALARA). The ALARA concept is discussed in Question 13.

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

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 research knowledge. We do know that the estimates of radiation effects are better known and are more certain than are those of most hazardous chemicals (Ref. 5). Being exposed to typical occupational radiation doses is taking a chance, but that chance is reasonably well understood. From currently available data, the NRC has adopted the risk value for an occupational dose of 1 rem (0.01 Sv) as representing a risk of 4 in 10,000 of developing a fatal cancer.

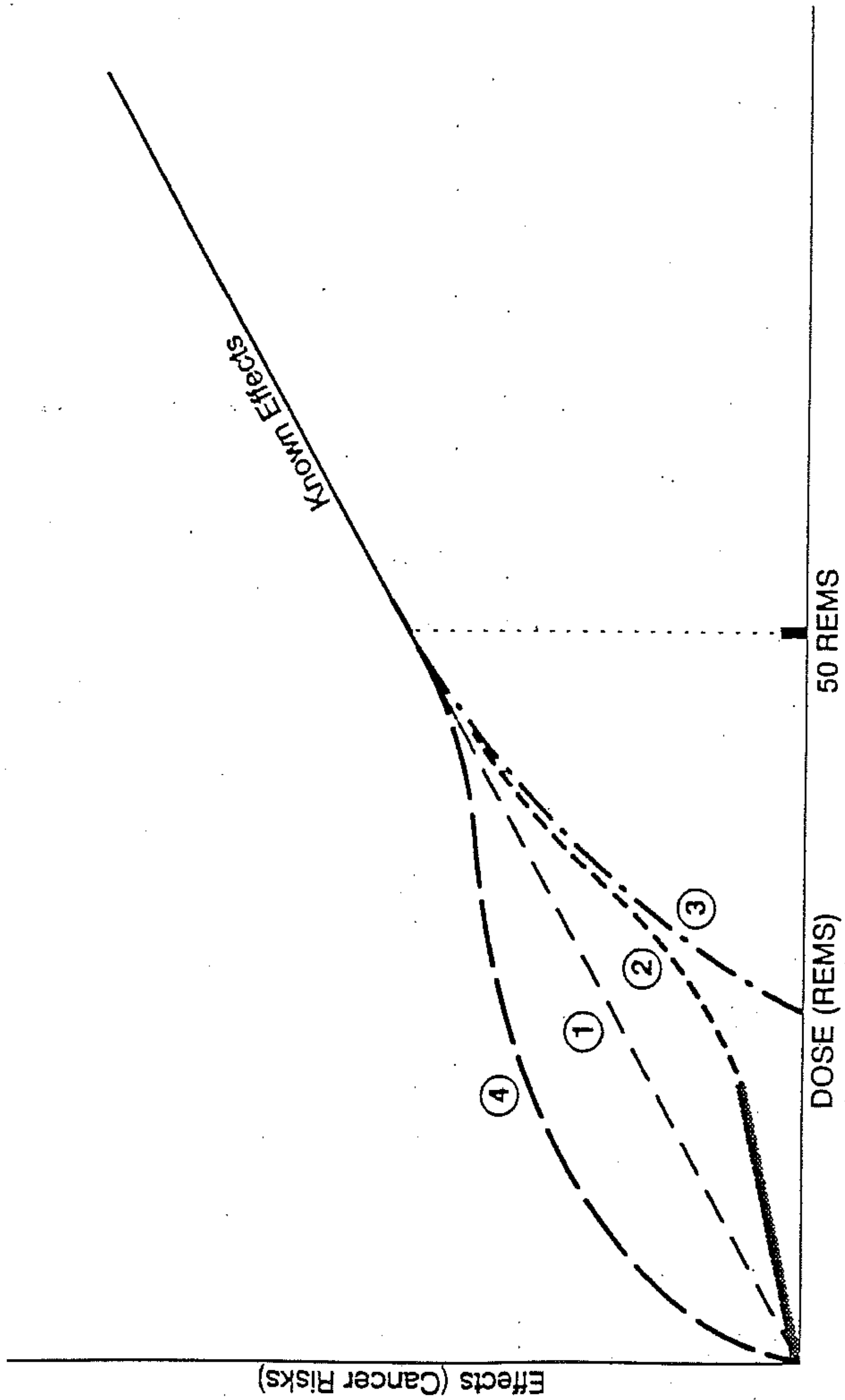

Figure 1. Some proposed models for how the effects of radiation vary with doses at low levels.

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 (0.05 Sv) in a year incurs 10 times as much risk as another worker who receives only 0.5 rem (0.005 Sv). Only a very few workers receive doses near 5 rems (0.05 Sv) per year (Ref. 6).

According to the BEIR V report (Ref. 3), approximately one in five adults normally will die from cancer from all possible causes such as smoking, food, alcohol, drugs, air pollutants, natural background radiation, and inherited traits. Thus, in any group of 10,000 workers, we can estimate that about 2,000 will die from cancer in the absence of any occupational radiation exposure. As stated earlier, there is a risk of 4 in 10,000 of a l-rem (0.0l-Sv) dose causing a fatal cancer. Another way of stating this risk of a fatal cancer is 1 in 2,500 per rem (0.01 Sv) received, or 0.0004 per rem (0.01 Sv).

To explain the significance of these estimates, we will use a group of 10,000 people, each exposed to 1 rem (0.01 Sv) of ionizing radiation. In this group of 10,000 workers, we could estimate that 4 would die from cancer because of that dose in addition to the 2,000 normal incidents, although the actual number could be more or less than 4. These deaths would be in addition to the natural death rate for cancer, which is 1 in 5 people. This means that a l-rem (0.01 Sv) dose to each of 10,000 workers might increase each individual worker's chances of dying from cancer from 20 percent to 20.04 percent. If one's lifetime occupational dose is 10 rems, we could raise the estimate to 20.4 percent. A lifetime dose of 100 rems may have increased your chances of dying from cancer from 20 to 24 percent. The average measurable dose for radiation workers reported to the NRC was 0.3 rem (0.003 Sv) for 1992 (Ref. 6). Today, very few workers ever accumulate 100 rems (1 Sv) and the average career dose of workers at NRC-licensed facilities is 1.5 rem (0.015 Sv), which represents an increased risk of dying from cancer from 20 to about 20.06 percent.
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 chance is 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 we can predict which persons will get the right card. The issue is further complicated by the fact that in a 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.

The normal chance of dying from cancer is about one in five for persons who receive no occupational radiation dose. The additional chance of developing fatal cancer from an occupational exposure of 1 rem (0.01 Sv) is about the same as the chances of drawing an ace from a full deck of cards three times in a row. The additional chance of dying from cancer from an occupational exposure of 10 rem (0.1 Sv) is about equal to your chance of drawing two aces successively on the first two draws from a full deck of cards.

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 projected small increases in cancer cases that might be caused by low exposures to radiation as compared to the normal rate of cancer. There is still uncertainty with regard to estimates of radiation risk from low levels of exposure. The numbers used here result from studies involving high doses and high dose rates.

These estimates are considered by the NRC staff to be the best available for the worker to 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 try to keep exposure to radiation as low as is reasonably achievable (ALARA) to avoid unnecessary risk.

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

Perhaps the most useful way to make these comparisons is to compare 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 average 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 average loss of life expectancy resulting from exposure to radiation with other health risks. The word average is important because an individual who gets cancer loses about 15 years of life expectancy, while his or her coworkers suffer no loss.

Some representative numbers are presented in Table 1. For the NRC-regulated industries, the average measurable occupational dose in 1992 was 0.3 rem (0.003 Sv) (Ref. 6). A simple calculation based on the article by Cohen and Lee (Ref. 7) shows that 0.3 rem (0.003 Sv) per year from age 18 to 65 results in a projected estimate of life expectancy loss of 15 days. 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.

Another useful comparison is to look at estimates of the average number of days of life expectancy lost from occupational exposure to radiation and to compare this number with days lost for several types of industries. Table 2 shows average days of life expectancy lost as a result of fatal work-related accidents. Table 2 does not include nonaccident types of occupational risks such as occupational disease and stress.

12. What are the NRC occupational dose limits?

For adults, an annual limit that does not exceed:

- 5 rems (0.05 Sv) for the Total Effective Dose Equivalent (TEDE), which is the sum of doses from external exposure to the whole body and from the equivalent internal doses from intakes of radioactive material. Doses to an organ or tissue must be multiplied by risk-weighting factors to compare the dose to a whole body exposure before they are added to the external dose.

- 50 rems (0.5 Sv) for the Total Organ Dose Equivalent (TODE), which is the sum of doses from external exposure to the whole body and the dose from intakes of radioactive material to any individual organ or tissue, other than the lens of the eye.

- 15 rems (0.15 Sv) for the Lens Dose Equivalent (LDE), which is the external dose to the lens of the eye.

- 50 rems (0.5 Sv) for the Shallow Dose Equivalent (SDE), which is the external dose to the sensitive portion of the skin or to any extremity.

For minors, the annual occupational dose limits are 10 percent of the dose limits for adult workers.

For the embryo/fetus of a declared pregnant woman, the dose limit is 0.5 rem (5 mSv) during the entire pregnancy.

The occupational dose limit for adult workers of 5 rem (0.05 Sv) TEDE is based on consideration of potential delayed biological effects. The 5-rem (0.05 Sv) limit, together with application of the concept of keeping occupational doses ALARA, provides a level of risk of delayed effects considered acceptable by the NRC. The limits for individual organs are below the levels of observed early biological effects in the respective organs.

The dose limit for the embryo/fetus of a declared pregnant woman is based on consideration of the special sensitivity to radiation of the embryo/fetus. This limit is in effect only when a woman declares her pregnancy in writing to the licensee.

TABLE 1
Estimated Loss of Life Expectancy from Health Risks[a]

Health Risk	Estimate of Life Expectancy Lost
Smoking 20 cigarettes a day	6 years
Overweight (by 15%)	2 years
Alcohol consumption (U.S. average)	1 year
All accidents combined	1 year
Motor vehicle accidents	207 days
Home accidents	74 days
Drowning	24 days
All natural hazards (earthquake, lightning, flood, etc.)	7 days
Medical radiation	6 days
Occupational Exposure	
0.3 rem/y[b] from age 18 to 65	15 days
1 rem/y from age 18 to 65	51 days

[a] Adapted from Reference 7.
[b] From NUREG-0713, Reference 6.

TABLE 2
Estimated Loss of Life Expectancy from Industrial Accidents[a]

Industry Type	Estimates of Days of Life Expectancy Lost, Average
All industries	60
Agriculture	320
Construction	227
Mining and Quarrying	167
Transportation and Public Utilities	160
Government	60
Manufacturing	40
Trade	27
Services	27

[a] Adapted from Ref. 7.

13. What is meant by ALARA?

ALARA means "as low as is reasonably achievable." In addition to providing an upper limit on an individual's permissible radiation exposure, the NRC requires that its licensees establish radiation protection programs for maintaining occupational exposures, and exposures to the public, as far below the limit as is reasonably achievable. Reasonably achievable also means practical. What is practical depends on the purpose of the job, the state of technology, the costs for reducing the exposures, and the benefits. Although ALARA is a required integral part of each licensee's radiation protection program, it does not establish an occupational dose limit.

In practice, ALARA includes planning tasks involving radiation exposure so as to reduce exposure to individual workers, the work group, and those who, although not part of the work group, may be exposed as a result of the work group's actions. Work practices should be reviewed with the objective of preventing unnecessary exposures.

There are several ways to control radiation doses, e.g., limiting the time in radiation areas, maintaining distance from sources of radiation, and providing shielding of radiation sources to reduce dose rates. The use of engineered controls is also a requirement of the ALARA concept -- from the design of facilities and equipment to the actual set-up and conduct of work activities.

The ALARA concept should also be used in determining the appropriate use of respiratory protection. To the extent practical, engineering controls such as containments and ventilation systems should be used to reduce workplace airborne radioactive materials. In evaluating whether or not to use respirators, the ALARA goal is to achieve the lowest sum of external and internal doses. For example, the use of respirators can lead to increased work time within radiation areas, which increases external dose. The advantage of using respirators to reduce internal exposure must be evaluated against the increased external exposure caused by longer working times. The goal is to maintain total exposure ALARA.

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

The average person is constantly exposed to ionizing radiation from several sources. Our environment and even the human body contain naturally occurring radioactive materials (e.g., potassium-40 and thorium) that contribute to the radiation we receive. The largest source of human radiation exposure is terrestrial radon, a colorless, odorless, chemically inert gas, which causes about 55 percent of our average, nonoccupational exposure. 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 to our population exposure. As shown below in Table 3, the average person receives an annual radiation dose of about 0.36 rem (3.6 mSv). By age 20, the average person will accumulate over 7 rems (70 mSv) of dose. By age 50, the total dose is up to 18 rems (180 mSv). After 70 years of exposure this dose is up to 25 rems (250 mSv).

15. What are the typical radiation doses received by workers?

For 1992, the NRC received reports on about a quarter of a million people who were monitored for occupational exposure to radiation. Almost half of those monitored had no measurable doses. The other half had an average dose of about 300 mrem (3 mSv) for the year. Of the total group of about a quarter of a million people, 97 percent received an annual dose of less than 1 rem (10 mSv); 99.7 percent received less than 2 rems (20 mSv); and the highest reported dose was for an individual who received between 5 and 6 rems (50 and 60 mSv).

Table 4 lists average occupational doses for workers (persons who had measurable doses) in various occupations based on 1992 data.

TABLE 3
AVERAGE ANNUAL EFFECTIVE DOSE EQUIVALENT TO INDIVIDUALS IN THE U.S.[a]

Source	Dose Equivalent (mrems)	
Natural		
Radon	200	
Other than Radon	100	
Total		300
Nuclear Fuel Cycle		0.05
Consumer Products[b]		9
Medical		
Diagnostic X-rays	39	
Nuclear Medicine	14	
Total		53
Total		~360 mrem/year

[a] Adapted from Table 8.1, NCRP 93 (Ref. 8).
[b] Includes tobacco, building material, television receivers, luminous watches, smoke detectors, etc. (from Table 5.1, NCRP 93, Ref. 8).

TABLE 4
Reported Occupational Doses for 1992[a]

Occupational Subgroup	Average Measurable Dose per Worker (millirems)
Industrial Radiography	490
Manufacturing and Distribution	260
Low-Level Waste Disposal	450
Independent Spent Fuel Storage	130
Fuel Fabrication	110
Commercial Power Reactors	310

[a] From Table 3.1 in NUREG-0713 (Ref. 6).

16. How do I know how much my dose (exposure) is?

The NRC requires your employer, the NRC licensee, to determine your exposure, to maintain records of your exposure, and, at least on an annual basis, to inform you of your exposure.

External exposures are monitored by using individual monitoring devices. These devices are required to be used if it appears likely that your external exposure will exceed 10 percent of your allowed annual dose. The most commonly used monitoring devices are film badges, thermoluminescent dosimeters (TLDs), electronic dosimeters, and direct reading pocket dosimeters.

With respect to internal exposure, your employer is required to monitor your occupational intake of radioactive material and assess the dose if it appears likely that you will receive greater than 10 percent of the annual limit on intake (ALI) if you are an adult, or a dose in excess of 0.05 rem (0.5 mSv) from intakes in one year if you are a minor or a declared pregnant worker. Internal exposure can be estimated by measuring the radiation emitted from the body (for example, with a "whole body counter") 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.

17. What happens if a worker exceeds the annual dose limit?

The regulations do not permit any additional occupational exposure to a person who is exposed in excess of the limit during the remainder of the year in which the limit is exceeded. The licensee is also required to file an overexposure report with the NRC and provide a copy to the individual. The licensee will be subject to NRC enforcement action (possibly a fine), just as you are subject to a traffic fine for exceeding the speed limit. The fines and, in some serious or repetitive cases, suspension of license are intended to encourage efforts to operate within the limits.

Radiation protection limits such as 5 rems (0.05 Sv) a year are not absolute limits that determine safe or unsafe levels of radiation exposures. Exceeding this limit does not mean that you will necessarily be harmed. It is assumed that risks are related to the size of the radiation dose. Therefore, when your dose is higher your risk is also higher. These limits are similar to highway speed limits. If you drive at 70 mph, your risk is higher than at the 55 mph limit, even though you may not actually have an accident. Those who set speed limits have determined that the risks of driving in excess of the speed limit are not acceptable. In the same way, the revised 10 CFR Part 20 establishes a limit for normal occupational exposures of 5 rems (0.05 Sv) a year. Although you will not necessarily get cancer or some other radiation effect at doses above the limit, it does mean that the licensee's safety program has failed in some way. Investigation is warranted to determine the cause and correct the conditions leading to the exposure in excess of the limit.

Risks from higher doses that might be incurred in exceptional situations or emergencies are explained in Questions 19 and 22.

18. Is the use of extra workers a good way to reduce dose?

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 individuals. The less the dose, the less 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.

The use of extra workers may actually increase the total occupational dose and the resulting collective risks. The use of extra workers may not be 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 best 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.

19. What is meant by a planned special exposure?

A "planned special exposure" means an infrequent exposure to radiation, separate from, and in addition to, the doses received under the annual limits. The licensee can authorize additional dose that is equal to the annual occupational dose limits as long as the individual's total dose does not exceed five times the annual dose limits during the individual's lifetime. For example, licensees may authorize "planned special exposures" for an adult radiation worker to receive doses up to an additional 5 rems (0.05 Sv) in a year above the 5-rem (0.05 Sv) annual TEDE occupational dose limit. Each worker is limited to no more than 25 rems (0.25 Sv) from planned special exposures in his or her lifetime. Such exposures are only allowed in exceptional situations when alternatives for avoiding the additional exposure are not available or are impractical. Before the licensee grants approval, the licensee must ensure that the worker is informed of the purpose and circumstances for the planned operation, the estimated doses expected, and the procedures to keep the doses ALARA while considering other risks that may be present. (See Regulatory Guide 8.35, "Planned Special Exposures," for further information.)

20. 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 analyses can be made as each additional increment of dose is approved for a worker. Secondly, an administrative limit that is set lower than the NRC limit provides a safety margin designed to help the licensee avoid exposures in excess of the limit.

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

NRC rules exempt medical exposure, but equal doses of medical and occupational radiation have equal risks.[3] Medical exposure to radiation is justified for reasons that are quite different, however, from those applicable to occupational exposure. A physician prescribing an x-ray should be convinced that the benefit to the patient from the resulting medical information justifies the risk associated with the radiation. Each worker must decide, however, on the benefits and acceptability 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 (0.02 Sv) 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 4 rems (0.04 Sv) on the job, the combined dose of 6 rems (0.06 Sv) would not incapacitate the worker. A dose of 6 rems (0.06 Sv) is not especially dangerous and is not large compared to the allowed cumulative occupational dose. Restricting the worker from additional job exposure during the remainder of the year would have no effect one way or the other on the risk from the 2 rems (0.02 Sv) 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 accepts the risks associated with job-related exposure on the basis of employment benefits, it would be unfair to restrict the worker from employment in radiation areas for the remainder of the year.

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[3] It is likely that a significant portion of reported medical x-ray exposures are to parts of the body only. An exposure of 100 mrem (1mSv) to the whole body is more significant than a 100-mrem x-ray to the hand.

22. How should radiation risks be considered in an emergency?

Although the use of planned special exposures allows an additional 5 rems (0.05 Sv) a year for special occasions, that allowance does not apply to emergencies. Emergencies are "unplanned" events in which actions to save lives or property may warrant additional doses for which no particular limit applies. Even though the revised 10 CFR Part 20 does not set any dose limits for lifesaving activities, workers should remember that radiation risks increase with increasing dose and that the ALARA principle applies for emergencies as well as routine activities. In addition, any doses received during emergencies have to be reported to the NRC and included on the worker's lifetime dose record. The NRC has not sanctioned any "forgivable" emergency dose that would not be counted in an individual worker's lifetime dose.

The Environmental Protection Agency (EPA) has published emergency dose guidelines (Ref. 2). These guidelines state that doses to all workers during emergencies should, to the extent practicable, be limited to 5 rems (0.05 Sv). There are some emergency situations, however, for which higher emergency limits may be justified. Justification of any such exposure must include the presence of conditions that prevent the rotation of workers or other commonly used dose reduction methods. Except as noted below, the dose resulting from such emergency exposures should be limited to 10 rems (0.1 Sv) for protecting valuable property, and to 25 rems (0.25 Sv) for lifesaving activities and the protection of large populations. In the context of this guidance, exposure of workers that is incurred for the protection of large populations may be considered justified for situations in which the collective dose avoided by the emergency operation is significantly larger than that incurred by the workers involved.

Situations may rarely occur in which a dose in excess of 25 rems (0.25 Sv) for emergency exposure would be unavoidable in order to carry out a lifesaving operation or to avoid extensive exposure of large populations. However, persons undertaking any emergency operation in which the dose will exceed 25 rems (0.25 Sv) to the whole body should do so only on a voluntary basis and with full awareness of the risks involved, including the numerical levels of dose at which prompt effects of radiation will be incurred and numerical estimates of the risks of delayed effects.

Table 5 presents the approximate risk of premature death for a group of 1,000 workers of various ages who have all received an acute dose of 25 rems (0.25 Sv). If needed, the referenced EPA source document should be used for training regarding risks of high doses.

Even under emergency conditions, licensees and radiation workers should make every effort to evaluate the potential exposures before authorizing additional necessary doses. To the extent possible in an emergency, workers should be informed of the situation and procedures to follow to keep exposures ALARA.

TABLE 5
Risk of Premature Death from Exposure to 25-Rem (0.25-Sv) Dose

Age at Exposure (years)	Estimated Risk of Premature Death (Deaths per 1,000 Persons exposed)
20-30	9.1
30-40	7.2
40-50	5.3
50-60	3.5

Source: EPA-400-R-92-001 (Ref. 2)

23. Who developed the radiation risk estimates used in this guide?

Radiation risk estimates were developed by several national and international scientific organizations over the last 40 years. These organizations include the National Academy of Sciences (which has issued five reports from the Committee on the Biological Effects of Ionizing Radiations, BEIR), the National Council on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), and the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR). Each of these organizations continues to review new research findings on radiation health risks.

Several recent reports from these organizations present new findings on radiation risks based upon revised estimates of radiation dose to survivors of the atomic bombs at Hiroshima and Nagasaki. For example, UNSCEAR published revised risk estimates in 1988 (Ref. 9). The NCRP also published a report in 1988, "New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates" (Ref. 10). In January 1990, the National Academy of Sciences released the fifth report of the BEIR Committee, "Health Effects of Exposure to Low Levels of Ionizing Radiation" (Ref. 3). Each of these publications also provides extensive bibliographies on other published studies concerning radiation health effects for those who may wish to read further on this subject.

24. How were radiation dose limits established?

The NRC radiation dose limits in 10 CFR Part 20 were established by the rulemaking procedures required for Federal agencies. Under the rulemaking procedures, the NRC staff developed a proposed rule that was then reviewed and approved by the 5-member Commission that directs the NRC. Following the Commission's approval, the proposed rule was published in the *Federal Register* public comment. The *Federal Register* may be considered to be the government's newspaper. Publication in the *Federal Register* provided legal notice to all persons that the NRC was considering setting new radiation dose limits.

In developing the proposed dose limits, the staff considered the 1987 Presidential Guidance on occupational exposure. That guidance was developed under the lead of the EPA. The guidance was signed by the President and was intended for use by all Federal agencies. The staff also considered the recommendations of the International Commission of Radiological Protection (ICRP) and its U.S. counterpart, the National Council on Radiation Protection and Measurements (NCRP).

In addition to publication of the proposed Part 20 in the *Federal Register* in January 1986, the NRC sent copies to all NRC licensees and to many other interested parties. More than 800 sets of comments were received and considered by the staff in developing the final rule.

Note that the proposed rule presented a tentative NRC position on radiation dose limits. The final rule was developed only after consideration of comments from licensees, labor unions, public interest groups, other Federal agencies, scientific organizations, and other interested parties.

25. Several scientific reports have recommended that the NRC should use lower limits Does the NRC plan to reduce the regulatory limits?

Since publication of the proposed rule in 1986, the ICRP in 1990 revised its recommendations for radiation protection based on newer studies of radiation risks (Ref. 11), and the NCRP followed with a revision to its recommendations in 1993. The ICRP recommended a limit of 10 rems (0.1 Sv) effective dose equivalent (from internal and external sources), over a 5-year period with no more than 5 rems (0.05 Sv) in 1 year (Ref. 11). The NCRP recommended a cumulative limit, not to exceed 1 rem (0.01 Sv), times the individual's age with no more than 5 rems (0.05 Sv) in any year (Ref. 8).

The NRC does not believe that additional reductions in the dose limits are urgently required. Because of the practice of maintaining radiation exposures ALARA ("as low as is reasonably achievable"), the average radiation dose to occupationally exposed persons is well below the limits in the current Part 20 that became mandatory January 1, 1994, and the average risks to radiation workers are below those limits recommended by the ICRP and the NCRP.

For example, in 1992, only a few workers (0.3 percent) in nuclear facilities reporting to the NRC received annual doses that exceeded 2 rems (0.02 Sv) (Ref. 6), and few are likely to exceed the 5-year limit recommended by the ICRP. The facilities included here were from six of the reporting industries that have the highest potential for occupational radiation exposures: nuclear power plants, industrial radiography, reactor fuel fabrication, low-level waste disposal, spent fuel storage, and radioisotope manufacturing. For another example, in 1992 about 97 percent of the same workers received annual doses of less than 1 rem (0.01 Sv), which provides reasonable assurance that cumulative dose limits based on age as proposed by the NCRP are being met.

The current dose limits contained in 10 CFR Part 20 are also consistent with the Federal guidance on occupational radiation exposure (described in Question 24), and any changes would be the subject of a future rulemaking.

26. What are my options if I decide the risks associated with my occupational radiation exposure are too high?

If the risks from exposure to radiation 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 the exposure to radiation that workers, on the average, actually receive are considered acceptable when compared to other occupational risks by virtually all the scientific groups that have studied them. From an NRC regulatory basis, your employer is not obligated to guarantee you a transfer if you decide not to accept an assignment that requires 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 may find different kinds of risk but you will not necessarily find significantly lower risks in another job.

You and your employer should 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.

27. Where can I get additional information on radiation risk?

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

- Your employer - the radiation protection of health physics office where you are employed.

- Nuclear Regulatory Commission Regional Offices:

King of Prussia, Pennsylvania	(215) 337-5000
Atlanta, Georgia	(404) 331-4503
Lisle, Illinois	(708) 829-9500
Arlington, Texas	(817) 860-8100

- U.S. Nuclear Regulatory Commission Headquarters
  Radiation Protection & Health Effects Branch
  Office of Nuclear Regulatory Research
  Washington, DC 20555
  Telephone: (301) 415-6187

- Department of Health and Human Services
  Center for Devices and Radiological Health
  1390 Piccard Drive, MS HFZ-1
  Rockville MD 20850
  Telephone: (301) 443-4690

- U.S. Environmental Protection Agency
  Office of Radiation and Indoor Air
  Criteria and Standards Division
  401 M Street NW.
  Washington, DC 20460
  Telephone: (202) 233-9290

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11. International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Oxford, UK, 1991.

APPENDIX D EXCERPT FROM US NRC REGULATORY GUIDE 8.13 — INSTRUCTION CONCERNING PRENATAL RADIATION EXPOSURE

INSTRUCTIONS CONCERNING PREGNANT WOMEN

Regulations require that licensees instruct individuals working with licensed radioactive materials in radiation protection as appropriate for the situation. This Appendix describes information that you should know about the radiation exposure of pregnant women. In particular, radiation protection regulations allow a pregnant woman to decide whether she wants to formally declare her pregnancy to her employer, thereby taking advantage of the special dose limits provided to protect the developing embryo/fetus. This Appendix provides information on the potential effects of declaring a pregnancy in order to help women make informed decisions on whether or not to declare pregnancy. The information is provided in the form of answers to a woman's questions.

MAKING THE DECISION TO DECLARE PREGNANCY

1. If I become pregnant, am I required to inform my employer of my pregnancy?

No. It is your choice whether to declare your pregnancy to your employer. If you choose to declare your pregnancy, a lower radiation dose limit will apply to you. If you choose not to declare your pregnancy, you will continue to be subject to the same radiation dose limits that apply to nonpregnant workers even if you are visibly pregnant.

2. If I inform my employer in writing of my pregnancy, what happens?

The amount of radiation that you will be allowed to receive will decrease because there is a lower dose limit for the embryo/fetus of female workers who have formally declared their pregnancy in writing. Ordinarily, the radiation dose limit for a worker is 5 rems (50 millisieverts) in a year. But if you declare in writing that you are pregnant, the dose to the embryo/fetus is generally limited to 0.5 rem (5 millisieverts) during the 9-month pregnancy, which is one-tenth of the dose limit that an adult worker may receive in a year. In addition, licensees must make efforts to avoid substantial variation above a uniform monthly dose rate so that all the dose received does not occur during a particular time of the pregnancy. This may mean that, if you declare your pregnancy, you may not be permitted to perform some of your normal job functions and you may not be able to have emergency response responsibilities.

3. Why do the regulations have a lower dose limit for a woman who has declared her pregnancy than for a normal worker?

The purpose of the lower limit is to protect her unborn child. Scientific advisory groups recommend (References 1 and 2) that the dose before birth be limited to about 0.5 rem rather than the 5-rem (50-millisievert) occupational annual dose limit because of the sensitivity of the embryo/fetus to radiation. Possible effects include deficiencies in the child's development, especially the child's neurological development, and an increase in the likelihood of cancer.

4. What effects on development can be caused by radiation exposure?

The effects of large doses of radiation on human development are quite evident and easily measurable, whereas at low doses the effects are not evident or measurable and therefore must be inferred.

For example, studies of the effects of radiation on animals and humans demonstrate clearly and conclusively that large doses of radiation -- such as 100 rems (1 sievert) -- cause serious developmental defects in many of the body's organs when the radiation is delivered during the period of rapid organ development (References 2, 3, 4, and 5).

The developing human brain has been shown to be especially sensitive to radiation. Mental retardation has been observed in the survivors of the atomic bombings in Japan exposed *in utero* during sensitive periods. Additionally, some other groups exposed to radiation *in utero* have shown lower than average intelligence scores and poor performance in school (Reference 4).

The sensitivity of the brain undoubtedly reflects its structural complexity and its long developmental period (and hence long sensitive period). The most sensitive period is during about the 8th to 15th weeks of gestation followed by a substantially less sensitive period for the 2 months after the 15th week (Reference 4). There is no known effect on the child's developing brain during the first two months of pregnancy or the last three months of pregnancy (Reference 4).

No developmental effects caused by radiation have been observed in human groups at doses at or below the 5-rem (50-millisievert) occupational dose limit. Scientists are uncertain whether there are developmental effects at doses below 5 rems (50 millisieverts). It may be that the effects are present but are too mild to measure because of the normal variability from one person to the next and because the tools to measure the effects are not sensitive enough. Or, it may be that there is some threshold dose below which there are no developmental effects whatsoever.

In view of the possibility of developmental effects, even if very mild, at doses below 5 rems (50 millisieverts), scientific advisory groups consider it prudent to limit the dose to the embryo/fetus to 0.5 rem (5 millisieverts) (References 1 and 2). At doses greater than 5 rems (50 millisieverts), such as might be received during an accident or during emergency response activities, the possibility of developmental effects increases.

5. How much will the likelihood of cancer be increased?

Radiation exposure has been found to increase the likelihood of cancer in many studies of adult human and animal groups. At doses below the occupational dose limit, an increase in cancer incidence has not been proven, but is presumed to exist even if it is too small to be measured. The question here is whether the embryo/fetus is more sensitive to radiation than an adult.

While the evidence for increased sensitivity of the embryo/fetus to cancer induction from radiation exposure is inconclusive, it is prudent to assume that there is some increased sensitivity. Scientific advisory groups assume that radiation exposure before birth may be 2 or 3 times more likely to cause cancer over a person's lifetime than the same amount of radiation received as an adult (Reference 1). If this is true, there would be 1 radiation-induced cancer death in 200 people exposed *in utero* at the occupational dose limit of 5 rems (50 millisieverts) (Reference 1). Scientific advisory groups have considered this risk to be too high and have thus recommended that the radiation dose to the embryo/fetus be limited to a maximum of 0.5 rem (5 millisieverts). At that dose, there would be 1 radiation-induced cancer death per 2000 people. This would be in addition to the 400 cancer deaths from all causes that one would normally expect in a group of 2000 people.

6. How does the risk to the embryo/fetus from occupational radiation exposure compare to other avoidable risks?

The risk to the embryo/fetus from 0.5 rem or even 5 rems of radiation exposure is relatively small compared to some other avoidable risks.

Of particular concern is excessive consumption of alcohol during pregnancy. The U.S. Public Health Service has concluded that heavy alcohol consumption during pregnancy (three drinks per day and above) is the leading known cause of mental retardation (Reference 6). Children whose mothers drank heavily during pregnancy may exhibit developmental problems such as hyperactivity, distractibility, short attention spans, language difficulties, and delayed maturation, even when their intelligence is normal.

In studies tracking the development of children born to light or moderate drinkers, researchers have also correlated their mothers' drinking patterns during pregnancy with low birth weight, decreased attention spans, delayed reaction times, and lower IQ scores at age 4 years. Youngsters whose mothers averaged three drinks per day during pregnancy were likely to have IQs averaging 5 points lower than normal.

Cigarette smoking may also harm the unborn (Reference 6). There is a direct correlation between the amount of smoking during pregnancy and the frequency of spontaneous abortion and fetal death. Children of mothers who smoke while pregnant are more likely to have impaired intellectual and physical growth. Maternal smoking has also been associated with such behavioral problems in offspring as lack of self-control, irritability, hyperactivity, and disinterest. Long-term studies indicate that these children perform less well than matched youngsters of nonsmokers on tests of cognitive, psychomotor, language, and general academic functioning.

Alcohol and smoking are only examples of other risks in pregnancy. Many other toxic agents and drugs also present risk. In addition, many factors that cannot be controlled present risk. There is an increased risk in pregnancy with increasing maternal age. Maternal disease may be an important risk factor. Malnutrition, toxemia, and congenital rubella may be associated with birth defects. Maternal diabetes and high blood pressure have been associated with problems in the newborn. In addition, many birth defects and developmental problems occur without an obvious cause and without any obvious risk factors. For example, viruses that we may not even be aware of can cause defects, and defects can arise from spontaneous random errors in cell reproduction. But these are things that we can't do anything about.

In summary, you are advised to keep radiation exposure of your unborn child below 0.5 rem, but you should also remember that alcohol consumption, cigarette smoking, and the use of other drugs can do a great deal of harm.

7. What if I decide that I do not want any radiation exposure at all during my pregnancy?

You may ask your employer for a job that does not involve any exposure to occupational radiation at all, but your employer may not have such a position or may not be willing to provide you with a job involving no radiation exposure. Even if you receive no occupational exposure at all, you will receive a dose typically about 0.3 rem (3 millisieverts) from unavoidable natural background radiation (Reference 7).

8. What effect will formally declaring my pregnancy have on my job status?

Only your employer can tell you what effect a declaration of pregnancy will have on your job status. As part of your radiation safety training, your employer should tell you its policies with respect to the job status of declared pregnant women. In addition, we recommend that, before you declare your pregnancy, you talk to your employer and ask what a declaration of pregnancy would mean specifically for you and your job status. However, if you do not declare your pregnancy, the lower exposure limit of 0.5 rem (5 millisieverts) does not apply.

It is most likely that your employer will tell you that you can continue to perform your job with no changes and still meet the NRC's limit for exposure to declared pregnant women. A large majority of licensee employees (greater than 90%) receive, in 9 months, occupational radiation doses that are below the 0.5-rem (5-millisievert) limit for a declared pregnant woman.

If the dose you currently receive is above the 0.5-rem (5-millisievert) dose allowed for a declared pregnant woman, it is quite likely that your employer can and will make a reasonable accommodation that will allow you to continue performing your current job, for example, by having another qualified employee perform a small part of the job that accounts for much of the radiation exposure.

On the other hand, it is possible, although not common, that your employer will conclude that there is no reasonable accommodation that can be made without undue hardship that would allow you to do your job and remain within the dose limits for a declared pregnant woman. In these few instances, your employer may conclude that you can no longer be permitted to do your current job, that you must be removed from your job, and that there is no other job available for someone with your training and job skills.

If your employer concludes that you must be removed from your current job in order to comply with the lower dose limits for declared pregnant women, you may be concerned about what will happen to you and your job. The answer to that depends on your particular situation. That is why you should talk to your employer about your particular situation. In addition, telephone numbers that may be useful for obtaining information are listed in response to question 20 in this guide.

HOW TO DECLARE YOUR PREGNANCY

9. What information must I provide in my declaration of pregnancy?

You must provide your name, a declaration that you are pregnant, the estimated date of conception (only the month and year need be given), and the date that you give the letter to your employer. A sample form letter that you can use is included at the end of these questions and answers. You may use that letter or write your own letter.

10. To declare my pregnancy, do I have to have documented medical proof that I am pregnant?

No. No proof is necessary.

11. Can I tell my employer orally rather than in writing that I am pregnant?

No, the declaration must be in writing. As far as the regulations are concerned, an oral declaration or statement is the same as not telling your employer that you are pregnant.

12. If I have not declared my pregnancy in writing, but my employer notices that I am pregnant, do the lower dose limits apply?

No. The lower dose limits for pregnant women apply only if you have declared your pregnancy in writing. The choice of whether to declare your pregnancy and thereby work under the lower dose limits is your choice, not your employer's. Your employer may not remove you from a specific job because you appear pregnant.

13. If I am planning to become pregnant but am not yet pregnant, and I inform my employer of that in writing, do the lower dose limits apply?

No. The lower limits apply only if you declare that you are already pregnant.

14. What if I have a miscarriage or find out I am not pregnant?

If you have declared your pregnancy in writing, you should promptly inform your employer that you are no longer pregnant. The regulations do not require that the revocation of a declaration be in writing, but we recommend that you revoke the declaration in writing to avoid confusion. Also, your employer may insist upon a written revocation for its own protection. If you have not declared your pregnancy, there is no need to inform your employer of your new, nonpregnant status.

If you have a miscarriage and become pregnant again before you have revoked your original declaration of pregnancy, you should submit a new declaration of pregnancy because the date of conception has changed.

15. How long is the lower dose limit in effect?

The dose to the embryo/fetus must be limited until (1) your employer knows you have given birth, (2) you inform your employer that you are no longer pregnant, or (3) you inform your employer that you no longer wish to be considered pregnant.

16. If I have declared my pregnancy in writing, can I revoke my declaration of pregnancy even if I am still pregnant?

Yes, you may. The choice is entirely yours. If you revoke your declaration of pregnancy, the lower dose limits no longer apply.

17. What if I work under contract at the licensed facility and my employer is not the licensee?

The regulations state that you should formally declare your pregnancy to your employer in writing. You can ask your employer to give a copy of your declaration to the licensee, or you may give a copy of your written declaration directly to the licensee.

18. Can I tell my employer I am pregnant when I know I am not in order to work under the lower dose limits?

The purpose of the NRC regulations is to allow a pregnant woman to choose a heightened level of protection from radiation exposure for the embryo/fetus during her pregnancy. That purpose would not be served by intentionally declaring yourself to be a pregnant woman when you know you are not pregnant. There are no NRC regulatory requirements specifically addressing the actions your employer might take if you provide a false declaration. However, nothing in NRC regulations would prevent your employer from taking action against you for deliberately lying.

STEPS TO LOWER RADIATION DOSE

19. What steps can I take to lower my radiation dose?

Your employer should already have explained that to you as part of the instructions that licensees must give to all workers. However, you should ask your supervisor or the radiation safety officer whether any additional steps can be taken.

The general principles for maintaining exposure to radiation as low as reasonably achievable are summarized below. You should already be applying these principles to your job, but now is a good time to review them.

External Radiation Exposure: External radiation is radiation you receive from radiation sources or radioactive materials that are outside your body. The basic principles for reducing external radiation exposure are time, distance, and shielding -- decrease your time near radiation sources, increase your distance from radiation sources, and increase the shielding between yourself and the radiation source. You should work quickly and efficiently in a radiation area so that you are not exposed to the radiation any longer than necessary. As the distance is increased from the source of radiation, the dose decreases.

When possible, you should work behind shielding. The shielding will absorb some of the radiation, thus reducing the amount that reaches you.

Internal Radiation Exposure: Internal radiation is radiation you receive from radioactive materials that have gotten into your body, generally entering with the air you breathe, the food you eat, or the water you drink. Your employer will have specific procedures to minimize internal radiation exposure. Those procedures probably incorporate the following general precautions that should be taken when you are working with radioactive materials that are not encapsulated:

1. Wear lab coats or other protective clothing if there is a possibility of spills.
2. Use gloves while handling unencapsulated radioactive materials.
3. Wash hands after working with unencapsulated radioactive materials.
4. Do not eat, drink, smoke, or apply cosmetics in areas with unencapsulated radioactive material.
5. Do not pipette radioactive solutions by mouth.

These basic principles should be incorporated into the specific methods and procedures for doing your individual work. Your employer should have trained you in those specific rules and procedures.

If you become pregnant, it is a good time to review the training materials on the methods and procedures that you were provided in your training. You can also talk to your supervisor about getting refresher training on how to keep radiation doses as low as reasonably achievable.

ADDITIONAL INFORMATION

20. Where can I get additional information?

You can find additional information on the risks of radiation in NRC's Regulatory Guide 8.29, "Instruction Concerning Risks from Occupational Radiation Exposure."

You can also telephone the NRC Regional Offices at the following numbers: Region I - (610) 337-5000; Region II - (404) 331-4503; Region III - (708) 829-9500; and Region IV - (817) 860-8100. Legal questions should be directed to the Regional Counsel, and technical questions should be directed to the Division of Radiation Safety and Safeguards.

If you believe you have been discriminated against, you should contact the U.S. Equal Employment Opportunity Commission (EEOC), 1801 L Street NW., Washington, DC 20507, or an EEOC Field Office by calling (800) 669-4000 or (800) 669-EEOC. For individuals with hearing impairments, the EEOC's TDD number is (800) 800-3302.

REFERENCES

1. National Council on Radiological Protection and Measurements, *Limitation of Exposure to Ionizing Radiation*, Report No. 116, Bethesda, MD, 1993. [The National Council on Radiological Protection and Measurements (NCRP) is a nonprofit corporation chartered by Congress in 1964 to collect information and make recommendations on protection against radiation. This publication, on pages 37-39, summarizes the conclusions of the NCRP with respect to protection of the human embryo/fetus against radiation. This publication should be available through most good public library systems and most good university libraries. Your employer may also have a copy.]

2. *ICRP Publication 60 -- 1990 Recommendations of the International Commission on Radiological Protection*, *Ann. ICRP 21*:No. 1-3, Pergamon Press, 1991. [This publication, on pages 146-149, summarizes the conclusions of the ICRP on the effects of radiation on the human embryo/fetus.]

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FORM LETTER FOR DECLARING PREGNANCY

This form letter is provided for your convenience. To make your declaration of pregnancy, you may fill in the blanks in this form letter and give it to your employer or you may write your own letter.

DECLARATION OF PREGNANCY

To: ______________________________________
(Name of your supervisor or other employer representative)

I am declaring that I am pregnant. I believe I became pregnant in ________________, ______ (only the month and year need be provided).

I understand that my occupational radiation dose during my entire pregnancy will not be allowed to exceed 0.5 rem (5 millisieverts) (unless that dose has already been exceeded between the time of conception and submitting this letter). I also understand that meeting the lower dose limit may require a change in job or job responsibilities during my pregnancy.

If I find out that I am not pregnant, or if my pregnancy is terminated, I will promptly inform you in writing that my pregnancy has ended. (This promise to inform your employer in writing when your pregnancy has ended is optional. The sentence may be crossed out if you wish.)

____
(Your signature)

____
(Your name printed)

____
(Date)

APPENDIX E SI UNITS AND CONVERSION FACTORS

SI Units for Radioactive Materials

Prepared by

U.S. Council for Energy Awareness
Committee on Radionuclides and Radiopharmaceuticals

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202/293-0770

SI (Systeme International) units are now being used in many countries as the primary measurement system, including measurement of radioactivity, and the system is coming into use in the United States. Many journals (including those published by the American Medical Association) now require the use of SI units, and U.S. regulatory agencies are beginning to use SI units as well as conventional units in regulations. It is the policy of the United States Government that regulations should not impede the transition to SI units.

The U.S. Trade Act of 1988 includes a provision establishing federal policy to designate the metric system as the preferred measurement system for U.S. trade and commerce. It also requires all federal agencies to adopt the metric system for business-related activities by 1992, except where it proves impractical.

USCEA's Committee on Radionuclides and Radiopharmaceuticals is seeking to familiarize users of radioactive materials with SI units and to facilitate their use in the United States. The SI unit for radioactivity is the becquerel (Bq), and is defined as one nuclear transformation per second. It is a small unit when compared to the curie (Ci), and it is convenient to use multiples of the unit (see listing later in this brochure). It does have the convenience however of relating directly to count rate once corrections have been made for counting efficiency.

Most suppliers of radioactive materials including the National Institute of Standards Technology (NIST-formerly NBS) have been using dual units (curies and becquerels) in catalogs, product literature and labelling for some time and plan to do so for the foreseeable future. The European Economic Community (EEC) has stated that it will accept only SI units for radioactivity after 1999, and it is anticipated that all suppliers of radioactive products will be using only SI units at that time. In Canada, Atomic Energy Control Board documents produced since 1985 have been in SI units only, and conversion of regulations is in progress.

Other SI radiation measurement units are as follows:

Exposure and Exposure Rate

The roentgen (R) is the traditional unit of measurement for exposure, the charge produced in air by γ or x-rays. The SI unit of exposure is coulombs per kilogram (C/kg) of air.

1 C/kg = 3876 R
1 R = 2.58 x 10^{-4} C/kg

No special name has been given to this SI unit (C/kg) and since there is no convenient conversion to other SI units, it is seldom used. Instead, the observed dose rate in air, that is the air kerma rate, is typically being used as the SI measurement to replace exposure rate. An example of the use of air kerma rate is to define the radiation output from a sealed radioactive source in SI units. The SI units usually used to express air kerma rate are grays/second. In traditional units, exposure rate from a sealed source has typically been expressed in roentgens/hour at a distance of 1 meter from the source.

Charge as defined in exposure (charge produced in air by γ and X-radiation) does not include ionization produced by bremsstrahlung arising from absorption of electrons (β-particles). Apart from this difference, which is significant only with high energy β-particles, exposure is the ionization equivalent of air kerma. For a further discussion of air kerma see ICRU (International Commission on Radiation Units and Measurements) Report 33, 1980.

Absorbed Dose

This is the amount of energy imparted to matter, and the rad has been the unit of measurement. The SI unit for absorbed dose is the gray (Gy).

1 Gray (Gy) = 100 rad
1 rad = 0.01 Gy

One roentgen of X-radiation in the energy range of 0.1-3 MeV produces 0.96 rad in tissue.

Dose Equivalent

The dose equivalent is the absorbed dose multiplied by modifying factors such as a quality factor (accounts for the biological effect of different types of radiation) and the dose distribution factor. The rem is the unit of measurement that has been used, and the SI unit is the sievert (Sv).

1 Sv = 100 rem
1 rem = 0.01 Sv

We are giving advance notice of the change to SI Units to allow users time to become familiar with the new units. Do not hesitate to contact your supplier of radioactive materials or USCEA should you have any questions concerning SI units or the implementation of the change.

CONVERSION TABLE FOR RADIOACTIVITY

Curie Units	**Becquerel Units**
μCi mCi Ci	kBq MBq GBq
0.1	3.7
0.25	9.25
0.5	18.5
0.75	27.75
1	37
2	74
3	111
5	185
7	259
10	370
20	740
25	925

Curie Units	**Becquerel Units**
μCi mCi Ci	MBq GBq TBq
50	1.85
60	2.22
100	3.7
200	7.4
250	9.25
500	18.5
800	29.6
1000	37

To convert from one unit to another, read across from one column to the other ensuring the units are in the same line of the column headings. For example:

From the first table:	From the second table:
0.1 mCi = 3.7 MBq	*50 mCi = 1.85 GBq*
0.1 Ci = 3.7 GBq	*3.7 MBq = 100 μCi*

SI Units

1 becquerel (Bq) = 1 disintegration/second

1 becquerel = 2.7027 x 10^{-11} curie or ≈ 27 picocuries (pCi)

To convert becquerels to curies, divide the becquerel figure by 37 x 10^{9} (alternatively multiply the becquerel figure by 2.7027 x 10^{-11})

1 curie (Ci) = 3.7 x 10^{10} disintegrations/second or 37 gigabecquerels (GBq)

To convert curies to becquerels, multiply the curie figure by 37 x 10^{9}

Curie units that are frequently used:

1 Curie (Ci) = 1000 mCi
1 millicurie (mCi) = 1000 μCi
1 microcurie (μCi) = 1000 nCi
1 nanocurie (nCi) = 1000 pCi (picocuries)

Becquerel units that are frequently used:

1 kilobecquerel (kBq) = 1000 Becquerels (Bq)
1 megabecquerel (MBq) = 1000 kBq
1 gigabecquerel (GBq) = 1000 MBq
1 terabecquerel (TBq) = 1000 GBq

1 Ci = 37 GBq
1 mCi = 37 MBq
1 μCi = 37 kBq
1 nCi = 37 Bq

11/14/91

APPENDIX F GLOSSARY OF TERMS

ABSORBED DOSE: The energy imparted by ionizing radiation per unit mass of irradiated material.

ABSORPTION: The process by which radiation imparts some or all of its energy to any material through which it passes.

ACTIVITY: The rate of decay (disintegrations/time) of a given amount of radioactive material.

ALARA: An acronym for *A*s *L*ow *A*s *R*easonably *A*chievable. The principal that radiation doses should be kept as low as reasonably achievable taking into account economic and social factors.

ALPHA PARTICLE (α): A strongly ionizing particle emitted from the nucleus during radioactive decay which is equivalent to a helium nucleus (2 protons and 2 neutrons).

ANNIHILATION RADIATION: The two 511 keV photons produced when a positron combines with an electron resulting in the annihilation of the two particles.

ANNUAL LIMIT ON INTAKE (ALI): The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a CEDE of 5 rem or a CDE of 50 rem to any individual organ or tissue.

ATOMIC MASS UNIT (amu): One-twelfth the mass of a neutral atom of C-12. (1 amu $\approx 1.66 \times 10^{-24}$ g)

ATOMIC NUMBER (Z): The number of protons in the nucleus of an atom.

ATTENUATION: Process by which a beam of radiation is reduced in intensity when passing through material — a combination of absorption and scattering processes.

AUTORADIOGRAPH: Record of radiation from radioactive material in an object, made by placing the object in close proximity to a photographic emulsion.

BACKGROUND RADIATION: Ionizing radiation arising from sources other than the one directly under consideration. Background radiation due to cosmic rays and the natural radioactivity of materials in the earth and building materials is always present.

BECQUEREL (Bq): The SI unit of activity equal to one disintegration per second. (1 Bq $= 2.7 \times 10^{-11}$ Ci).

BETA PARTICLE (β): A charged particle emitted from the nucleus of an atom, having a mass equal to that of the electron, and a single positive or negative charge.

BIOLOGICAL HALF-LIFE: The time required for the body to eliminate by biological processes one-half of the amount of a substance which has entered it.

BREMSSTRAHLUNG: X-rays produced by the deceleration of charged particles passing through matter.

CARRIER FREE: An adjective applied to one or more radionulcides of an element in minute quantity, essentially undiluted with stable isotope carrier.

COMMITTED DOSE EQUIVALENT (CDE): The dose equivalent to organs or tissues of reference that will be received from an intake of radioactive material by an individual during the fifty-year period following the intake.

COMMITTED EFFECTIVE DOSE EQUIVALENT (CEDE): The sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the CDE to these organs or tissues.

COMPTON SCATTERING: The elastic scattering of a photon by an essentially free electron.

CONTAMINATION: The deposition of radioactive material in any place where it is not desired, particularly in any place where its presence may be harmful.

COUNT: The external indication of a device designed to enumerate ionizing events.

CURIE (Ci): The unit of activity equal to 3.7×10^{10} disintegrations per second.

DEEP-DOSE EQUIVALENT (DDE): The dose equivalent at a tissue depth of 1 cm from external radiation.

DOSE: A general term denoting the quantity of radiation or energy absorbed in a specified mass.

DOSE EQUIVALENT: The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest.

EFFECTIVE HALF-LIFE: Time required for a radioactive nuclide in the body to be diminished fifty percent as a result of the combined action of radioactive decay and biological elimination.

$$\text{Effective half-life} = \frac{\text{Biological half-life} \times \text{Radioactive half-life}}{\text{Biological half-life} + \text{Radioactive half-life}}$$

EFFICIENCY: The ratio of the count rate given by a radiation detection instrument and the actual disintegration rate of the material being counted.

ELECTRON CAPTURE: A mode of radioactive decay involving the capture of an orbital electron by its nucleus resulting in conversion of a proton to a neutron.

ELECTRON VOLT (eV): A unit of energy equal to the amount of energy gained by an electron passing through a potential difference of 1 volt.

ERG: A unit of energy. 1 erg = 6.24×10^{11} eV.

ERYTHEMA: An abnormal reddening of the skin due to distention of the capillaries with blood.

EXPOSURE: A measure of the ionizations produced in air by x-ray or gamma radiation. Sometimes used to mean dose.

EYE DOSE EQUIVALENT: The dose equivalent at a tissue depth of 0.3 cm from external radiation at the eye.

FILM BADGE: A packet of photographic film in a holder used for the approximate measurement of radiation dose.

GAMMA: Electromagnetic radiation (photon) of nuclear origin.

GEIGER-MUELLER (G-M) COUNTER: A radiation detection and measurement instrument.

GRAY (Gy): The SI unit of absorbed dose equal to 1 Joule/kilogram.

HALF VALUE LAYER: The thickness of any specified material necessary to reduce the intensity of an x-ray or gamma ray beam to one-half its original value.

HEALTH PHYSICS: The science concerned with the recognition, evaluation, and control of health hazards from ionizing radiation.

ION: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

IONIZATION: The process by which a neutral atom or molecule acquires either a positive or a negative charge.

IONIZATION CHAMBER: A radiation detection and measurement instrument.

IONIZING RADIATION: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, by interaction with matter.

ISOTOPES: Nuclides having the same number of protons in the nuclei, and hence having the same atomic number, but differing in the number of neutrons, and therefore in mass number. Almost identical chemical properties exist among isotopes of a particular element.

LABELLED COMPOUND: A compound consisting, in part, of radioactive nuclides for the purpose of following the compound or its fragments through physical, chemical, or biological processes.

LINEAR ENERGY TRANSFER (LET): Average amount of energy lost per unit track length by the individual particles or photons in radiation passing through an absorbing medium.

MASS NUMBER (A): The number of protons and neutrons in the nucleus of an atom.

NUCLIDE: An of atom characterized by its mass number, atomic number, and energy state of its nucleus.

POSITRON: A particle having a mass equal to that of an electron and a charge equal to that of an electron, but positive.

QUALITY FACTOR (Q): The LET-dependant modifying factor that is used to derive dose equivalent from absorbed dose.

RAD: The unit of absorbed dose equal to 100 erg/gram (or 0.01 Joule/kilogram).

RADIATION: Energy propagated through space or a material medium.

RADIOACTIVE DECAY: Disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles, neutrons, and/or photons.

RADIOACTIVE HALF-LIFE: The time required for a radioactive substance to lose fifty percent of its activity by decay.

RADIOACTIVITY: The property of certain nuclides of spontaneously disintegrating and emitting radiation.

RADIONUCLIDE: An unstable (radioactive) nuclide.

RADIOTOXICITY: The potential of a radioactive material to cause damage to living tissue by radiation after introduction into the body.

REM: The unit of dose equivalent equal to the absorbed dose in rad multiplied by any necessary modifying factors.

ROENTGEN (R): The unit of radiation exposure in air equal to 2.58×10^{-4} coulombs/kilogram.

SCINTILLATION COUNTER: A radiation detection and measurement instrument in which light flashes produced in a scintillator by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

SHALLOW-DOSE EQUIVALENT: The dose equivalent at a tissue depth of 0.007 cm from external exposure of the skin or an extremity.

SIEVERT (Sv): The SI unit of dose equivalent equal to 1 Joule/kilogram.

SPECIFIC ACTIVITY: Total activity of a given radionuclide per unit mass or volume.

SYSTEME INTERNATIONAL (SI): A system of units adopted by the 11th General Conference on Weights and Measurements in 1960 and used in most countries of the world.

THERMOLUMINESCENT DOSIMETER (TLD): A dosimeter made of a crystalline material which is capable of both storing energy from absorption of ionizing radiation and releasing this energy in the form of visible light when heated. The amount of light released can be used as a measure of absorbed dose.

TOTAL EFFECTIVE DOSE EQUIVALENT (TEDE): The sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). TEDE = DDE + CEDE

TOTAL ORGAN DOSE EQUIVALENT (TODE): The sum of the DDE and the CDE to an organ or tissue.

WEIGHTING FACTOR: The proportion of the risk of stochastic effects for an organ or tissue when the whole body is irradiated uniformly.

X-RAY: Electromagnetic radiation (photon) of non-nuclear origin having a wavelength shorter than that of visible light.

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