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DEPARTMENT OF THE ARMY
HARRY DIAMOND LABORATORIES
2800 POWDER MILL RD. ADELPHI, MD 20783

REPLY TO ATTENTION OF

DELHD-SA

28 October 1982

SUBJECT: Nuclear Regulatory Commission Request for Additional Information in Support of Renewal Application for Byproduct Material License 19-17250-01, Harry Diamond Laboratories

30-12438

THRU: ~~Commander
US Army Electronics Research
and Development Command
ATTN: DRDEL-SS
2800 Powder Mill Road
Adelphi, MD 20783~~ aEB

Commander
US Army Materiel Development
and Readiness Command
ATTN: DRCSF-P
5001 Eisenhower Avenue
Alexandria, VA 22333

TO: Nuclear Regulatory Commission
Washington, D.C 20555

1. References:

a. Letter, Nuclear Regulatory Commission, 7 Oct 82.

b. Letter, DRCSF-P, HQ, DARCOM, 12 Oct 82, subject as above, with 1st Indorsement, DRDEL-SS, HQ, ERADCOM, 22 Oct 82, same subject.

2. The requested additional information in support of renewal application for subject license is submitted as follows:

a. Instrument Calibration Procedures - Inclosure 1.

b. Radiation Survey Program - Inclosure 2.

c. Personnel Exposures - Inclosure 3.

FOR THE COMMANDER:

3 Incls
as

R. WILLIAMS
Safety Manager

INSTRUMENT CALIBRATION PROCEDURES

1. All portable instrumentation used for radiation protection (See Suppl #3) are calibrated quarterly by Rad Services, Inc., as indicated in Item 11a. The in-house calibrations referred to in Supplements #1 and #2 are the calibrations of permanently located Remote Area Monitors within our Co^{60} Gamma Radiation Facility, licensed under BML 19-17250-05, and calibration of Nuclear Measurements Corp, Model PC-4 proportional counter. For Remote Area Monitor description and calibration procedures, reference BML 19-17250-05, Supplement #4, pages 1 and 2. For PC-4 calibration procedures, see item 3, this letter.

2. As indicated in Supplement #2, this license, only three of the subject sources are used for calibration. The remaining are kept in a locked Radiation Storage Area, as described in Supplement #2.

3. In the event that any of the stored sources are needed for calibration, they will be used in the Co^{60} Facility, following the same procedures and precautions used for the present sources.

4. The RAM's and associated calibration sources are stored and used in a restricted area (See Fig 3, Suppl #2). Only authorized facility personnel conducting the calibration are present during calibrations. Authorized calibrators are identified in Item 6, and are the same personnel who are listed as the Gamma Radiation Facility Operators in BML 19-17250-05, item 6.

5. HDL calibration sources F and H (See Suppl #2) are operated remotely from the facility control room. Operators are therefore provided shielding designed for 40,000 Ci Co^{60}. The calibration sources are normally in-air for calibration only 5-10 minutes every 3 months, and are then remotely returned to their shielding pig (Suppl #2, Figs 1 and 2).

6. HDL source B is stored and used at the location indicated in Fig 3, Suppl #2. This source is used to calibrate RAM 1, which monitors the dose rate within the control room. The source is removed from its pig and held on the end of a 12 inch extension, at arms length, at varying distances from the detector. The whole body dose rate from this 1 mCi Co^{60} source at arms length is about 1.3 mR/hr. As the source is only handled for 5-10 minutes, expected dose is about .2 mrem. This procedure is only conducted once every three months. In addition, this source is used by facility operators to response check and constancy check portable instrumentation as they are entering the exposure area. The source remains in its pig for these checks.

RADIATION SURVEY PROGRAM

1. Please reference BML 19-17250-05, Annex 6-B for a copy of HDLM 385-20, Ionizing Radiation Protection Program, 24 Mar 80. (NRC Ltr, para 2a).

2. Radiation surveys are performed IAW AMC Regulation 385-25, Radiation Safety, 12 Aug 68 (Reference BML 19-17250-05, Annex 6-A), paragraph 17, page 17. In addition to monthly surveys, all areas where radioactive materials are used or stored are quarterly wipe tested for removable contamination. (NRC Ltr, para 2b).

3. Only authorized personnel have access to and are permitted to use radioactive materials. Personnel are not authorized until they successfully complete Radiation Worker Training and Evaluation. Evaluation includes Radiation Control Committee review of training and experience, and written examination. Please reference HDLM 385-20, Ionizing Radiation Protection Program, 24 Mar 80, para 20, page 14, for training requirements. Training includes both oral and written material regarding the use of radioactive material, from which the examination questions are taken. The written material is kept by the radiation workers for further reference. Attached is a copy of training material and examination. Workers are also provided a copy of NRC Regualtory Guide 8.29. HDL-M 385-20 provides additional guidance in the safe use of radioactive materials, as does the standard operating procedure for the particular facility. Please reference BML 19-17250-05, Suppl #4, pages 1 and 2 for written instructions regarding the use of subject material. (NRC Ltr, para 2c)

LEAK TEST PROCEDURES

Leak tests and wipe tests are analyzed on a Nuclear Measurements Corp, Model PC-4 proportional counter, by Michael Borisky, Radiation Protection Officer. Calibration is conducted prior to each use. The following sources are used to conduct the calibration, depending upon the sample to be counted:

Co^{60}, American Nuclear Products, SN 313, 1.04 uCi $\pm$ 5% as of 01 Oct 75

Cs^{137}, American Nuclear Products, SN 312, 1.15 uCi $\pm$ 5% as of 01 Oct 75

Both sources are SS configuration, 0.9 mg/cm^2 Mylar covered, backed by stainless steel planchet, 7/8" diameter.

1. Procedure

a. Proportional counter is turned on, and "test run" started to ensure counting circuitry and timing curcuitry functioning properly. After one minute, counter should display 3600 counts.

b. Place Nuclear Measurement Corp, Pb^{210} check cource, SN 7240, "Gold Standard" series into counter. Run a high voltage versus count to determine operating voltage for beta counting, normally 1700-1800 volts.

c. Count background at operating voltage for 10-20 consecutive counts, 1 minute each. Calculate mean value, variance, standard deviation, and perform Pearsons Chi Square test to ensure that sample distribution is normally distributed. Further calculate Reliability Factor to ensure that counts obey Poisson characteristics of radioactive decay.

d. Count calibration source long enough so that relative standard deviation of the net count is about 2% or less. For subject calibration sources, a 1 minute count is sufficient. Count 10-20 times serially for 1 minute each. Calculate mean, standard deviation, and perform Chi square test and reliability factor test. Correct for "dead time" if necessary.

e. Calculate counting efficiency for isotope of interest.

2. Sample Calibration

Calibration Source = Co^{60}, 1.04 uCi $\pm$ 5% (01 Oct 75)

a. Background Determination (1 minute counts)

45	53	48
5?	59	41
53	48	57
57	44	42
46	56	55

$\bar{\bar{X}} = 50.73 \pm 6.15\ (1.96)$

SD = 6.15

$X^2 = 10.42$ ∴ normally dist

$RF = \frac{6.15}{\sqrt{50.73}} = .86$ ∴ proper instrument operation.

b. Calibration Source (1 min counts)

364,744	363,855
363,785	364,270
364,313	364,147
364,926	366,154
365,721	365,013
363,740	365,253
365,596	364,906
364,776	365,337
365,078	364,394
364,766	365,192

$\bar{X}$ = 364,798 cpm ± 659.58 (1.961) 95% conf.

SD = 659.88 cpm

X^2 = 22.68 ∴ normally distributed

$RF = \frac{659.88}{\sqrt{364,798}} = 1.09$ ∴ Instrument functioning properly

c. Correct for resolving time

t = 1.8 usec = 1.8×10^{-6} sec = 3×15^{-8} min

$$\text{Count actual} = \frac{\text{count observed}}{1 - t\ (\text{count observed})} = \frac{364,798}{1-(3\times10^{-8})(364,798)} = 368,834 \text{ cpm}$$

d. Efficiency Determination:

Net count rate = 368,834 - 50(bkg) = 368,784 cpm

As of 01 Oct 82, Co^{60} source = 1.04 uCi ± 5%

Correct for decay, $t_{1/2}$ = 5.263yr, λ = .1317 yr^{-1}

$A = 1.04 \text{ uCi } e^{-(.1317\ yr^{-1})(7\ yr)}$
= .4137 uCi as of 01 Oct 82

$$\text{efficiency} = \frac{368,784 \text{ cpm}}{(.4137 \text{ uCi})(2.2\times10^{6} \text{ dpm/uCi})} = .4052 \approx 40.52\%$$

3. Determination of Co^{60} Sample Activity

$$A_{uCi} = \frac{\text{cpm}}{(.4052 \text{ cpm/dpm})(2.2\times10^{6} \text{ dpm/uCi})}$$

e.g. Suppose that sample count was 364,798/min

a. Correct for resolving time

$$\text{Count actual} = \frac{364,798}{1-(3\times10^{-8})(364,798)} = 368,834$$

b. Subtract background to obtain net count.

368,834 cpm - 50 cpm = 368,784 cpm

c. Calculate activity

$$A = \frac{368{,}784}{(.4052\text{cpm/dpm})(2.2\times10^{6}\ \text{dpm/uCi})} = .4137\ \text{uCi}$$

PERSONNEL EXPOSURE

One of the major objectives of the Harry Diamond Laboratories Radiation Protection Program is to keep personnel exposures ALARA. HDLM 385-20, Ionizing Radiation Protection Program, specifically addresses this requirement in para 6. (See BML 19-17250-05, Annex 6B).

Harry Diamond Laboratories has been very successful in keeping personnel exposures ALARA. It is very rarely that our film badge service, Lexington Ionizing Radiation Dosimetry (US Army), reports any exposure for HDL occupationally exposed individuals, occassionally exposed individuals, or visitors. The following exposure history, extracted from individual exposure histories, is offered as evidence:

Gamma Radiation Facility Operators (See BML 19-17250-05)

These individuals are issued a film badge on a montly basis, and have the greatest probability of accumulating exposure.

Charles C. Casaer, Facility Operator
- no exposure reported between Jan 80 and present, i.e. 32 consecutive months exposure-free (below minimum reportable)
- Dec 79 reported exposure - 0.010 rem.
- no exposure reported between Jan 80 and Mar 78, i.e., 19 consecutive months exposure-free.
- Mar 78 reported exposure - 0.012 rem.
- no exposure reported between Jan 76 and Mar 78, i.e., 26 consecutive months exposure-free
- Dec 75 reported exposure - 0.011 rem.

Perry Sarigianis, Facility Operator
- no exposure reported between Feb 79 and present, i.e., 44 consecutive months exposure-free
- Jan 79 reported exposure - 0.010 rem.
- no exposure reported between Dec 76 and Jan 79, i.e., 26 consecutive months exposure-free
- Nov 76 reported exposure - 0.017 rem.

Klaus G. Kerris, Facility Supervisor
- no exposure reported between Apr 79 and present, i.e., 41 consecutive months exposure-free
- Mar 79 reported exposure - 0.002 rem.
- no exposure reported between Apr 78 and Mar 79, i.e., 12 consecutive months exposure-free
- Mar 78 reported exposure - 0.007 rem.
- no exposure reported between Oct 76 and Mar 78, i.e., 17 consecutive months exposure-free
- Nov 76 reported exposure - 0.009 rem.

All Occupationally & Occassionally Exposed Individuals during the last calendar year, film badges were issued 565 person months. Only 3 persons received a reportable monthly exposure during the period - .002 rem, .002 rem, and .003 rem.

Although exposures are being kept well below 10% of the limits specified in 10CFR-Part 20, further action is taken to reduce exposure to ALARA when possible. The following is offered as an example:

When the Co^{60} sources in the Gamma Radiation Facility are raised out of the pool to conduct irradiation experiments, a 7 mR/hr dose rate is present at the maze door. This represents the "hottest" location within the control room during in-air operation, all other locations being less than 0.15 mR/hr. Although the whole control room is licensed as an occupiable area during in-air irradiations, an area within the control room has been designated for personnel exclusion during in-air irradiations. This area is an area in which a person might receive greater than 1.0 mR/hr while the sources are in-air. The area extends about 1 meter from the doors, and all the way along that wall. Opting for a dose rate less than 1.0 mR/hr would have been desirable, but would not allow room for the experimenters to set up and operate their experimental equipment. (Reference BML 19-17250-05 for Gamma Radiation Facility Description.)

LECTURE NOTES I-I

STUDENT HANDOUT - GLOSSARY OF TERMS

I. GENERAL TERMS

NOTES

HUMAN USE of radioactive materials refers to the diagnostic and therapeutic application of radioactive material to a human being.

NON-HUMAN USE of radioactive materials refers to those applications in which radioactive material is not applied or injected into human beings. Invitro studies of human tissues are included in this category providing none of the product material is to be applied to humans.

PRINCIPAL USER is an individual who, by virtue of his training and experience with radioactive material, has been authorized by the Radioisotope Committee to possess and use radioactive material for a given purpose. A principal user bears the responsibility for the safe handling of the material and proper precautionary measures to protect himself and others from unwarranted exposure to radiation. He may dictate such rules, procedures or other restrictions as he deems necessary to effect the proper handling of the radioactive material. He is directly responsible to the Radiosotope Committee.

COWORKER is an individual who possesses adequate training and experience with comparable radioactive material or equipment to qualify him as a principal user. A coworker performs such duties under the authorization of the principal user as directed and is responsible to the principal user for safe and proper handling of radioactive materials.

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TECHNICIAN is an individual who, under the supervision of the principal user and/or coworker, performs certain routine duties involving the use of radioactive material. He does not possess suitable training and experience to be classified as a principal user or coworker and is not undergoing such training as would qualify him to attain that status. Technicians are trained in the safe handling of radioactive material, contamination control, and precautionary measures which may be taken to protect himself and others from unwarranted exposure to radiation.

TRAINEE is an individual who does not possess adequate training and experience to be authorized as a principal user himself. He is assigned to this category so that he may obtain the necessary experience under the direct supervision of the principal user and coworkers. It is the aim of the trainee to obtain suitable training and experience to be classified as a principal user or coworker.

HEALTH PHYSICS is a profession devoted to the protection of man and his environment from unwarranted radiation exposure.

2. TECHNICAL TERMS RELATING TO AN UNDERSTANDING OF MATTER

MOLECULE - (1) A group of atoms held together by chemical forces. Atoms may be identical: H_2, S_2, S_8; or different: H_2O, CO_2.

(2) Ultimate unit quantity of a chemical compound which can exist by itself and retain all of the properties of the original substance.

MOLECULAR WEIGHT - The sum of the atomic weights of all of the atoms in the molecule.

ELEMENT - Pure substances consisting of atoms of the same atomic number which cannot be decomposed by ordinary chemical means.

ATOM - The smallest particle of an element which is capable of entering a chemical reaction. It consists of a central core called the *nucleus*, which contains *protons* and *neutrons*. *Electrons* revolve in orbits in in the region surrounding the nucleus.

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NUCLEUS - (Atomic Nucleus) - The small, central, positively charged region of an atom which is only about 1/10 000 of the diameter of the atom, but which carries essentially all of the mass. It is composed of protons, neutrons, and strange particles.

NUCLEON - A constituent of the atomic nucleus.

PROTON - An elementary nuclear particle with a positive electric charge equal numerically to the charge of an electron and a mass of 1.007594 mass units.

NEUTRON - A neutral particle (i.e. with no electrical charge) of approximately unit mass, present in the nuclei of all atomic nuclei except those of ordinary (light) hydrogen.

ELECTRON - A negatively charged particle which is a constituent of every neutral atom.
Charge - 4.802×10^{-10} esu or 1.6×10^{-19} Coulombs
Rest Mass - 0.000548 amu or 1/1836 of Hydrogen Atom

It is NOT found in the nucleus but rather in orbits around the nucleus. The electrons determine the atom's chemical properties.

ATOMIC NUMBER - The number of positive charges (protons) in the nucleus (Symbol: Z)

ATOMIC MASS - The mass of a neutral atom, usually expressed in terms of atomic mass units (Symbol: A)

ATOMIC MASS UNIT - (amu) - (1) one-twelfth of the mass of one neutral $^{12}_{6}C$ atom (Physicists' Nomenclature) or

(2) One-sixteenth of the mass of one neutral $^{16}_{8}O$ atom (Chemists' Nomenclature)
1.657×10^{-24} grams

$^{A}_{Z}X$ NOMENCLATURE

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ISOTOPE - Forms of the same element having identical chemical properties but differing in their atomic masses (due to different numbers of neutrons in their respective nuclei) and in their nuclear properties, e.g. radioactive vs stable, fissionable vs nonfissionable, etc.
e.g. ^{235}U, ^{238}U, ^{239}U AND ^{1}H, ^{2}H, ^{3}H

NUCLIDE - A species of atom characterized by the constituents of its nucleus. Often used synonomously with isotope, although this is not strictly correct and should be discouraged.

3. TECHNICAL TERMS RELATING TO AN UNDERSTANDING OF RADIOACTIVITY

RADIOACTIVITY - Spontaneous nuclear disentegration with emission of corpuscular or electromagnetic radiations.

RADIATION - The propogation of energy through matter or space in the form of waves. In atomic physics, the term has been extended to include fast-moving particles (*alpha*, *beta*, *neutron*, etc). *Gamma* rays and *X*-rays, of particular interest in atomic physics, are electromagnetic radiation in which energy is propogated in packets called *photons*.

BACKGROUND RADIATION - Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and sources of naturally occurring radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building materials themselves, in the experimental apparatus, etc.

ALPHA PARTICLE (α) - A particle ejected spontaneously from the nucleus of some radioactive elements. It is identical in all measured properties to a helium nucleus ($^{4}_{2}He$),

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which has an atomic mass number of 4 and an electrostatic charge of +2. It has low penetrating power and short range. The most energetic alpha particle will generally fail to penetrate the skin. The mass of an alpha particle is 4.00150 amu.

BETA PARTICLE (β) - A small particle ejected spontaneously from a nucleus of a radioactive element. It is identical to an electron and therefore has a charge of -1 and a mass of 1/1840 of a proton or neutron. It has low penetrating power and short range. The most energetic beta particles will penetrate skin and tissue. The damage is manifested by "skin burns". β, β-, β+ are reserved for electrons on nuclear origin.

ELECTROMAGNETIC RADIATION - A traveling wave motion consisting of electric and magnetic waves that travel in a vacuum at the speed of light.

GAMMA RAY (γ) - Very penetrating, high energy, short wavelength electromagnetic radiation emitted by a nucleus. Energies usually range from 0.010 to 10 MeV (Million Electron Volts). Except for location of origin γ-rays are identical to X-rays.

X-RAY - Penetrating electromagnetic radiation originating in the extranuclear part of the atom, but identical in all other respects to γ-rays.

4. TECHNICAL TERMS RELATING TO AN UNDERSTANDING OF THE MEASUREMENT OF RADIOACTIVITY

ELECTRON VOLT - A Unit of energy equivalent to the amount of energy gained by an electron passing through a potential difference of one volt.
eV - 1.5×10^{-12} ergs
keV - 10^3 eV
MeV - 10^6 eV

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ACTIVITY - The rate of decay of radioactive materials expressed as the number of nuclear disintegrations per second.

SPECIFIC ACTIVITY - The amount of activity contained in a unit volume (or weight) of material, e.g. 3 mCi/cc or 5 μCi/g

CURIE (Ci) - That quantity of a radioactive nuclide disintegrating at the rate of 3.7×10^{10} atoms per second.

MILLICURIE - 10^{-3} Ci - 3.7×10^{7} - mCi
MICROCURIE - 10^{-6} Ci - 3.7×10^{4} - μCi
NANOCURIE - 10^{-9} Ci - 3.7×10^{1} - nCi
PICOCURIE - 10^{-12} Ci - 3.7×10^{-2} - pCi or μμCi

5. TECHNICAL TERMS RELATING TO AN UNDERSTANDING OF RADIOACTIVE DECAY PROCESS

RADIOACTIVE DECAY - The spontaneous nuclear transformation or disintegration of one nuclide into a different nuclide or into a different energy state of the same nuclide by the emission of charged particles and/or electromagnetic radiation.

Every decay process has a definite *Half-Life*.

RADIOACTIVE SERIES - A succession of nuclides, each of which transforms, by radioactive disintegration, into the next until a stable nucleus results.

The first member is called the *parent*, the intermediate members are called *daughters*, and the final (stable) member is called the *end product*.

DECAY CONSTANT (λ) - The fraction of the number of atoms of a radioactive nuclide which decay in a unit time.

Half-Life $(T_{\frac{1}{2}}) = \frac{0.693}{\lambda}$ or $\lambda = \frac{0.693}{T_{\frac{1}{2}}}$

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HALF-LIFE ($T_{1/2}$) / PHYSICAL HALF-LIFE / RADIOACTIVE HALF-LIFE - Time required for a radioactive substance to lose 50% of its activity by radioactive decay.

Each radionuclide has a unique half-life.

BIOLOGICAL HALF-LIFE - The time required for the body to eliminate one-half of an administered dose of any substance by regular processes of elimination. This is approximately the same for both stable and radioactive isotopes of the same element.

EFFECTIVE HALF-LIFE - The time required for the activity of a given radioactive element to decrease to ½ of its initial activity in a biological organism. Results from the radioactive half-life and the biological half-life.

$$Eff\,T_{\frac{1}{2}} = \frac{Biol\,T_{\frac{1}{2}} \times Rad\,T_{\frac{1}{2}}}{Biol\,T_{\frac{1}{2}} + Rad\,T_{\frac{1}{2}}}$$

6. TECHNICAL TERMS RELATING TO AN UNDERSTANDING OF THE DOSE DUE TO RADIOACTIVITY

DOSE - A quantity (total or accumulated) of ionizing radiation.

EXPOSURE DOSE (EXPOSURE) - A measure of the total amount of ionization that the quantity of X-or γ-radiation could produce in air.

Given in R (*Roentgens*)

ROENTGEN (R) - A unit of exposure dose to ionizing radiation.

That quantity of X- or γ- radiation which will produce one statcoulomb of positive ions and one statcoulomb of negative ions in one cubic centimeter (0.001293 g) of air at 0°C and 760 mm of Hg pressure.

R is not a fixed quantity, it is an infinitesimal interaction unit.

ABSORBED DOSE - The quantity of energy imparted to or deposited in a mass of material exposed to ionizing radiation.

Given in rad

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rad - Originally an abbreviation for radiation absorbed dose. Now a unit of absorbed dose, or a measure of the energy imparted to matter by ionizing radiation and particles per unit mass of irradiated material at the place of interest; = 100 ergs/g.

BIOLOGICAL DOSE - a measure of the biological effectiveness of the radiation exposure; Units: rem.

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE) - A factor which is used to compare the biological effectiveness of absorbed radiation doses due to different types of radiation. Specifically it is the ratio

RBE = Dose of std (250 keV X-ray) radiation / Dose of radiation in question which produces the same biological response in replicate specimens.

rem - Originally abbreviation for Roentgen Equivalent Mammal (Man). Now the unit of the RBE dose, i.e. rem = rad x RBE

Specifically, that dose of ionizing radiation which elicits the same biological effect as 1 R of standard (250 keV) X-ray.

DOSE RATE - Radiation dose delivered per unit time.

FLUX - For electromagnetic radiation - The quantity of radiant energy flowing per unit time.

For particles and photons - The number of particles or photons flowing per unit time.

For Neutrons - A term used to express the intensity of neutron radiation. The number of neutrons passing through a unit area in unit time. For neutrons of a given energy, the product of neutron density with speed.

7. TECHNICAL TERMS RELATING TO AN UNDERSTANDING OF RADIATION PROTECTION

ATTENUATION - The process by which a beam of radiation is reduced in intensity when passing through some material. It is a combination of absorption and scattering processes and leads to a decrease in flux density of a beam when projected through matter.

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IONIZATION - The separation of normally electrically charged components. The term is also employed to describe the degree or extent to which the separation occurs. Ionization is the removal of an electron (negative charge) from the atom or molecule, either directly or indirectly, leaving a positively charged ion. The separated electron and ion are referred to as an ion pair.

EXCITATION - The addition of energy to a system, thereby transferring it from its ground state to an excited state. Excitation of a nucleus, atom, or molecule can result from the absorption of photons or from inelastic collisions with other particles.

DELTA RAYS - Any secondary ionizing particle ejected by recoil when a primary ionization particle passes through matter.

SHIELDING - Any material which is used to absorb radiation and thus effectively reduce the intensity of radiation.

HALF THICKNESS
HALF VALUE LAYER (HVL) - The thickness of any particular material necessary to reduce the intensity of a beam of radiation to one-half its initial value. It may be expressed in units of thickness or of mass per unit area.

8. TECHNICAL TERMS RELATING TO AN UNDERSTANDING OF CONTAMINATION

CONTAMINATION (Radioactive) - Deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence may be harmful. The harm may be in vitiating the validity of an experiment or a procedure, or in actually being a source of danger to personnel.

DECONTAMINATION - The removal of radioactive contamination from surfaces, as by cleaning and washing with chemicals.

9. TECHNICAL TERMS RELATING TO AN UNDERSTANDING OF PERSONNEL EXPOSURE

RADIATION CONTROL AREA - Any room, enclosure, or operating area to which access will be limited by Health Physics and in

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which precautionary measures are taken for the purpose of protecting individuals from exposure to ionizing radiation and radioactive materials.

HIGH RADIATION AREA - Any area, accessable to personnel, in which thereexists radiation in whole or in part within licensed material at such levels that a major portion of the body could receive in one hour 100 millirem.

RADIATION AREA - An area, accessable to personnel, in which there exists radiation, originating in whole or in part within licensed material, at such levels that a major portion of the body could receive in one hour 5 millirem, or in any 5 consequtive days a dose in excess of 100 millirem.

CONTROLLED AREA - a. Any room, enclosure, or operating area accessable to personnel in which an individual, if he were continually present, could receive a dose in excess of 2 millirem in any one hour or a dose in excess of 100 millirem in seven (7) consecutive days; or,

b. Any area in which there exists radioactive material in excess of those amounts specified in Appendix C, 10 CFR 20; or,

c. Any other area so designated by the WRAMC Health Physics Officer.

10. DEFINITION OF TERMS USED IN SUBSEQUENT INSTRUCTION

CRITICAL ORGAN - The critical organ is determined by consideration of the following criteria:

a. The organ which accumulates the greatest concentration of radioactive material.

b. The organ is essential or indispensable to the well being of the individual.

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c. The organ damaged by entry of the radionuclide into the body.

d. The radiosensitivity of the organ.

MAXIMUM PERMISSABLE BODY BURDEN - The quantity of an isotope which can be continually present in standard man in a particular organ and will not do clinically detectable damage. (MPBB)

MAXIMUM PERMISSABLE CONCENTRATION - (MPC) The amount of radioactive material in air, water, and foodstuffs which competent authorities have established as the maximum which would not create undue risk to human health. Calculations are based upon the assumptions that (1) the individual already has an MPBB of the isotope and (2) that the environment will not be allowed to add the radioisotope any faster than it is diminished through physical and biological processes.

STANDARD - Something established as a measure or model to which other similar things should conform.

CALIBRATION - Intercomparison between two items, one of which is a certified standard of known accuracy, to detect and to correlate or addjust any variation in the accuracy of the item being compared in relation to the certified standard.

ACCURACY - The degree of agreement between the measured value and the true value of the quantity being measured.

PRECISION - The degree of reproducibility of the measurement(s) under consideration.

COUNTING EFFICIENCY - A measure of the probability that
DETECTION EFFICIENCY - a count will be recorded when radiation is incident in the detector.

It is determined by the following expression:

$$\text{EFFICIENCY} = \frac{\text{COUNTS PER MINUTE}}{\text{DISINTEGRATIONS PER MINUTE}}$$

Mathematics

I. INTRODUCTION

This review is primarily concerned with the use of exponents, including powers of ten and logarithms. Their use as "short-hand" representation of both large and small numbers, their manipulation in equations, and their presentation in graphical form are described.

To facilitate a working knowledge of these mathematical concepts, illustrative examples of their use in typical problems encountered in radiological health are included.

II. DEFINITION OF TERMS

A. Exponents

An exponent is a term written above and to the right of any expression to indicate the number of times the expression is repeated as a factor of itself.

For example: $(2)^3 = (2)(2)(2) = 8$

A number raised to a power is referred to as an exponential number. The 3 is the exponent or power, and the (2) is the base in the foregoing expression.

Negative exponents denote the reciprocal of the base, raised to the same positive power. Or, in general,

$$x^{-n} = \frac{1}{x^n}$$

For example: $(2)^{-3} = \frac{1}{(2)^3} = \frac{1}{8} = 0.125$

B. Roots

Fractional exponents are commonly referred to as "roots." The square root of a number indicates that the number is raised to the $\frac{1}{2}$ power, and similarly, the cube root indicates the $\frac{1}{3}$ power. In addition to the normal notation of roots as fractional exponents, they are also occasionally written:

$\sqrt{x}$ for $(x)^{\frac{1}{2}}$, $\sqrt[3]{x}$ for $(x)^{\frac{1}{3}}$, etc.

For example: $\sqrt[3]{8} = (8)^{\frac{1}{3}} = 2$

C. Powers of Ten

When representing numbers in terms of "powers of ten," this merely stipulates that the base of the exponential expression is 10. When manipulating both extremely large or small numbers, the use of powers of ten enables a shorthand method of expressing such cumbersome numbers.

Several numbers with their powers of ten representation are shown below:

1,000,000	$= 10^6$	
1,000	$= 10^3$	
10	$= 10^1$	
1	$= 10^0$	(any base, except zero, raised to the zero power is 1)
.		
0.001	$= 10^{-3}$	
0.000,001	$= 10^{-6}$	

Two constant numbers frequently encountered in radiological health are the velocity

of light and Planck's constant. Numerical values acceptable for common use are:

Velocity of light = *30,000,000,000. cm/sec
= 3×10^{10} cm/sec

Planck's constant = *0.000,000,000,000,000, 000,000,000,006,625 erg-sec

= 6.625×10^{-27} erg-sec

Powers of ten thus simplify the expression of such numbers.

D. Logarithms

Logarithms may be thought of as a further simplification of representing numbers in terms of powers of ten. For example, 200 can be represented as 2×10^2 but this can be further simplified as $10^{2.3010}$. The number 2.3010 is called the logarithm, to the base 10, of 200. A logarithm, therefore, is an exponent.

1. COMMON LOGARITHMS

The base of the common logarithm, or Briggsian, system is 10. The logarithms, or logs, of some simple numbers are given below:

Number	Exponential form	Log*
0.001	10^{-3}	-3
0.01	10^{-2}	-2
0.1	10^{-1}	-1
1.0	10^{0}	0
10	10^{1}	1
100	10^{2}	2
1,000	10^{3}	3

*Manipulation of negative value logs is commonly done as follows: log 0.001 = -3.0000 = 7.0000 - 10

Values of the log for numbers can be obtained from a slide rule or from tables of common logarithms. In the example cited earlier, the log of 200 is between 2 and 3 and the exact value, 2.3010, may be found by reference to such tables. In all cases, the value of the left of the decimal point is called the "characteristic" and the value to the right is called the "mantissa". The characteristic locates the decimal point of the number.

2. NATURAL LOGARITHMS

Another system of logarithms in wide usage is the natural, or Naperian system. The base for this system is e (which numerically is equal to approximately 2.718)--the limit resulting from the expansion of a convergent series. This logarithm is abbreviated $\log_e$, or more commonly ln.

To convert from one system to the other, the following relationships may be useful:

$$\log N = 0.4343 \ln N$$

or

$$\ln N = 2.3026 \log N.$$

To determine the natural log of a number directly, reference must be made to tables or a slide rule. Normally the tables cover the ln of numbers from 1 to 9.99 with ln's of multiples of ten given separately. Using such a table, the procedure for determining natural logarithms of numbers not directly included is given by example below:

$$\ln 679 = \ln (6.79 \times 10^2) = \ln 6.79 + \ln 10^2$$
$$= 1.9155 + 4.6052 = 6.5207$$

$$\ln 0.0679 = \ln (6.79 \times 10^{-2}) = \ln 6.79 - \ln 10^2$$
$$= 1.9155 - 4.6052 = -2.6897$$

III. BASIC RULES IN SOLVING EXPONENTIAL EXPRESSIONS

Addition: When adding quantities with the same exponents, the exponent does not change.

$$ax^n + bx^n = (a + b)x^n$$

*These are approximate values and are used for most calculations. More precise values are known.

Example: $2(3)^2 + (3)^2 = (2 + 1)(3)^2 = (3)(9) = 27$

Subtraction: When subtracting quantities with the same exponents, the exponent does not change.

$$ax^n - bx^n = (a - b)x^n$$

Example: $2(3)^2 - (3)^2 = (2 - 1)(3)^2 = (3)^2 = 9$

Multiplication: The exponent of any number in a product equals the sum of its exponents in the factors of the product as long as the base is the same.

$$(x^n)(x^m) = x^{n+m}$$

Example: $(2^3)(2^2) = (2)^{3+2} = (2)^5 = 32$

Division: To divide two like quantities (same base), each raised to some power, the exponents are subtracted and the common base is retained.

$$\frac{x^n}{x^m} = x^{n-m}$$

Example: $\frac{(2)^3}{(2)^2} = (2)^{3-2} = (2)^1 = 2$

Powers: Any exponential quantity raised to a power is equal to the base raised to the product of the two exponents.

$$(x^n)^m = x^{nm}$$

Example: $(3^2)^3 = (3)^6 = 729$

Manipulation of Logarithms: Following these above rules, the manipulation of logarithms is facilitated by the following:

Multiplication $\log ab = \log a + \log b$

Division $\log \left(\frac{a}{b}\right) = \log a - \log b$

Powers $\log b^a = a \log b$

IV. GRAPHICAL PRESENTATION OF EQUATIONS

An equation is a statement of equality between two expressions. The solving of an equation is a process of determining values for unknowns which will satisfy the conditions of the equation. This process can be accomplished either by algebraic methods or by a graphic solution.

A graph is simply a pictorial representation of an equation, each point of the graph satisfying the conditions of the expression from which it is derived. Graphic presentations are based on the principle of representing a number by a vector, that is, by a linear distance on a selected scale. The relationship between two variables is represented by two coordinate axes at right angles to each other.

A. Rectangular (Cartesian) Coordinate System*

The most frequently used method of specifying the position of a point in a plane is the rectangular coordinate system.

The point of intersection, O, is called the origin. Established on each line is a number system in graphic form. By letting X and Y be variables, they are free to assume any assigned values on their respective numerical scales. Accordingly, the horizontal line is called the X-axis, and the vertical line is called the Y-axis. (See Figure 1.)

Now that the framework is established, consider locating the position of a point, A, corresponding to X = 3 and Y = 2. Draw a line perpendicularly from point 3 on the X-axis, and a second line perpendicularly from point 2 on the Y-axis as shown in Figure 2. The point of intersection of the two lines establishes the position of A.

* After René Descartes (Cartesius).

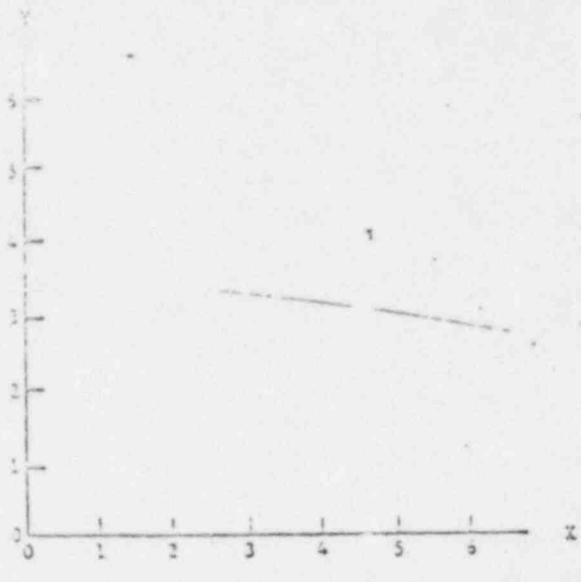

Figure 1.-Rectangular Coordinate System

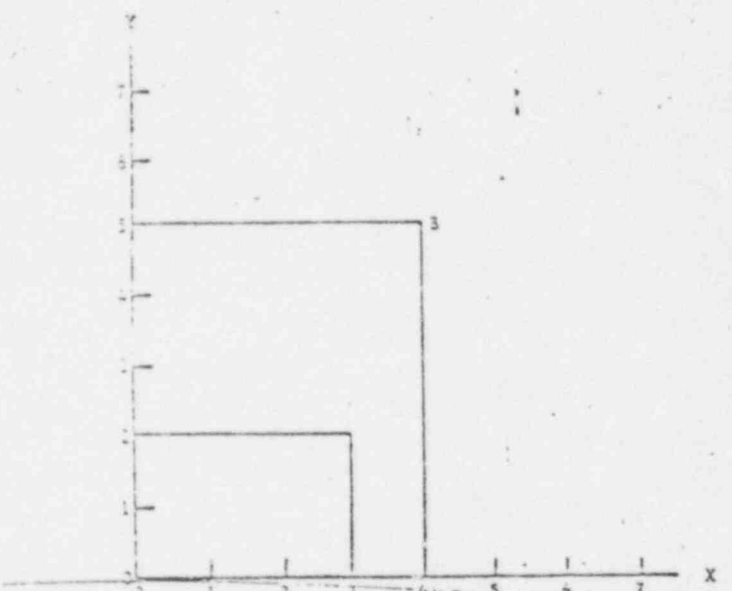

Figure 2.-Locating Points by Coordinates

Now consider determining the values of X and Y which correspond to the position of a point, B. For this purpose draw two lines through B parallel to the two axes.

The number corresponding to the numerical value, 4 on the X-axis is called the abscissa of B and the numerical value, 5, on the Y-axis is called the ordinate of B. The same relation holds for their values, 2 and 3, with respect to point A. The abscissa and ordinate of a point are called its coordinates.

In the rectangular coordinate system just described, every point in the plane has one and only one pair of coordinates, and every pair of coordinates describes the position of only one point.

Using this general method of representing the position of a point in a plane, it is possible graphically to represent an equation by plotting the values which satisfy the conditions of the equation. Consider the graphical representation of a linear equation, that is, one which plots as a straight line on such a graph and has the general form:

$$y = mx + b$$

where, y = dependent variable (ordinate)

x = independent variable (abscissa)

m = slope of the plotted equation $\frac{(\Delta y)}{(\Delta x)}$

b = y intercept, or value of y when $x = 0$

In order to plot a linear equation, it is necessary to know either:

1. The coordinates of 2 points, which can then be connected by a straight line; or
2. The coordinates of one point and the slope of the line, so that a line of that slope drawn through the known point will satisfy the equation.

For reference purposes, two other types of equations are plotted in Figure 3. Both of these types are encountered frequently in radiological health work. To facilitate solution of these types of equations graphically, it is necessary to plot them on a coordinate system so that they result in straight lines. Semi-logarithmic and logarithmic plots will be described which meet this purpose.

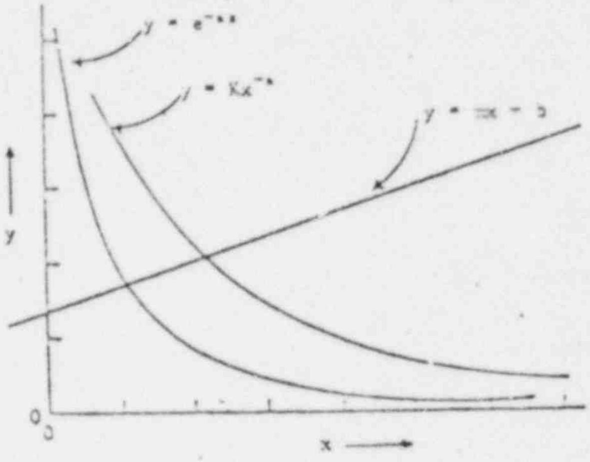

Figure 3.-Arithmetic Coordinates

B. Semi-logarithmic Coordinate System

An equation of the form $y = e^{-ax}$, where "e" is the base of the natural logarithms and "a" is a constant, may be transformed by use of logarithms as follows:

$$y = e^{-ax}$$

Taking the natural logarithm of both sides of the equation:

$$\ln y = (-ax) \ln e$$

$$\text{Since } \ln e = 1, \ln y = -ax$$

$$\text{or } 2.3026 \log y = -ax$$

This, then, can be plotted as a straight line on arithmetic coordinates if "log y" values are plotted versus X values. To simplify the solution, however, the use of a logarithmic scale upon which Y values may be plotted directly accomplishes the same objective. Such a coordinate system, in which commonly the ordinate is constructed on a logarithmic scale, is called a semi-log graph. This is illustrated in Figure 4.

C. Log-log Coordinate System

Considering next the equation, $y = Kx^{-a}$, where "K" and "a" are constants, such may also be transfored by use of logarithms.

$$y = Kx^{-a}$$

$$\log y = \log K - a \log x$$

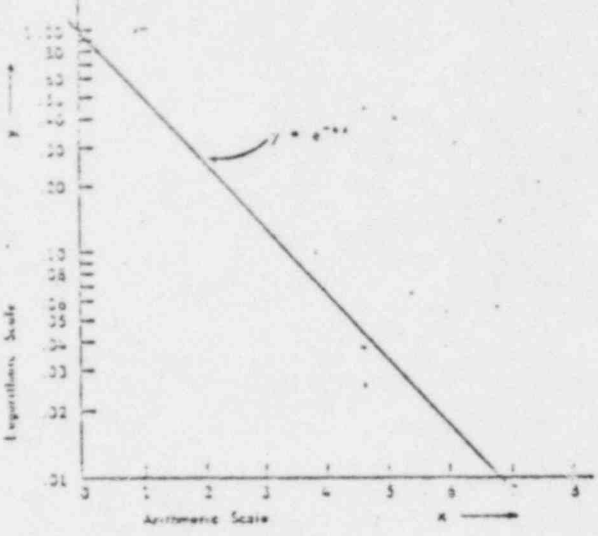

Figure 4.-Semi-log Coordinate

This equation may be plotted as a straight line on arithmetic coordinates provided "log y" values are plotted versus "log x" values. Again, to simplify such solution, logarithmic coordinates may be used, for both ordinate and abscissa in this case. A log-log graph is shown in Figure 5. From this plot, "K" may be determined graphically from the y axis when X = 1.

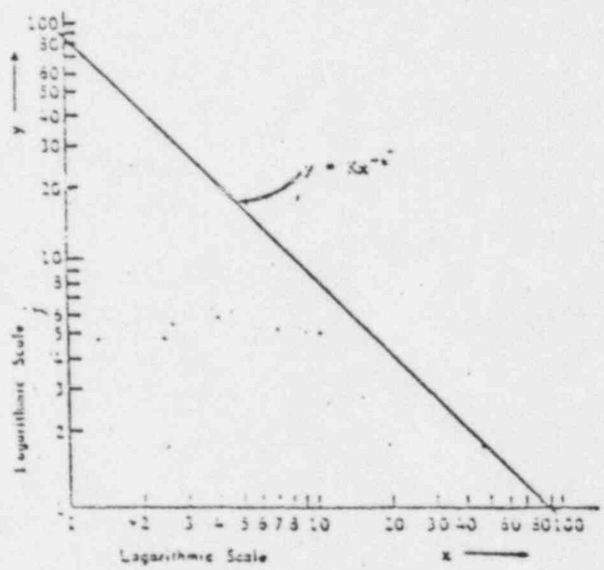

Figure 5.-Log-log Coordinate

V. ILLUSTRATIVE EXAMPLES

A. Radionuclide Decay

A radionuclide decays according to the following equation:

$$A = A_0 e^{-\frac{(0.693)\,t}{T_{\frac{1}{2}}}}$$

where, A = Activity at time t

A_0 = Activity when $t = 0$

$T_{\frac{1}{2}}$ = Half-life of the radionuclide

given: A_0 = 100 mCi and A = 20 mCi when t = 32 days

find: $T_{\frac{1}{2}}$

Algebraic Solution:

Taking natural logarithms of both sides of the equation:

$$\ln A = \ln A_0 - \frac{(0.693)\,t}{T_{\frac{1}{2}}}$$

$$\ln 20 = \ln 100 - \frac{(0.693)32}{T_{\frac{1}{2}}}$$

$$2.995 = 4.605 - \frac{22.2}{T_{\frac{1}{2}}}$$

$$T_{\frac{1}{2}} = \frac{22.2}{1.61} = 13.8 \text{ days (same units as t)}$$

B. Fallout Decay

The mixture of radionuclides in fallout decays approximately as:

$I\,t^{-n} = k$ where, I = intensity at time t; n and k are constants

given: $I = 82$ when $t = 1$

$I = 10$ when $t = 9$

find: I when $t = 20$

Graphic Solution:

Refer to Figure 5, plotting "I" values on Y-axis and "t" values on X-axis.

$I = 4.3$ when $t = 20$

Chemistry

I. CONCEPTS OF ATOMS AND ATOMIC WEIGHTS

A. Identification of Matter

To identify the various kinds of matter which make up the material world, the properties of any substance under consideration can be described in either physical or chemical terms.

1. Physical properties are those characteristics which can be stated without reference to any other substance, as color, density, form, size, solubility, melting point, boiling point, and many others.

2. Chemical properties are those characteristics of a substance which describe its behavior with reference to other substances. For example, hydrogen reacts with oxygen to produce water, this being a chemical property of hydrogen and also of oxygen. The chemical properties of an atom depend upon the number and arrangements of electrons which surround its nucleus. Chemical changes or reactions do nothing to the atoms involved except change the number or arrangement of these electrons.

B. Classification of Matter

As first considered, the universe seems to be made up of an enormous number of different kinds of matter, but further consideration shows that it is possible to classify all matter as being either heterogeneous or homogeneous.

1. Heterogeneous matter is made up of distinct parts differing from each other in physical properties with definite surface boundaries. The individual constituents can often be recognized visually or be separated by simple mechanical means, such as separation of iron filings from sulfur by use of a magnet.

2. Homogeneous matter is uniform in structure and every part has the same properties. Homogeneous matter is frequently referred to as a pure substance, and may be further classified as an element or a compound.

a. Elements are pure substances which cannot be broken down into simpler substances by a chemical change or reaction. At present, there are over 100 known elements.

b. Compounds show uniformity of structure and composition; nevertheless, they may be resolved into two or more simpler substances by chemical change. Mercuric oxide, for example, is decomposed by heat into mercury and oxygen, both of which are elements. Every compound consists of two or more elements in a fixed and definite proportion by weight. This definiteness of composition is a characteristic which distinguishes compounds from mixtures.

C. Continuity of Matter

If a quantity of homogeneous matter is mechanically or physically subdivided into 100 equal parts, it can be established that each of these 100 parts has the same properties as the original material. If this process could be repeated, it would be found that matter is continuous to a point where further division of the substance is impossible without a corresponding change in properties. This last unit, which bears all the characteristics of the original sample, is known as molecule.

Although molecules are unchanged by mechanical processes, they may be broken down by chemical reactions into their fundamental

components which are called atoms. At the beginning of the 19th century, John Dalton, an English chemist, proposed the atomic theory, and established the existence of atoms. His theory stated that:

1. Elements are made up of minute particles called atoms, which are not divisible by any known chemical means.

2. The atoms of different elements have different masses and properties.

3. A compound is formed by a definite combination of the atoms of two or more elements in simple numerical proportions, resulting in the formation of the ultimate particle of the compound called the molecule.

D. Symbols and Formulas

For simplicity in chemical notation, each element is represented by a symbol, which is often the first letter or the first two letters of its name. A compound is represented by a formula consisting of the symbols of its constituent elements followed by subscript numbers indicating the number of atoms of that element present in each molecule of the compounds. One molecule of water is written as H_2O, showing that there are two atoms of hydrogen and one of oxygen per molecule.

E. Atomic Weights and Measurements

The weight of an atom of each element is based upon the weight of one atom of a standard, or reference nuclide, carbon-12, to which an arbitrary value (weight) of 12 has been assigned. The actual weight of any atom is based on a unit which is 1/12 the weight of any carbon-12 atom. This unit is used frequently in nuclear physics and is called an atomic mass unit (a.m.u.).

To obtain the atomic weight of each element, it is necessary to weigh a definite number of atoms of each element and compare this weight with the weight of the same number of atoms of the standard, thus giving the ratio of the weights of single atoms. For example, the atomic weight of sulfur may be determined by measuring samples of carbon-12 and sulfur which contain the same number of atoms. It will be found that sulfur weighs 32.064/12 times the weight of carbon-12 and therefore, an atomic weight of 32.064 is assigned to sulfur.

The technique of obtaining the same number of atoms, in the sample and the reference element, is not simple. Elements in the rare gas groups (He, Ne, Ar, Kr, Xe, and Rn) have only one atom per molecule; in weighing a definite number of molecules of these gases, a like number of atoms are weighed. To determine the relative weights of other atoms, the number of atoms per molecule must be first established and from this their weights are derived, as in the case of sulfur and carbon-12. The following concepts are useful for such determinations:

1. Gram Atomic Weight (G.A.W.) is the atomic weight of an element expressed in grams. The atomic weight of phosphorus is 30.974 and 30.974 grams is the G.A.W. of phosphorus.

2. Gram Molecular Weight (G.M.W.) or mole is the molecular weight expressed in grams. Sulfuric acid (H_2SO_4) has a molecular weight of 98.078 and 98.078 grams is its G.M.W. Water (H^2O) has a molecular weight of 18.015 and 18.015 grams is its G.M.W.

3. Gram Molecular Volume is the volume occupied by one gram molecular weight (mole) of a substance in the gaseous state at standard conditions of temperature and pressure (STP, which is 0°C and 760 mm Hg). This volume is 22.414 liters.

4. Avogardro's Number (N_0) is the number of molecules present in one gram molecular weight of any compound or in 22.414 liters of any gas measured at STP. It is also the number of atoms present in one gram atomic weight of any element. Its numerical value is 6.023×10^{23}.

5. Valence is a number which represents the combining or displacing power of an element or radical compared with that of a hydrogen atom taken as unity. Thus, it is a number which represents the number of

atoms of hydrogen that one atom of any element or radical will combine with or displace, being positive if the element is displacing hydrogen and negative if combining with hydrogen.

6. The equivalent weight or combining weight of an element or ion is its atomic or formula weight divided by its valence. Elements entering into combination always do so in quantities proportional to their equivalent weights.

F. Atomic Structure

It has been stated that the atom is the simplest unit of an element which participates in a chemical reaction and that it cannot be broken down by ordinary means. However, by nuclear reactions, it may be shown that the atom consists of two main parts, termed the nucleus and the electron cloud.

1. The nucleus is the central portion of the atom which constitutes practically all of the mass of the atom and has a positive charge. The nucleus is composed of 2 types of particles--neutrons and protons, often referred to collectively as nucleons.

a. A neutron has no electrical charge and a mass of approximately 1. (Using 1/12 the weight of carbon-12 as unity.)

b. A proton has a single positive charge and a mass also of approximately 1.

The total number of protons and neutrons in the nucleus of an atom constitutes the mass number. The number of protons alone is referred to as the atomic number.

2. The electron cloud surrounding the nuclear portion of the atom contains electrons which are in motion about the nucleus. The atom can be compared to the planetary solar system in which the planets revolve in elliptical paths about the sun as a nucleus. The electrons in the atom revolve about the nucleus in elliptical and/or circular paths termed orbits. Regardless of the motion or path of the individual electrons, the electrons of an atom are grouped in well-defined orbits (shells) which have certain energy quantum levels. These shells have diameters which are large compared to the diameter of the nucleus. Nonetheless, the moving electrons create a dense electrical field which is of equal magnitude but of opposite charge (negative) to that within the nucleus.

a. Electron arrangement

The electron shells are commonly designated in alphabetical terms. The first shell is designated K, the second L, the third M, and on through the alphabet to Q (seventh shell), which is the outermost shell found in any of the presently known elements. The diameter of the Q shell is of the order of 3×10^{-8} centimeters, whereas the diameter of the nucleus is of the order of 3×10^{-12} centimeters for the heavier atoms and 3×10^{-13} for the lighter atoms.

3. Elements which have the same atomic number, but different mass numbers are called isotopes of that element. They differ in the number of neutrons contained in their nuclei. For example, $^{235}_{92}U$ has 92 protons and 143 neutrons, $^{238}_{92}U$ has 92 protons and 146 neutrons. The isotopes of all the elements are referred to as the nuclides. If the isotope or nuclide in question is radioactive, it is referred to as a radioisotope or radionuclide.

II. PERIODIC CHART OF THE ELEMENTS

A. Introduction

The periodic chart of the elements was the outgrowth of an attempt to classify the elements in a radical manner.

In 1869, Mendeleev stated that the properties of elements are periodic functions of their atomic weights. That is, by arranging all the elements (in chart form) in the order of their increasing atomic weights, the properties of the elements recur at regular intervals. His table consisted of (1) horizontal rows of elements (in order of their increasing atomic weights), called periods, (2) vertical

PERIODIC TABLE OF THE ELEMENTS

BASED ON CARBON-12

IMPORTANT ATOMIC CONSTANTS

(Carbon 12 scale)

Atomic Mass of

Electron M_e = (5.48589 ± 0.00006) × 10^{-4}

Proton M_p = 1.007277 ± 0.000001

Neutron M_n = 1.008665 ± 0.000002

Deuteron M_d = 2.013554 ± 0.000001

Triton M_t = 3.015500 ± 0.000002

Rest Mass of

Electron m_e = (9.1091 ± 0.0004) × 10^{-28} gm

Proton m_p = (1.67252 ± 0.00008) × 10^{-24} gm

Neutron m_n = (1.67482 ± 0.00008) × 10^{-24} gm

Electronic charge e = (4.8030 ± 0.0002) × 10^{-10} esu

Rydberg constant R_∞ = 109737.31 ± 0.01 cm^{-1}

Velocity of light c = (2.997927 ± 0.000002) × 10^{10} cm sec^{-1}

Fine structure constant α = (137.038 ± 0.001)$^{-1}$

Planck's constant h = (6.6249 ± 0.0003) × 10^{-27} erg sec

Boltzmann's constant k = (1.38047 ± 0.00007) × 10^{-16} erg deg^{-1}

Avogadro's constant N = (6.0228 ± 0.0002) × 10^{23} $mole^{-1}$

Gas constant R = (8.3143 ± 0.0003) × 10^{7} erg deg^{-1} $mole^{-1}$

Faraday F = 96488 ± 0.1 coul $mole^{-1}$

Standard volume of ideal gas V_0 = 22413.6 ± 0.6 cm^3 $mole^{-1}$

1 amu (C^{12} = 12) = 1.000314 amu (O^{16} = 16)

1 amu (C^{12} = 12) = 1.000043 amu (O = 16)

1 amu (O = 16) = 1.000275 amu (O^{16} = 16)

1 H 1.00797																	2 He 4.003
3 Li 6.939	4 Be 9.012											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.9994	9 F 19.00	10 Ne 20.183
11 Na 22.990	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.909	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc	44 Ru 101.1	45 Rh 102.905	46 Pd 106.4	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.905	56 Ba 137.34		72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.98	84 Po	85 At	86 Rn
87 Fr	88 Ra		104	105	106	107	108										

Lanthanide Series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm	62 Sm 150.35	63 Eu 152.0	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
Actinide Series	89 Ac	90 Th 232.04	91 Pa	92 U 238.03	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lw

Z — Atomic Symbol

CENTRAL SCIENTIFIC COMPANY
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LIST OF ELEMENTS

Atomic Number	Symbol	Name	Atomic Number	Symbol	Name
0	n	neutron	52	Te	tellurium
1	H	hydrogen	53	I	iodine
2	He	helium	54	Xe	xenon
3	Li	lithium	55	Cs	cesium
4	Be	beryllium	56	Ba	barium
5	B	boron	57	La	lanthanum
6	C	carbon	58	Ce	cerium
7	N	nitrogen	59	Pr	praseodymium
8	O	oxygen	60	Nd	neodymium
9	F	fluorine	61	Pm	promethium
10	Ne	neon	62	Sm	samarium
11	Na	sodium	63	Eu	europium
12	Mg	magnesium	64	Gd	gadolinium
13	Al	aluminum	65	Tb	terbium
14	Si	silicon	66	Dy	dysprosium
15	P	phosphorus	67	Ho	holmium
16	S	sulfur	68	Er	erbium
17	Cl	chlorine	69	Tm	thulium
18	Ar	argon	70	Yb	ytterbium
19	K	potassium	71	Lu	lutetium
20	Ca	calcium	72	Hf	hafnium
21	Sc	scandium	73	Ta	tantalum
22	Ti	titanium	74	W	tungsten
23	V	vanadium	75	Re	rhenium
24	Cr	chromium	76	Os	osmium
25	Mn	manganese	77	Ir	iridium
26	Fe	iron	78	Pt	platinum
27	Co	cobalt	79	Au	gold
28	Ni	nickel	80	Hg	mercury
29	Cu	copper	81	Tl	thallium
30	Zn	zinc	82	Pb	lead
31	Ga	gallium	83	Bi	bismuth
32	Ge	germanium	84	Po	polonium
33	As	arsenic	85	At	astatine
34	Se	selenium	86	Rn	radon
35	Br	bromine	87	Fr	francium
36	Kr	krypton	88	Ra	radium
37	Rb	rubidium	89	Ac	actinium
38	Sr	strontium	90	Th	thorium
39	Y	yttrium	91	Pa	protactinium
40	Zr	zirconium	92	U	uranium
41	Nb	niobium	93	Np	neptunium
42	Mo	molybdenum	94	Pu	plutonium
43	Tc	technetium	95	Am	americium
44	Ru	ruthenium	96	Cm	curium
45	Rh	rhodium	97	Bk	berkelium
46	Pd	palladium	98	Cf	californium
47	Ag	silver	99	Es	einsteinium
48	Cd	cadmium	100	Fm	fermium
49	In	indium	101	Md	mendelevium
50	Sn	tin	102	No	nobelium
51	Sb	antimony	103	Lw	lawrencium

columns called groups, and (3) after passing through the first three periods, the groups are subdivided into two subgroups, A and B. The elements in these subgroups resemble each other in chemical and physical properties and are called a "family of elements."

Moseley's work (1912-1914) on atomic numbers gave us the new periodic law which states that the properties of elements are periodic functions of their atomic numbers. The table of elements arranged in order of increasing atomic number is shown on page 12. It consists of seven (horizontal) periods, eight (vertical) regular groups, and ten (vertical) transition groups. The end element in each period is a member of the inert gas or helium group. The number in the upper left-hand corner of each rectangle allotted to each element is the atomic number. The number in the upper right-hand corner is the atomic weight.

B. Periods and Groups

The periods, or horizontal rows, are numbered successively from 1 to 7. Consequently, the number of a period in which an element is placed indicates the number of shells which are present in the electron cloud of that atom. The vertical groups give an indication of the number of electrons which can be affected during a chemical change. The electrons in the outermost shell are called the valence electrons, and the number of valence electrons is generally the same as the group in which the element appear in the chart. In these various elements, the electrons are added with definite regularity until element number 18 is reached.

The first shell has a capacity of 2 electrons. Therefore, the total number of elements found in period 1 is two; namely, hydrogen with one electron and helium with two electrons in the K shell. Hydrogen is placed in Group I because each element in that group has one electron in its outermost orbit. Helium is not placed in Group II even though it has 2 electrons in its outer shell. Helium is placed in Group VIII, because it has properties characteristic of elements in that group; namely, zero valence, and, normally, no reactivity.

The next element above helium higher in complexity is lithium which has an atomic number of 3 and therefore three planetary electrons. Two of these are in the K shell and one in the L shell. With one electron in its outermost shell, its properties are such that it is in Group I. Each element from lithium to neon has one more electron than its predecessor. When neon is reached, the L shell is filled to its capacity of 8 electrons. Sodium starts the third period with 3 shells; two of its eleven electrons fill the K shell, eight more fill the L shell, and the last one is in the M shell. Since sodium has one electron in its outer shell, it appears in Group I under lithium.

From sodium to argon (atomic numbers 11 to 18) the successive electrons add in the M shell. After argon, instead of the last electron of potassium adding to the M shell, which has a capacity of 18, it starts a new shell (N) and having only one electron in its outermost shell, has properties similar to elements in Group I and is placed in that group. The element calcium follows potassium in period 4 and appears in Group II because it has two electrons in its outer shell.

In the next element, scandium, instead of the last electron adding to the N shell, it goes back into the M shell, which has a capacity of 18 electrons but had only 8 present in the preceding element. This irregularity of electron structure causes a deviation from the previous properties of elements in Group III as it does not have the same number of electrons in its outside shell as the number of the group in which it falls. To indicate this variance, scandium is offset to the left under the previous elements of this Group (III). This variance introduces a new family of elements within a group, and such subgroups or families are designated A and B. All elements in family A of any group will have like properties due to similar structure and all elements in family B of any group will have similar properties because of similar structure. Thus, the properties of elements of different families of the same group are not

alike because of dissimilar electron configuration. The property common to all elements of any group, whether they are in family A or B, is that they lose or gain the same number of electrons when participating in a chemical reaction, and therefore they will have like valences.

C. Rare Earths

The chemical properties of elements are due primarily to the electrons in the outer shell, secondarily to the electrons in the next inner shell, and finally to the electrons in the third outermost shell. However, if the two outermost shells of elements are alike, their properties will be very similar even though the number of electrons in the third outermost shell differs. This similarity is noticeable with elements of the rare earth group, one type of which occurs in period 6 and another type in period 7.

The rare earths of period 6 (elements 58 through 71) were not identified for a long time because their two outside shells were like the elements barium (56) and lanthanum (57) and, consequently, their properties were so similar that they could not be separated without difficulty from the neighboring elements. These elements, the lanthanides, are withdrawn from the body of the table and placed as a group at the bottom of the table. There are 14 of these elements in period 6 due to the fact that the K, L, M, O, and P shells are similar, whereas the N shell is building up from 18 to 32 electrons, the capacity for the N shell.

The rare earths, or actinides, in period 7 have similar K, L, M, N, P, and Q shells while the O shell is building up from 18 to 50, the maximum for the O shell. One might expect to find 32 elements in this rare earth series; however, only three have been found in nature and man has succeeded in manufacturing a growing additional number.

III. CHEMICAL REACTIONS

A. Ion Formation

Normally, an element will contain as many electrons as it does protons and be neutral. However, certain elements tend to lose electrons and other elements tend to gain electrons.

1. Elements which tend to lose electrons and become electro-positive are called metals and the resulting particle is called a positive ion.

Example: $Na^0 \rightarrow Na^+ + e^-$

2. Elements which tend to gain electrons and become electro-negative are called non-metals and the resulting particle is called a negative ion.

Example: $Cl_2^0 + 2e^- \rightarrow 2Cl^-$

B. Chemical Equations

A chemical reaction or combination can be represented by the use of chemical equations.

1. The reaction between hydrogen (H_2) and chlorine (Cl_2) may be expressed as follows:

$$H_2 + Cl_2 \rightarrow 2\,HCl$$

These two elements will always react together in precisely this manner and will always react, by weight, in a fixed ratio of their equivalent weights. This is called The Law of Combining Weights.

C. Acids and Bases

1. When a compound like HCl is added to H_2O, it ionizes to form H^+ (hydrogen) ions. Compounds which ionize in this manner are called acids and the concentration of H^+ ions formed is a measure of the acidity of the resulting solution.

Acids: HCl, HNO_3, H_2SO_4, $HClO_4$, H_3PO_4, HBr, HI

2. When a compound like NaOH is added to H_2O, it ionizes to form OH^- (hydroxyl) ions. Compounds which ionize in this manner are called bases and the concentration of OH^- ions formed is a measure of the basicity (alkalinity) of the resulting solution.

Bases: NaOH, KOH, $Ca(OH)_2$, NH_4OH

D. Oxidation - Reduction

Every chemical combination or reaction involves an interchange or interaction of the electrons of the participating substances.

1. A loss of electrons by an element is known as oxidation.

Example: $2Cl^- \rightarrow 2e^- + Cl_2^0$ (a gain in positive charge)

2. A gain of electrons by an element is known as reduction.

Example: $Na^+ + e^- \rightarrow Na^0$ (a loss in positive charge).

IV. RADIOCHEMISTRY

A. Introduction

In environmental radiation surveillance, it is necessary to analyze samples of air, water, food and milk for gross radioactivity or specific radionuclides.

Since a typical radionuclide in an environmental sample weighs only about 10^{-14} or 10^{-15} grams, standard analytical chemistry procedures cannot be used without the addition of a carrier.

B. Carriers

A carrier is a stable nuclide that is added to a sample to reduce the loss of the desired radionuclide by adsorption and other phenomena affecting trace quantities of materials undergoing physical and chemical processing steps. The desired radionuclide is "carried" through the various chemical steps of the purification process since both carrier nuclide and the desired radionuclide exhibit similar, if not identical, chemical behavior. In other words, there are two types of carriers: isotopic and non-isotopic.

The carrier usually is added in quantities of 5-100 milligrams. By comparison of typical carrier-radionuclide weight ratios, it becomes evident that the carrier is present in tremendous excess over the radionuclide.

1. Isotopic carriers

In isotopic carrying of a radionuclide, the carrier is a stable isotope of the element of interest.

Examples:

a. Addition of stable barium to carry radioactive barium.

b. Addition of stable strontium to carry radioactive strontium.

2. Non-isotopic carriers

Non-isotopic carrying, on the other hand, means that the carrier is a stable isotope of an element different from the radioactive element which is being sought.

Examples:

a. Addition of stable lanthanum to carry radioactive uranium, plutonium, or neptunium.

b. Addition of stable cerium to carry radioactive promethium.

Physics

I. INTRODUCTION

The purpose of this section is to review certain fundamentals of physics essential to radiological health work.

II. BASIS OF NUCLEAR ENERGY

A. In an ordinary chemical reaction, energy is released through rearrangement of molecular bonds.

B. In reactions involving the nuclei of atoms, matter itself may be converted into energy.

1. A basic law of physics states that matter and energy are conserved. If matter disappears, an equivalent amount of energy must be yielded. And conversely, energy may be transformed into its mass equivalent.

2. Mathematically, this relationship is expressed by Einstein's famous equation:

$$E = mc^2$$

where, E = energy

m = mass

c = speed of light

3. To understand such an equation, however, the radiological health worker must be familiar with certain units and concepts.

III. UNITS OF NUCLEAR ENERGY

A. The Erg

1. One of the more common forms of energy is that resulting from the motion of a body. This form, known as kinetic energy, may be calculated using the equation:

$$E = \frac{1}{2} mv^2$$

where, v = velocity of the body, and

m = mass of the body

2. Thus a one gram mass, having a velocity of 10 cm/sec, would have a kinetic energy of:

$$E = (\tfrac{1}{2})(1 \text{ gm})(10 \text{ cm/sec})^2$$

$$= 50 \text{ gm-cm}^2/\text{sec}^2$$

3. The unit $\left(\frac{\text{gm-cm}^2}{\text{sec}^2}\right)$ is frequently encountered in physics and radiological health work. For purposes of brevity, it is commonly referred to as an erg, so that:

$$50 \ \frac{\text{gm-cm}^2}{\text{sec}^2} = 50 \text{ ergs}$$

B. The Electron Volt

1. A neutron or a proton has a mass of about one atomic mass unit (1 a.m.u.). In terms of grams, this is very small since:

$$1 \text{ a.m.u.} = {}^{*}1.66 \times 10^{-24} \text{ gm}$$

2. Thus even a fast moving proton or neutron would not posse[illegible] energy. For example, the fastest ve[illegible] known to man is that of light, which is:

$$c = {}^{*}3 \times 10^{10} \text{ cm/sec}$$

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*These are approximate values and are used for most calculations. More precise values are known.

A particle of 1 a.m.u. moving with a velocity one tenth that of light would have a kinetic energy of:

$$E = \frac{1}{2} mv^2$$

$$E = (\tfrac{1}{2})(1.66 \times 10^{-24} \text{ gms}) \times (3 \times 10^{9} \text{ cm/sec})^2$$

$$= (\tfrac{1}{2})(1.66 \times 10^{-24} \text{ gms}) \times (9 \times 10^{18} \text{ cm}^2/\text{sec}^2)$$

$$= 7.47 \times 10^{-6} \text{ ergs}$$

3. Obviously for atomic particles a much smaller unit of energy is needed. The unit commonly employed is the electron volt (eV). This is the energy which a single electron acquires in moving across an electric potential difference of one volt.

To gain a concept of the magnitude of the electron volt, it might be pointed out that one million electron volts (MeV) are only enough energy to lift a milligram weight one millionth of a centimeter.

The relationship of the electron volt and erg is as follows:

$$1 \text{ eV} = {}^{*}1.6 \times 10^{-12} \text{ ergs}$$

or

$$1 \text{ MeV} = {}^{*}1.6 \times 10^{-6} \text{ ergs}$$

4. Thus the energy of 1 a.m.u. moving at one tenth the velocity of light may now be expressed as:

$$E = 7.47 \times 10^{-6} \text{ ergs}$$

$$= (7.47 \times 10^{-6} \text{ ergs}) \left(\frac{1 \text{ eV}}{1.6 \times 10^{-12} \text{ ergs}}\right)$$

$$= 4.67 \times 10^{6} \text{ eV}$$

$$= 4.67 \text{ MeV}$$

*These are approximate values and are used for most calculations. More precise values are known.

IV. MASS AND ENERGY EQUIVALENCE

A. Referring once again to Einstein's equation, certain mass energy relationships may be calculated. For example, if one a.m.u. of matter is converted into energy there will result:

$$E = mc^2$$

$$= (1.66 \times 10^{-24} \text{ gm})(3 \times 10^{10} \text{ cm/sec})^2$$

$$= 14.94 \times 10^{-4} \; \frac{\text{gm-cm}^2}{\text{sec}^2}$$

$$= 1.49 \times 10^{-3} \text{ ergs}$$

$$= (1.49 \times 10^{-3} \text{ ergs}) \left(\frac{1 \text{ MeV}}{1.6 \times 10^{-6} \text{ ergs}}\right)$$

$$= 931 \text{ MeV}$$

B. Therefore, if one a.m.u. could be completely transformed into energy, 931 MeV would result. This important relationship is depicted in Figure 6.

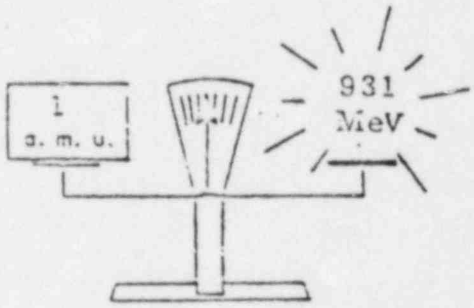

Figure 6.-Mass - Energy Equivalence

V. RADIATION

Radiation is often described as energy in transit. The transmission of energy by moving particles that can give up their kinetic energy upon collision with stationary targets is easily visualized. Less obvious, but equally important, is the transfer of energy by wave motions.

A. Waves (in general)

Waves are characterized by certain properties:

1. FREQUENCY

One property of a wave is its frequency or number of vibrations per second, usually denoted by the Greek letter ν (nu).

2. VELOCITY

When a wave is propagated, there will be a velocity, v, associated with the wave motion.

3. WAVELENGTH

If the velocity propagation is v and its frequency is ν, at the end of time, t, there will be νt waves spread over a distance vt in space. The distance occupied by one wave is the wavelength, usually denoted by the Greek letter λ (lambda) where:

$$\lambda = v/\nu$$

4. INTERACTION WITH MATTER

All wave motions exhibit certain phenomena when they move from one medium to another having different characteristics. Such phenomena include reflection (scattering) and refraction (bending).

B. Electromagnetic Waves

Certain waves consist of oscillating electric and magnetic fields. These, collectively known as electromagnetic waves or radiations, include radio and microwaves, infrared, ultra-violet, X- and gamma rays.

1. THE ELECTROMAGNETIC SPECTRUM

The known electromagnetic radiations have been categorized according to frequency and wavelength into what is known as the electromagnetic spectrum. (See Table 1.)

Electromagnetic radiation moves, in general, with a velocity equal to that of light (c). Since, as shown earlier,

$$\lambda = v/\nu$$

then for electromagnetic radiations,

$$\lambda = c/\nu$$

accordingly there is an inverse relationship between frequency and wavelength. Thus, in Table 1, as the frequency increases, the wavelength becomes smaller and vice versa.

Table 1.--THE ELECTROMAGNETIC SPECTRUM

Type of radiation	Frequency range (per second)	Wavelength* range (cm)
Electric Waves	0 - 1.0×10^{4}	∞ - 3.0×10^{6}
Radio Waves	1.0×10^{4} - 1.0×10^{11}	3.0×10^{6} - 3.0×10^{-1}
Micro Waves	3.0×10^{8} - 3.0×10^{13}	1.0×10^{2} - 1.0×10^{-3}
Infrared	1.0×10^{11} - 4.0×10^{14}	3.0×10^{-1} - 7.6×10^{-5}
Visible	4.0×10^{14} - 7.5×10^{14}	7.6×10^{-5} - 4.0×10^{-5}
Ultraviolet	7.5×10^{14} - 3.0×10^{18}	4.0×10^{-5} - 1.0×10^{-8}
X-rays	3.0×10^{15} - 3.0×10^{20}	1.0×10^{-6} - 1.0×10^{-13}
Gamma Rays	3.0×10^{16} - 3.0×10^{22}	1.0 x 10[illegible] - 1.0×10^{-12}
Cosmic Rays	3.0×10^{22} -	1.0×10^{-12} -

*Commonly expressed in Angstrom (Å) units: 1 cm = 10^{8} Å.

C. Wave - Particle Duality

1. Certain phenomena such as reflection and refraction, undergone by fast moving particles are best explained by applying to them wavelike properties.

2. In like fashion, certain properties of electromagnetic waves or radiations are most easily understood if waves are assumed to act as particles.

3. This is known as wave - particle duality.

D. Energy of Electromagnetic Radiations

Electromagnetic radiations possess energy much the same as fast moving particles.

1. If such radiations are pictured not as a smooth continuous flow but as a series of discrete packages or bundles, the nature of their energy becomes more apparent.

2. The energy in each such bundle or package (which is known as a photon or quantum) is directly related to the frequency of the wave and is given by the equation:

$$E = h\nu$$

where E = energy in ergs

ν = frequency in waves per second

h = Planck's constant or 6.6×10^{-27} erg sec

For example, X-rays having a frequency of 10^{18} per second and hence a wavelength of

$$\frac{3 \times 10^{10} \text{ cm/sec}}{10^{18} \text{ / sec}} = 3 \times 10^{-8} \text{ cm}$$

have an energy of

$$E = h\nu$$

$$= (6.6 \times 10^{-27} \text{ erg sec}) \times (10^{18} \text{ /sec})$$

$$= 6.6 \times 10^{-9} \text{ ergs}$$

$$= (6.6 \times 10^{-9} \text{ ergs}) \times \left(\frac{1 \text{ eV}}{1.6 \times 10^{-12} \text{ ergs}}\right)$$

$$= 4.13 \times 10^{3} \text{ eV}$$

$$= 4.13 \text{ keV}$$

where, 1 keV = 1000 eV

I. INTRODUCTION

The purpose of this section is to review some of the fundamentals of biology which are essential in radiological health work.

II. THE STRUCTURE AND FUNCTION OF BIOLOGICAL CELLS

A. Elements of Cells Structure

Individual living cells are the building blocks of which man and his living environment are composed. A typical cell is composed of protoplasm—a mixture of carbohydrates, lipids, proteins, nucleic acids, inorganic salts, gases, and about 80% water. The cell may be subdivided into cytoplasm, a nucleus, and a cell membrane as shown in Figure 7.

The jelly-like cytoplasm suspends the nucleus and is incased within the cell membrane. This membrane serves as a selective filter mechanism which allows food, salts, oxygen, and water to pass into the cytoplasm and permits waste products to migrate from the cell without loss of vital cell components. The cytoplasm usually contains fat droplets, vacuoles filled with either granular or fluid material, secretion granules, minute rods or threads called chondriosomes, and small bodies or networks called Golgi bodies. Contents of the oval or spherical cell nucleus are separated from the cytoplasm by a nuclear membrane. The nucleus acts as the control center of cellular activity; its chromatin thread component is vital to cellular division. Chromatin contains the genetic materials, called genes, which are the fundamental units of heredity. A cell deprived of its nucleus is incapable of undergoing division and lives only a limited period of time. An isolated nucleus is not able to form new cytoplasm to surround it.

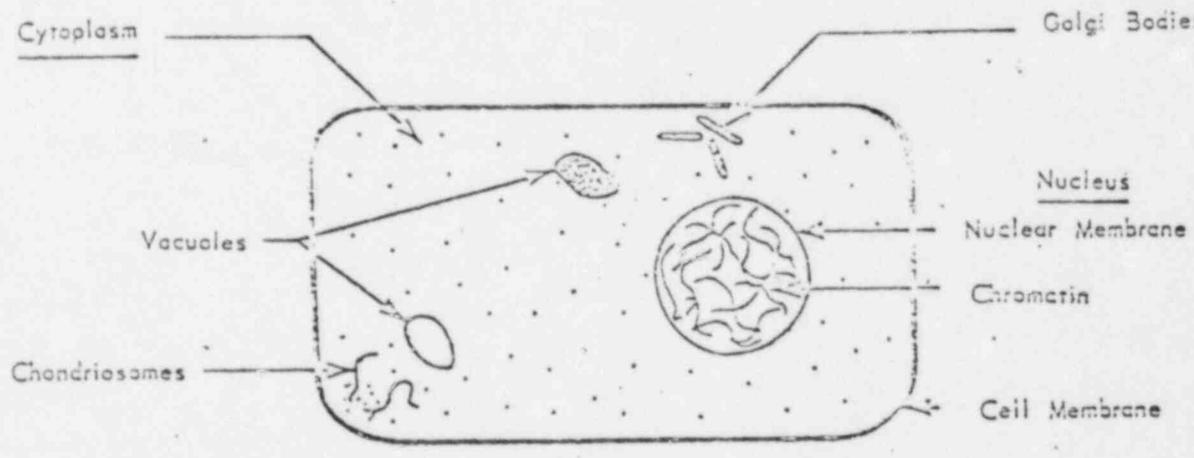

Figure 7.-Structure of Typical Cell
(Showing some of the principal components)

B. Cellular Activities

Dynamic changes are constantly taking place in living cells. Because of their characteristics these changes may be arranged in three classes.

1. METABOLISM

Metabolism is the term applied to the chemical transformation and use of materials for growth, maintenance, repair, and yielding of energy. Metabolism is essentially the sum of two major processes, anabolism and catabolism, which are constantly taking place in cells. Anabolism includes the transport of non-living material into the cell through the cell membrane and the synthesis of living protoplasm from it. On the other hand, catabolism refers to the processes by which cells tear apart some of their own protoplasm and other substances which have been stored within the cell in order to obtain energy for continued life. Catabolic disintegration yields simpler substances which are excreted through the membrane and may be used by other nearby cells for their anabolic processes.

2. IRRITABILITY

Irritability is the response which a cell exhibits following stimuli from its environment. Any change in the heat, light, moisture, pressure, chemical, or contact environment of a cell will usually result in a response such as cell movement, increased or decreased growth, secretion, etc. External stimuli may cause the cell to show increased activity or to become inhibited in normal activities.

3. REPRODUCTION

Reproduction is the ability of a cell to produce new cells which are like the parent cell. Cells usually reproduce by cell division--a process known as mitosis. In the early stages of cell division nuclear chromatin undergoes accumulation, shortening, and thickening to form orderly structures known as chromosomes. These chromosomes divide lengthwise, and in the final stages of cell division the two daughter cells each receive identical sets of chromosomes which are stored within their new nuclei in the form of chromatin.

III. THE ANATOMY AND PHYSIOLOGY OF HIGHER ORGANISMS

Simple organisms, such as the amoeba and paramecium, are single cells which perform a large spectrum of physiological processes necessary to continued existence. However, highly developed organisms such as man, trees, and other types of animal and plant life can only continue living by the co-ordinated efforts of many types of specialized cells of which the specific organism is composed. Specialized cells group together to form certain types of tissues, and several types of tissues may group together in an orderly fashion to form organs. Organs work together to establish specialized functional systems in the organism.

In the field of radiological health our primary concern is the effect of ionizing radiations upon the various tissues and organ systmes of the human body; we have less interest in radiological hazards to simple organisms, plants, or other mammals found in the human environment. It should, however, be realized that in the study of the fate of airborne and waterborne radionuclides these secondary organisms are of great importance from the standpoint of transferring radioactive materials to human populations through normal food chain mechanisms. The following discussion will be mainly concerned with the anatomy (or structure) and physiology (or biochemical functioning) of the human body.

A. Types of Tissues Found in the Human Body

The specialized cells of the highly developed human body may be incorporated into four specific types of tissues according to their structure and [illegible] physiology of cells from one type of tissue may be

entirely different from those [illegible] cells located in another part of the body. The four tissues are as follows:

1. CONNECTIVE TISSUES

These tissues connect and support other tissues of the body, and they usually have an abundant blood supply. Connective tissue may be subdivided into connective tissue proper, the blood cells, cartilage, and bone tissue.

Connective tissue proper is made up of collagen, fat, elastic, and fibrous tissues. It is the framework, cushion, support and/or joiner for nerves, blood vessels, lymph vessels, skin, lungs, heart, kidneys, vertebrae, and other organs, and has ion-exchange functions. An important component is the ground substance, or matrix. This is the primary connective, supportive and exchange part of the connective tissue. Without it, other components (and tissue cells) would collapse.

Blood is one of the most important liquid tissues from the standpoint of radiobiology. Blood consists of many white blood cells, red blood cells, and platelets which are suspended in an intercellular liquid called plasma. The function of blood is to transport food and waste substances and to fight invasive disease-causing organisms. The red blood cells, which are also called erythrocytes, contain an iron-protein material, hemoglobin, that readily combines with oxygen in the lungs. These cells are transported from the lungs to the various body tissues and release oxygen to the tissue cells for energy utilization purposes. The white blood cells, which are commonly called leucocytes, are capable of diffusing through capillary walls into surrounding tissues in order to engulf and destroy bacteria or other foreign materials. The platelets, which are known also as thrombocytes, are small disc-shaped bodies which cause blood to clot when exposed to air. Blood plasma is composed of about 90% water and 10% solids, and one of the most important solids is a protein material called gamma [illegible], gamma globulin [illegible] of the [illegible] plasma [illegible] whose function is primarily that of [illegible] disease.

Cartilage tissue is a firm, tough, and [illegible] material which covers the ends of bones in joints and forms part of the chest framework, larynx (voicebox), and external ear. Cartilage is very rarely supplied with blood vessels.

Bone tissue (also called osseous tissue) is made of living cells which are surrounded by an intercellular substance, and consists of mineral and organic fractions. The mineral fraction is composed largely of phosphate, carbonate, fluoride, hydroxide and citrate salts of calcium, while the organic fraction is composed largely of collagen in a gel of cement substance. In addition, bone tissue may be classified either as compact or spongy—the major difference being in the degree of porosity. The hollow centers of bones contain yellow marrow and red marrow. The former is ordinary bone marrow of the kind in which fat cells predominate. The latter plays an important role in hematopoiesis, the production of red blood cells and white blood cells.

2. MUSCULAR TISSUES

Muscular tissues, which are 40 to 50 percent of the total body weight, may be classified according to their morphological (or structural) differences. The types are: striated or skeletal muscle, cardiac or heart muscle, and smooth or visceral muscle. Striated muscle is sometimes called skeletal muscle since all of the large muscles acting upon the skeleton to produce movement of the joints are of this type. Cardiac muscle is so named because it is found in the heart. Smooth muscle is also known as visceral or plain muscle. It is found in layers in the walls of visceral organs such as the digestive tract, respiratory passages, urinary tract, and is responsible for much of their movement.

3. NERVE TISSUES

Nerve tissues are made of unique cells, called neurons, whose cellular protoplasm

may be extended to a distance of 2 to 4 feet. These extremely long cells have the purpose of conducting minute electrical impulses from certain sensory organs to nerve centers and from the central nervous system to muscular and secretory tissue. If nerve tissue is damaged it is almost certain that repair will not take place. Nerve fibers may or may not be surrounded by an insulating layer called the myelin sheath.

4. EPITHELIAL TISSUES

Epithelial tissues are tissues which cover the body or line body cavities. Usually the cells which comprise this type of tissue are packed extremely close together with very little intercellular substance between them. These tissues have no blood vessels to transport food and wastes to and from their cells, but these exchanges are facilitated by lymph, a form of plasma, which travels to the cells through the intercellular substance. Epithelial tissue of the skin, mouth, nose, and anus protects the body with its multi-layered armor-like structure, while similar tissues secrete fluids to lubricate parts of the lungs, eyes, ears, and other tissues. Some very specialized epithelial tissues, which line the gastrointestinal tract, secrete enzyme fluids which aid in digestion.

B. Organ Systems of the Human Body

The various organs of the body normally are grouped together in co-ordinated organ systems according to specific functions performed. In many cases a certain organ may perform several functions and thus belong to several organ systems. There are 10 major functions which must be carried on in the body in order for life to continue; thus, there are 10 major organ systems which will be described.

1. THE INTEGUMENTARY SYSTEM

The integumentary system consists of the skin, body hair, nails, sebaceous glands, and sweat glands. It has the primary function of protecting the body from detrimental agents such as friction, bacteria, chemical agents, and heat and as a secondary function it retains vital body fluids. The sweat glands secrete perspiration which cools the body upon evaporation and thereby serves as a body temperature control mechanism.

2. THE MUSCULAR SYSTEM

The muscular system refers to the many muscles some of which, under the conscious control of the organism, provide locomotion and aid the organism in preserving itself. Skeletal muscle is often referred to as "voluntary muscle," in distinction to cardiac and smooth muscle, which are said to be "involuntary." This distinction arises from man's ability to exercise voluntary control over contraction of skeletal muscle and his lack of conscious control over the others.

3. THE DIGESTIVE SYSTEM

The digestive system converts food into forms that can be used by the body for energy and building purposes, and it excretes non-useful residues from the body. The mechanical portions of this process include grinding of food by the teeth, a mixing with digestive fluids by the muscular stomach, movement through long portions of the small intestine and large intestine, and temporary storage in sections of the large intestine until defecation. There are a number of accessory organs, such as the salivary glands, the liver, and the pancreas which manufacture chemical agents which promote digestion of carbohydrates, fats, and proteins.

4. THE CIRCULATORY SYSTEM

The circulatory system provides a transportation system throughout the body for blood containing digested food, oxygen, waste products, minerals, disease-fighting white blood cells, hormones, and other vital substances. A four-chambered heart pumps the blood through heavy-walled arteries which by successive branching are reduced in size to

single-walled vessels called capillaries. Tissue wastes are carried by the blood out of the capillaries to large heavier vessels called veins. Blood in the veins is eventually recirculated to the heart's pumping station, and then it is repumped through the body with renewed pressure. Important reservoirs of blood are the liver, lungs, spleen and skin. There is a detour system around this normal mode of circulation which is called the lymph system. Lymph, which is essentially blood plasma mixed with white blood cells, diffuses through the arterial capillary walls into the intercellular matrix which surrounds tissue cells. On its return, it enters the system of lymph capillaries, which join in larger lymph vessels that ultimately empty in specific large veins of the body. The lymph system is vitally concerned with the fighting of invading organisms or other foreign materials. Along the lymph capillaries are lymph nodes which filter out harmful materials and manufacture lymphocytes, a form of white blood cell that is concerned with the production of substances called antibodies which are a part of the body's defense against diseases caused by microorganisms.

5. THE RESPIRATORY SYSTEM

The respiratory system gleans vitally needed oxygen from the atmosphere and disposes of carbon dioxide, a major waste product from energy processes in the body. This system has gas exchange organs, called the lungs, which are moist membranous sacs. Air passages in the nose and mouth lead down an air pipe (the trachea) which forms two branches (called bronchi), that go to a right and left lung. Each bronchus is subdivided into smaller air passages called bronchioles, and these bronchioles finally terminate in many small membrane sacs called alveoli—the fundamental components of lung tissue. The gas exchange surface area of the two lungs' alveoli is about 100 times the skin surface area of the human body. Muscular expansion of the body's chest wall causes a reduced pressure between the inside of the wall and the outside of the lungs resulting in expansion of the lungs under the higher air pressure inside the alveoli. Coordinated with the thoracic cage enlargement of the inspiration phase of the breathing process is the downward movement of the diaphragm--a dome-shaped muscle between the chest cavity and the abdomen. When the muscular effort ceases, the expiratory position of the diaphragm and thoracic cage is resumed as the air passes out of the lungs.

6. THE EXCRETORY SYSTEM

The excretory system, whose function is that of removing dissolved solid wastes and water from the body, is composed principally of the kidneys, skin, and lungs.

a. Kidneys

The two kidneys filter the blood of metabolic breakdown products, excess salts, and water. These materials are then passed through two hollow tubes (called ureters) to a balloon-shaped storage organ, the bladder. When the bladder contracts, it sends this fluid, commonly called urine, through an exit tube called the urethra. Not only do the kidneys remove normal wastes as creatinine, urea, ammonia, hippuric acid, and purine bodies which would poison body tissues, but they have the ability to trap poisons such as heavy metals that may accidently enter the body. The seizure of an excessive quantity of heavy metals sometimes destroys the kidneys, and the body dies from a condition known as uremia.

b. Skin

Although the sweat glands in the skin serve as a means of excretion of water and some salts, the quantities involved are generally insignificant in comparison with losses in urine.

c. Lungs

The lungs function as an additional means of water loss in large quantities. However, this is not active excretion, but evaporation as an incidental result of the lung mechanism.

7. THE NERVOUS SYSTEM

The nervous system has the prime function of controlling and co-ordinating all muscular activities of the body and is also concerned with certain sensory and secretory processes. The general nervous system may be subdivided into two parts, namely, the central nervous system and the autonomic nervous system. The central nervous system, consisting of brain and the spinal cord, controls the voluntary muscular activities of the body and is concerned with the conscious and mental processes of the individual. The autonomic (or self-acting) nervous system includes certain parts of the brain and spinal cord which automatically operate the heart, the digestive organs, and other internal organs without conscious willful control by the organism itself.

8. THE ENDOCRINE SYSTEM

The endocrine system is composed of a number of ductless glands which release hormone secretions directly into tissue fluids and the bloodstream instead of secreting substances on the body surface or into a cavity as do the exocrine (or duct) glands. These hormones are vitally important in growth, metabolism, sexual activity, and mineral and water balance in the body. To a great extent, all the endocrine glands are controlled by the secretions from a small "master gland," the pituitary, which is located on the underside of the brain. The thyroid gland, which is located in the throat area, controls metabolic rate and normal growth and development in young organisms by supplying a substance rich in iodine called thyroxine. The parathyroids, four small glands located on the thyroid's surface, play an important part in the maintenance of a normal calcium level in the blood and the irritability of the nervous system and muscles. Above the upper end of each kidney is located an adrenal gland which secretes epinephrine (commonly called adrenalin) and cortin. The former hormone is released in emergencies and causes the heart to beat faster and increases the blood supply to the muscles, nervous system, and heart. Cortin, a complex of hormones, contributes to the regulation of normal muscular and skeletal development, provides regulatory actions upon metabolic transformations in the body and upon the balance of electrolytes and water in the body.

9. THE REPRODUCTIVE SYSTEM

The reproductive system has the function of producing reproductive cells which, when properly combined, develop into new organisms. The female reproductive system has two ovaries which produce ova or eggs, while the male reproductive system has two testes that manufacture the male reproductive cells called spermatozoa or simply sperm. When a sperm cell is deposited in the uterus of the female genital tract and becomes attached to an ovum, fertilization occurs and the two combined single cells develop into a simple new organism called the embryo. After two months of complex embryonic development the organism is then referred to as a fetus. Formation continues for seven more months, and then the completely developed child is expelled from the female's uterus by the contractions of uterine and abdominal muscles.

10. SKELETAL SYSTEM

The skeletal system provides physical support and protection for the body, and it serves as a surface for the attachment of muscles concerned primarily with locomotion. A total of 206 bones make up this system in the adult human and they normally are slightly over 14% of the total body weight (including marrow). Bones of the cranium protect the delicate brain, while the vertebrae of the spinal column serve as armor for the spinal cord. The largest bone of the system, the femur or thighbone, is extremely important in locomotive and supportive capacities, while the pelvic bones act somewhat as a basin to hold the gastrointestinal, reproductive, and other internal organs.

2r

Glossary

The following is a brief list of definitions of the fundamental units and terms used in radiological health.

I. THE ATOM

The atom is the smallest unit of elemental matter capable of entering into a chemical reaction.

A. Constituents of the Atom

Proton - one of the three basic components of the atom. The proton has a mass number of one and is positively charged.

Electron - one of the three basic components of the atom. The electron is negatively charged and has a mass approximately 1/2000 of the proton.

Neutron - one of the three basic components of the atom. The neutron has a mass number of one and is electrically neutral.

Nucleon - a collective term used to refer to constituents of the nucleus of the atom. Protons and neutrons are nucleons.

B. Classification of Atoms

Element - any kind of a limited number (approximately 100) of distinct varieties of atoms. Atoms of the same element all have the same number of protons in their nuclei.

Isotopes - atoms having the same number of protons (that is, all representing the same element) but having different numbers of neutrons. For example, ^{88}Sr, ^{89}Sr, and ^{90}Sr are all isotopes of the element strontium.

Nuclide - a collective term used to refer to the isotopes of all the elements. For example, ^{90}Sr, ^{14}Na, ^{32}P, and ^{106}Ru are radioactive nuclides.

II. RADIATIONS FROM ATOMS

A. Types of Radiation

Alpha - the alpha particle is a fast moving package consisting of two protons and two neutrons (identical to the nucleus of the helium atom) propelled as a single entity from the nucleus of a radioactive atom. An atom emitting an alpha particle is said to have disintegrated or decayed.

Beta - a charged particle emitted from the nucleus of an atom and having a mass and charge equal in magnitude to those of the electron. An atom emitting a beta particle is also said to have decayed.

Gamma - electromagnetic radiation emitted from an atomic nucleus, differing from visible light only in wavelength (or energy). Gamma radiation may or may not accompany the emission of an alpha or beta particle.

B. Units of Measurement

Curie - a unit of activity defined as the activity of a quantity of any radioactive nuclide in which the number of disintegrations per second is 3.7×10^{10}; symbol, Ci.

Millicurie - one thousandth of a curie; symbol, mCi.

Microcurie - one millionth of a curie; symbol, μCi.

Half-life - the time required for one-half of a given number of radioactive atoms to undergo decay; symbol, $T_{\frac{1}{2}}$.

III. RADIATION EXPOSURE

A. Types of Exposure

Internal - radiation exposure originating from a source within the body.

External - radiation exposure originating from a source outside the body.

B. Units of Measurement

Roentgen (R) - unit of exposure used in evaluating X- and gamma radiation. Defined as the quantity of X- or gamma radiation that will produce one electrostatic unit (esu) of charge, either negative or positive, in one cubic centimeter of air at standard temperature and pressure.

Rad (Radiation Absorbed Dose) - unit of absorbed dose; measure of the energy absorbed in any material due to radiation exposure.

Rem (Roentgen Equivalent Man) - unit of biological dose; relates the effectiveness of the different types of radiation in producing biological damage to the quantity of absorbed dose.

GPO 828-883

Acute Clinical Effects of Penetrating Radiation**

RANGE		0 —— 100r SUBCLINICAL RANGE	100 —— 1,000r THERAPEUTIC RANGE			1,000 —— ∞ r LETHAL RANGE	
		0 —— 100r	100 —— 200r	200 – 600r	600-1,000r	1,000-5,000r	5,000-∞ r
			CLINICAL SURVEILLANCE	THERAPY EFFECTIVE	THERAPY PROMISING	THERAPY PALLIATIVE	
INITIAL REACTION	INCIDENCE OF VOMITING	0%	100r 5% 200r 50%	300r 100%	100%	100%	
	DELAY TIME		3 HOURS	2 HOURS	1 HOUR	30 MINUTES	
LEADING ORGAN			HEMATOPOIETIC TISSUE			GI TRACT	CNS
CHARACTERISTIC SIGNS			MODERATE LEUKOPENIA	SEVERE LEUKOPENIA PURPURA HEMORRHAGE INFECTION		DIARRHEA FEVER DISTURBANCE OF ELECTROLYTE BALANCE	CONVULSION TREMOR ATAXIA LETHARGY
RITICAL PERIOD POSTEXPOSURE				4-6 WEEKS		5-14 DAYS	1-48 HOURS
THERAPY		REASSURANCE	REASSURANCE HEMATOLOGIC SURVEILLANCE	BLOOD TRANSFUSION ANTIBIOTICS	BONE MARROW TRANSPLANTATION	MAINTENANCE OF ELECTROLYTE BALANCE	SEDATIVES
PROGNOSIS			EXCELLENT	GOOD	GUARDED	HOPELESS	
CAUSE OF DEATH				HEMORRHAGE INFECTION		CIRCULATORY COLLAPSE	RESPIRATORY FAILURE BRAIN EDEMA
TIME OF DEATH WITHIN				TWO MONTHS		TWO WEEKS	TWO DAYS
HUMAN DATA PRESENTLY AVAILABLE		NUMEROUS	200	40	4	1	1

*This mimeo supersedes M 90-330-400-1, 112.
**Reproduced for instructional purposes from "Acute Radiation Syndrome and Civil Defense" (unpublished paper, School of Aviation Medicine, Brooks Air Force Base, Texas), by Herbert [illegible]. Gerstner, M.D. Written consent of author has been obtained.

ACUTE CLINICAL RESPONSE TO WHOLE BODY EXPOSURE TO IONIZING RADIATION

RESPONSE ↓ / DOSE →	0-100 rad	100-200 rad	200-600 rad (200 → 1000 rad)	600-1000 rad	1000-5000 rad	>5000 rad
1. Syndrome	None	None	Hematopoietic		Gastrointestinal	Central nervous system
a. Prodromal Phase	None	0-50% Vomit >3 hrs after irradiation	50-100% Vomit <3 hrs after irradiation	100% Vomit <3 hrs after irradiation	100% severe vomiting and diarrhea <1 hr after irradiation	<1 hr prodromal and CNS symptoms together
b. Latent Phase	N/A	>2 weeks	1-2 weeks	<1 week	<2 days	None
c. Symptomatic Phase	Few persons mild anemia near 100 rad	mild fatigue moderate leukopenia	Fatigue, general anemia, moderate hemorrage, susceptibility to infection	Severe effects of anemia, infection, hemorrhage, moderate GI symptoms	Severe GI symptoms fever, bloody diarrhea	Fever, ataxia, convulsions, coma
d. Recovery or death	N/A	N/A	~50% recovery in 3-4 months ~50% death in 6-8 weeks	<10% recovery in 4-6 months >90% death in 4-6 weeks	100% death <2 weeks	100% death hours-2 days
2. Cause of death	N/A	N/A	Combined effects of anemia, infection, blood & fluid loss		Severe GI damage, loss of fluid, circulatory collapse	Respiratory failure, brain edema
3. Treatment	None	Rest, light supportive care as needed	Fluids, Blood, Rest, antibiotics (as needed), minimize exposure to disease, general supportive care, (THERE IS NO SPECIFIC TREATMENT)		Supportive care, fluids, rest	Rest, sedatives

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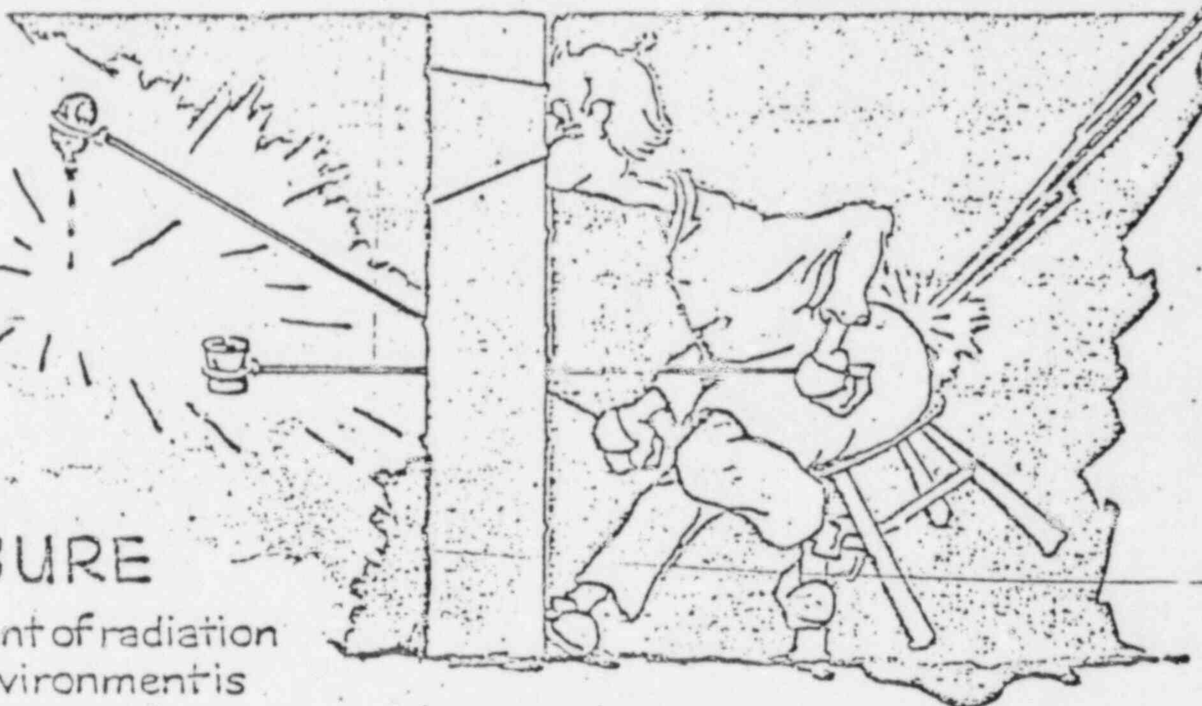
YOU ARE ALWAYS BEING EXPOSED TO RADIATION



EXPOSURE

The amount of radiation in your environment is easily measured as

Roentgens

R

of exposure

DOSE

Whatever your exposure, the amount actually absorbed in your body is calculated as the

Rad

radiation absorbed dose

ALLOWANCE

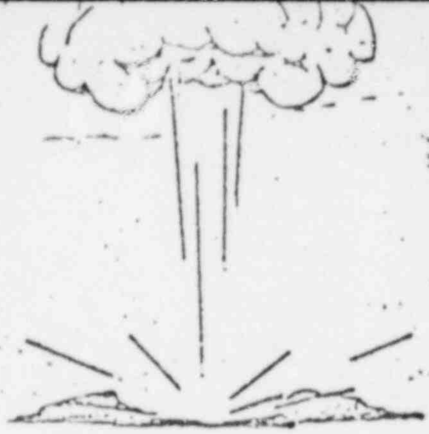
Because you, a mouse, a fruit fly and the kitchen sink are different in size, shape, material and susceptibility to different kinds of radiation, many "averages" are combined to estimate your dose in

Rem

radiation equivalent man

R IS A FACT; **Rad** IS A CALCULATION; **Rem** IS A STATISTICAL ESTIMATE.

THE LEVELS OF RADIATION



10^{6}	MEGA ROENTGEN "MR" MEGA CURIE "MCi"	DISASTER LEVEL
10^{3}	KILO ROENTGEN "KR" KILO CURIE "KCi"	RADIOTHERAPY LEVEL

THE ROENTGEN PRODUCES ONE ELECTROSTATIC UNIT IN 1cc OF AIR

THE CURIE PRODUCES 3.7×10^{10} DISINTEGRATIONS PER SECOND

10^{-3}	milli ROENTGEN "mR" milli CURIE "mCi"	THERAPY NUCLEAR MEDICINE LEVELS
10^{-6}	micro ROENTGEN "μR" micro CURIE "μCi"	DIAGNOSIS
10^{-9}	nano ROENTGEN "nR" nano CURIE "nCi"	TRACER LEVELS
10^{-12}	pico ROENTGEN "pR" pico CURIE "pCi"	LOW LEVEL INVESTIGATIONS
10^{-15}	FEMTO -	BACKGROUND LEVELS
10^{-18}	ATTO -	

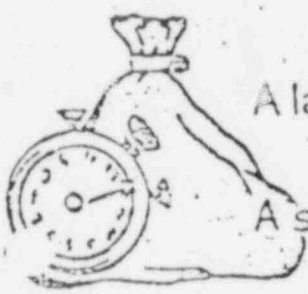
EXPOSURE and CONTAMINATION

Practically everything is radioactive

OVEREXPOSURE = "Too much for too long"

CONTAMINATION = An undesirable accumulation in the wrong place. at the wrong time."

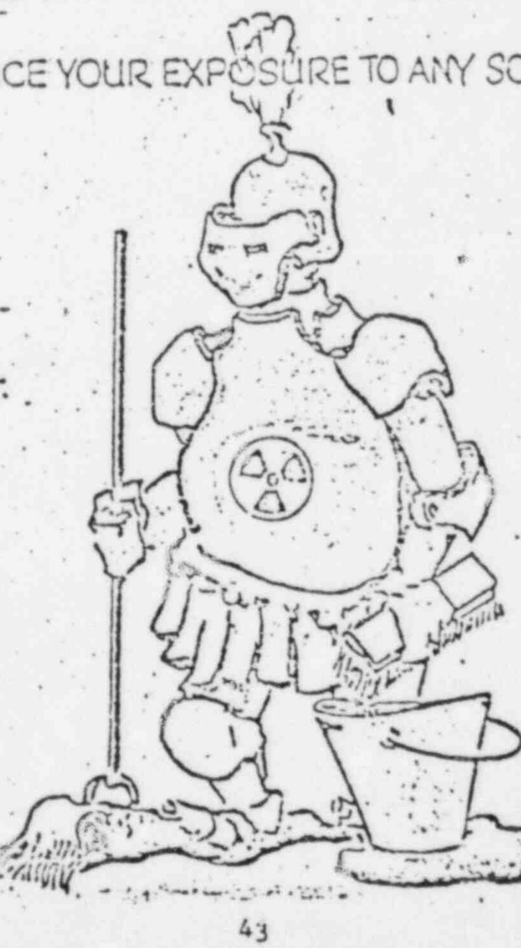
PROTECTION FROM "TOO MUCH" RADIATION ALWAYS INVOLVES BOTH DOSE AND TIME



A large amount for A short time } is just as safe (or dangerous) as { A small amount for A long time

YOU CAN EASILY REDUCE YOUR EXPOSURE TO ANY SOURCE OF CONTAMINATION

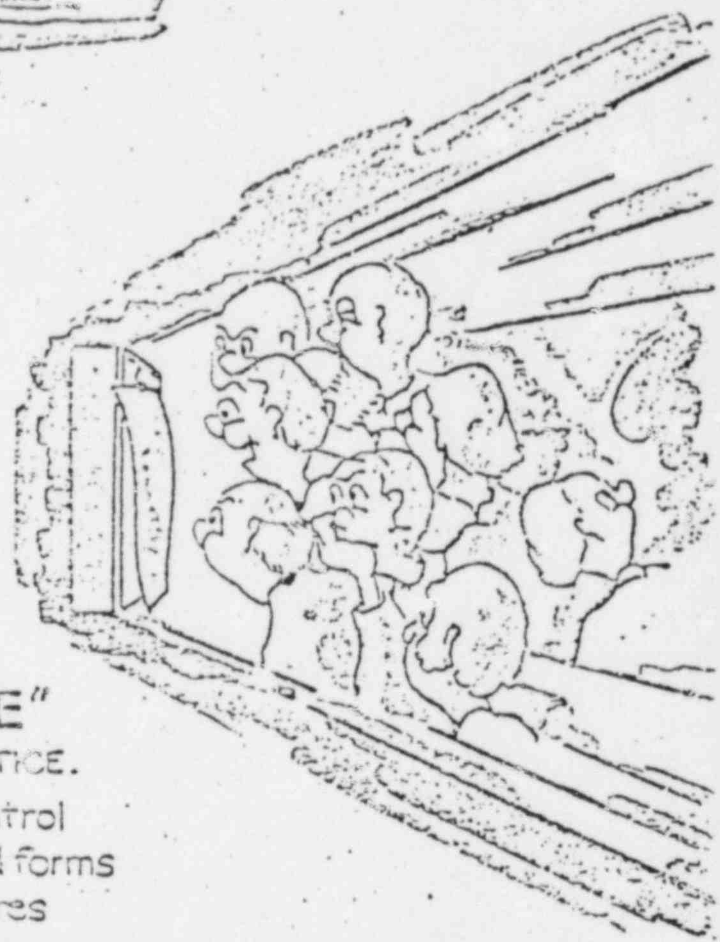
1. GET AWAY FROM IT! Distance is good protection.
2. SHIELD YOURSELF! 1 millimeter of lead is as good as 70 feet of air.
3. DISPERSE SMALL AMOUNTS! Increase the average distance between you and the source.
4. CONFINE LARGE AMOUNTS! and then put them behind lead.



Heavy Contamination is a health physics problem, but the light contamination common in nuclear medicine is easily controlled with GOOD HOUSEKEEPING.

CERTAIN RECORDS ARE REQUIRED BY LAW

OTHERS ARE REQUIRED BY GOOD PRACTICE



YOU MUST RECORD

THE RECEIPT, STORAGE, TRANSFER AND DISPOSAL OF ALL RADIOACTIVE MATERIALS.

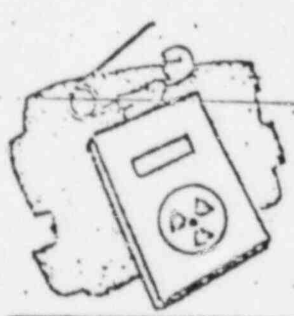
The technician must keep a daily log of all diagnostic materials received; but, in addition, every therapy dose must be traceable from manufacturer's lot number to each patient's name.

THE HOSPITAL'S "RADIOISOTOPE COMMITTEE"

SETS THE STANDARDS OF GOOD PRACTICE.

- Assay, Survey, and Monitoring control
- Equipment maintenance, and record forms
- Diagnostic and therapeutic procedures
- Personnel qualifications and training
- Emergency and housekeeping procedures

A RADIATION SAFETY OFFICER IS REQUIRED ON EACH COMMITTEE



FILM BADGES ARE REQUIRED ON ALL WORKERS

Each employee's exposure record must be available to him. For any employee who thinks he might be exposed, the best public relations and legal protection is to put him on a 6-month trial film badge control and prove or disprove his exposure.

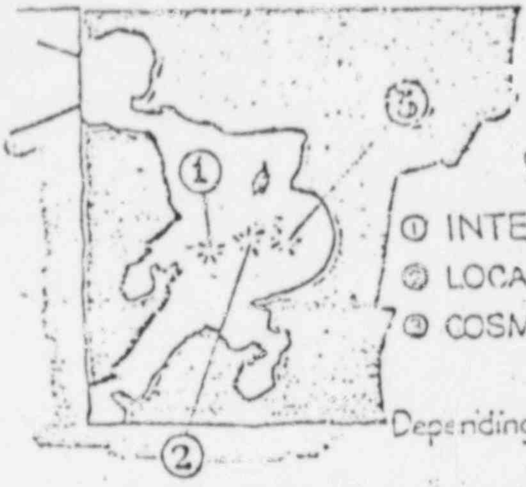
THE PHYSICIAN'S DECISIONS, DOSES, PROCEDURES, ARE **NOT** DICTATED BY LAW

BUT

IT IS UNLAWFUL TO USE OR POSSESS RADIOACTIVE DRUGS WITHOUT A LICENSE.

A GUIDE TO RADIATION PROTECTION FROM

THE OLD MAXIMUM PERMISSIBLE DOSE CONCEPT



Radiation can damage human tissue-but... the human body is designed to repair itself from a normal level of minor damage.

Every body absorbs about: . .

① INTERNAL RADIATION (mostly K-40)........20 m Rad/year
② LOCAL GAMMA RAYS (radium in earth).......50 m Rad/year
③ COSMIC RAYS..............................30 m Rad/year
100 m Rad/year

Depending on where you live, it may be 10 times higher than this average.

BUT... Different kinds of radiation (α, β, γ) cause different amounts of damage.

Red marrow and gonads are more sensitive than hands and feet.

Therefore, we must use the "Rem" average unit.

AND... We need a continuous running record of each individual worker to know that his work habits do not cause too much exposure.

Therefore, every worker wears a film badge.

BUT HOW MUCH EXPOSURE IS TOO MUCH EXPOSURE?

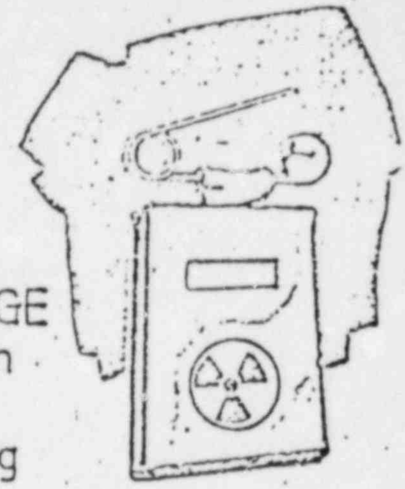
A very conservative international commission of very experienced physicians and very worried physicists were willing to gamble their lives and reputations that nobody would be hurt below a certain level of exposure.

THIS LEVEL WAS CALLED
THE MAXIMUM PERMISSIBLE DOSE

3 Rem/13-week quarter...
for a lifetime... but never more than
5 Rem/year in any one year... but call
anything over
25 Rem/once in a lifetime...
an accidental overexposure.

THIS IS ONLY A PRUDENT GUIDE TO A LIFETIME OF OCCUPATIONAL EXPOSURE.
DON'T APPLY IT TO DIAGNOSTIC EXPOSURES.
DON'T PLAY NUMBERS GAMES WITH MINUTES, HOURS, OR DAYS.
AND DON'T MAKE A FEDERAL CASE OUT OF IT.

AN ASAFETIDA BAG
around your neck
may protect you
from evil spirits . . .



. . . but your FILM BADGE
will only tell when
you are getting
sloppy in working
with radiation

Post one film
badge in the
best possible
place
. . . your office

Even if you
work with all
the patients
you can handle

Post one film
badge in the
worst possible
place
. . . the Hot Room

Your film badge should read only a fraction of the MAXIMUM PERMISSIBLE DOSE

An example – from a busy laboratory for one quarter

In the office	On the technicians	In the Hot Room
20mRem	160 mRem 110 mRem	1,150 mRem

BUT DON'T CHEW YOUR NAILS IF YOUR READING IS HIGH

1. Use a direct reading personal dosimeter to find out where it's coming from.
2. CALL HEALTH PHYSICS CONSULTATION TO FIND OUT WHY.
3. ...and then change your work habits.

IT IS ALMOST IMPOSSIBLE FOR A WELL-TRAINED TECHNICIAN
TO BE OVEREXPOSED IN A WELL-RUN NUCLEAR MEDICINE LABORATORY.

RADIATION PROTECTION INSTRUMENTS

IN THE NUCLEAR MEDICINE LAB

PEOPLE PROTECTION

How much last quarter?

FILM BADGES

A required administrative record of each worker's exposure

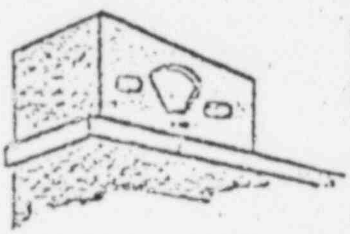
How much now?

POCKET DOSIMETER

A necessary operational tool to detect overexposure

REQUIRED

LABORATORY PROTECTION



Is there contamination?

LABORATORY MONITOR

A desirable continuous laboratory control

Where is it?

SURVEY METER

A required operational tool to find contamination

ESSENTIAL

BACKGROUND CONTROL

is there a buildup?

DAILY LOG OF BACKGROUND

A constant background means:
The instrument is in working order (probably).
You are in working order (possibly).
The laboratory is radiologically clean.

How much?

WIPE TEST

A steady buildup calls for Health Physics Consultation

UNAVOIDABLE

An ACCIDENT has occurred when somebody might have been inadvertently exposed to more than 25R in a short period of time.

An INCIDENT has occurred when somebody might have been inadvertently exposed to more than 3R per 13-week per quarter.

FIRST DUTY	CONFINE THE HAZARD	PROTECT THE WORKER	PROTECT OTHERS
SECOND DUTY	Prevent Spread	Call for help	Seal the area
THIRD DUTY	Shield the source	Contain the source	Monitor personnel
FOURTH DUTY	Call for help	Clean up the worker	Call for Health Physics consultation
FIFTH DUTY	Clean yourself	Clean yourself	Report incident

NO MATTER
How great the accident
How minor the incident
You always have three things working in your favor

TIME.........(work fast)
DISTANCE....(get away from it)
SHIELDING...(cover it with anything heavy)

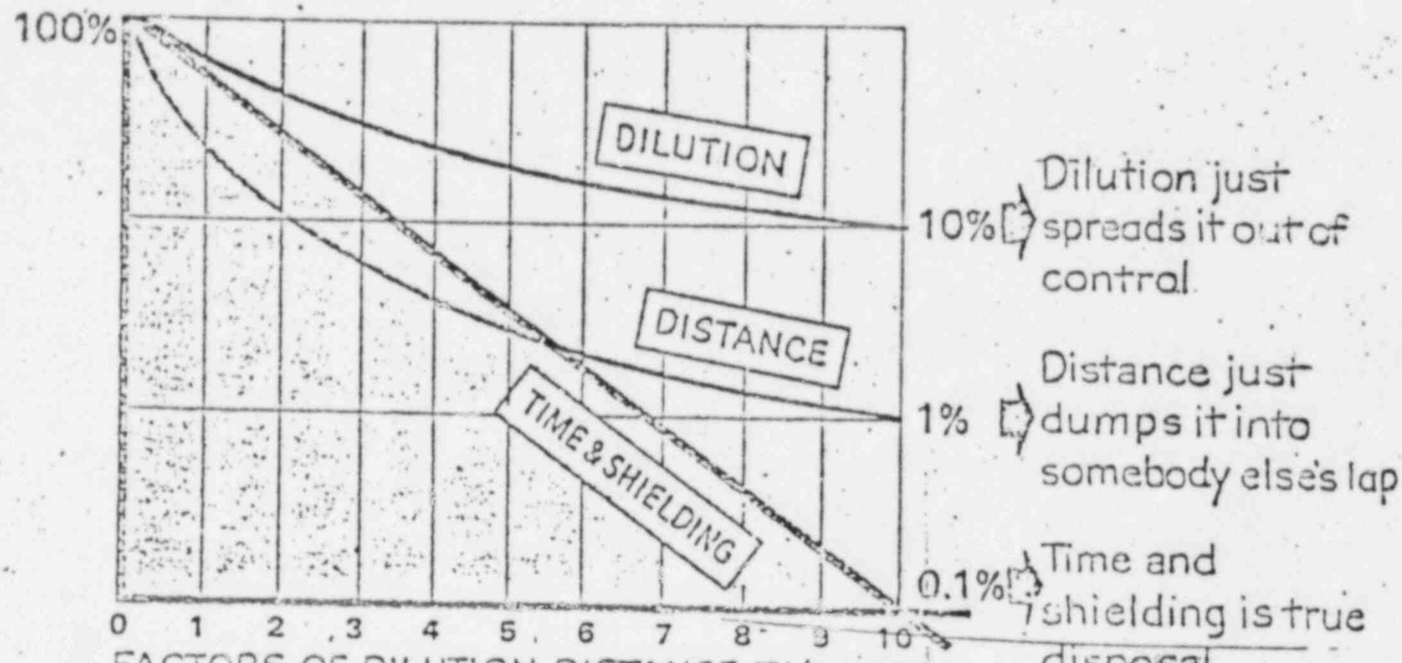
PHONE NUMBERS OF RESPONSIBLE PERSONNEL MUST BE POSTED IN CONSPICUOUS VIEW

RADIOACTIVE WASTE DISPOSAL

The ONLY way to get rid of a radionuclide is by decay:

in 3-1/3 half-lives only 10% remains
in 6-2/3 half-lives only 1% remains
in 10 half-lives only 0.1% remains

But you can get rid of the radiation!



For small, short-lived diagnostic doses you may use dilution-distance (just flush it down the sink!).

For large, long-lived, and therapeutic doses you must use the proper time & shielding for disposal.

HOW MUCH SHIELDING?

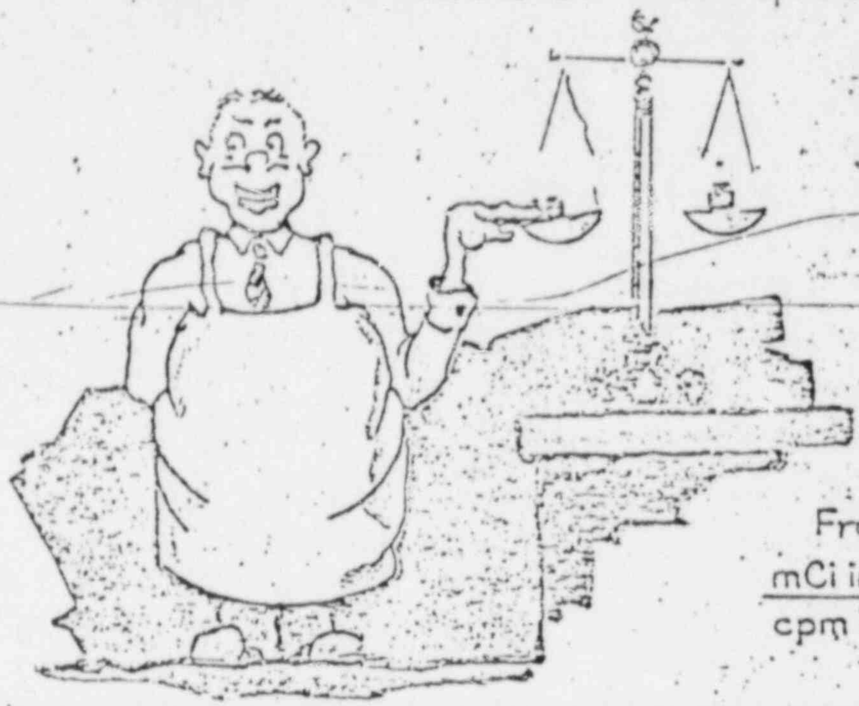
How thick must the shield be to reduce the radiation by half? (called a half-value-layer HVL)	if the Shield is LEAD	if the Shield is IRON	if the Shield is CONCRETE	if the Shield is WATER	meters of AIR
for low energy (150 keV) Co-57, Tc-99m...	0.03 cm	0.45 cm	2.0 cm	4.6 cm	42 M
For medium energy (300 keV) I-131, Au-198, Cr-51,...	0.28 cm	0.91 cm	3.0 cm	6.5 cm	60 M
For high energy (600 keV)	0.52 cm	1.15 cm	3.6 cm	7.8 cm	72 M

CONCENTRATE THE WASTE TO SMALLEST SIZE AND STORE IT IN A LOCKED CLOSET BEHIND LEAD UNTIL IT SURVEYS TO TWICE BACKGROUND. THEN USE ORDINARY WASTE DISPOSAL.

CALIBRATION IS COMPARISON WITH A STANDARD

ACCURACY = How close to the true value?

PRECISION = How reproducible is the measurement?



Since there are NO TRUE VALUES in Nuclear Medicine we must agree on an arbitrary standard (usually a National Bureau of Standards Calibration Standard).

From this:

$$\frac{\text{mCi in standard}}{\text{cpm in standard}} = \frac{\text{mCi in sample}}{\text{cpm in sample}}$$

SYMMETRICAL TEST REFERENCE STANDARD	UNSYMMETRICAL TEST REFERENCE STANDARD	KINETIC AUTONOMOUS STANDARD	PICTURE INTERPRETATION
Dose and Standard from the same bottle (e.g. blood volumes)	Dose and Standard each measured separately (e.g. thyroid uptakes)	Different aspects of a single dose are compared (e.g. renograms)	Comparison with an accepted "normal picture" (e.g. scans)

EACH LABORATORY MUST HAVE THREE SOURCES AVAILABLE FOR INSTRUMENT CALIBRATION:

A POINT SOURCE STANDARD to measure GEOMETRY OF RESPONSE

A VOLUME SOURCE STANDARD to measure SPECTRAL RESPONSE

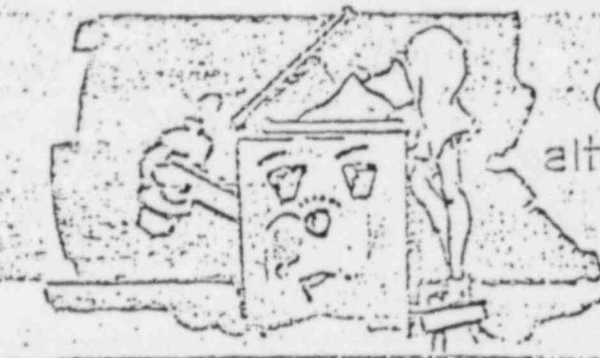
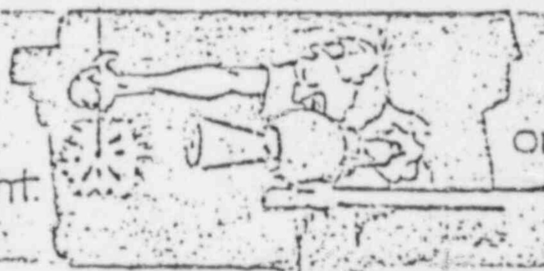
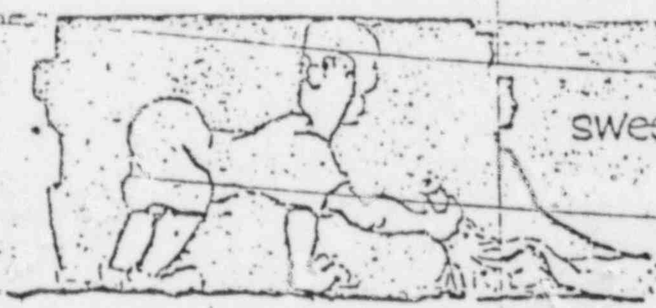
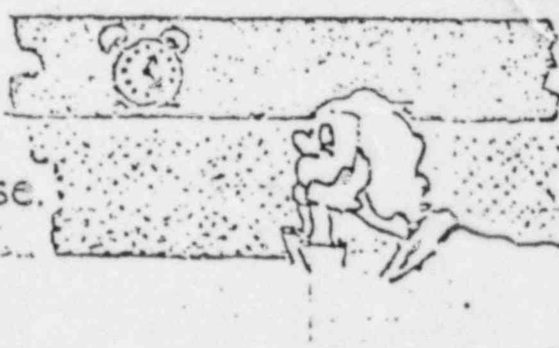
A QUANTITY SOURCE STANDARD to measure CPM PER CURIE

Depending on what the laboratory uses, three energies are sufficient for clinical precision:

Co-57 (122 KeV)	Ba-133 (356 KeV)	Cs-137 (662 KeV)
for low energies	for medium energies	for high energies

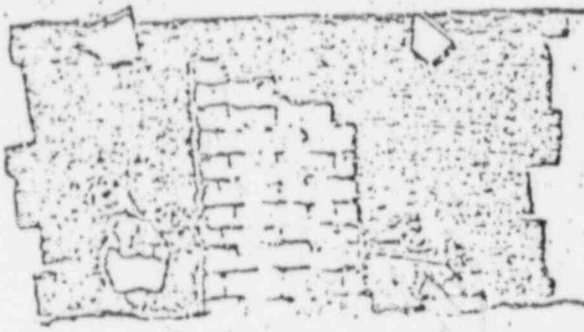
A TRUE CALIBRATION IS A Ph.D. RESEARCH PROJECT.
FOR CLINICAL WORK WE ACCEPT NBS CALIBRATION ON FAITH.

HOW TO TELL A NUCLEAR MEDICINE LAB FROM A SOUVENIR SHOPPE

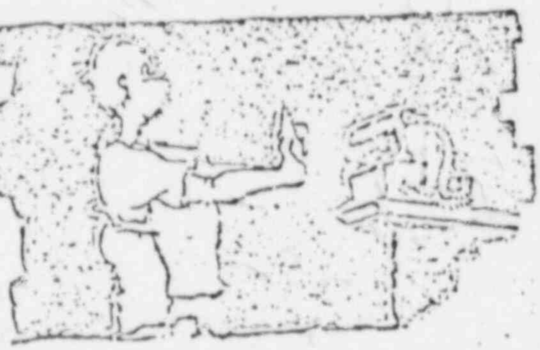
THE LABORATORY		THE SHOPPE
Calibrates its instruments every day......		Calibrates on alternate Thursdays when it rains
Measures the dose for each patient		Reads the label on the bottle with the lights on
Knows the Field-of-Vision of every instrument.		Reads the label on the bottle with lights off
Maintains a running log of background.		sweeps background under the log.
Waits for the patient's body to distribute the dose.		Thinks patients fill up like glass bottles

OTHER VIOLATIONS OF GOOD PRACTICE

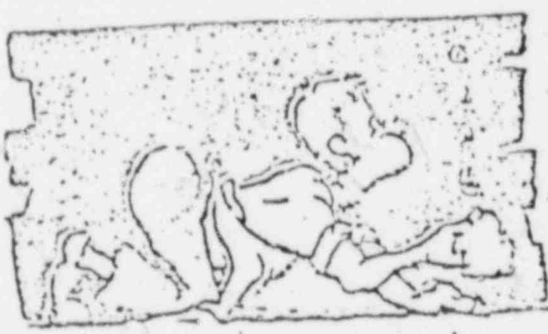
Pipetting by mouth
isn't illegal —
it's stupid.



Don't use Nuclear Power Plant
Health Physics for Nuclear Medicine:
Exaggeration is dangerous.



Don't trust your own clean technique;
Survey yourself after
Handling radioactivity.



Don't clean up spills tomorrow;
your instruments are affected today.
(AND THEY ARE A MILLION TIMES MORE SENSITIVE THAN YOU.)

Don't trust your memory: write
down all data right now.
You can write your memoirs
after you retire.

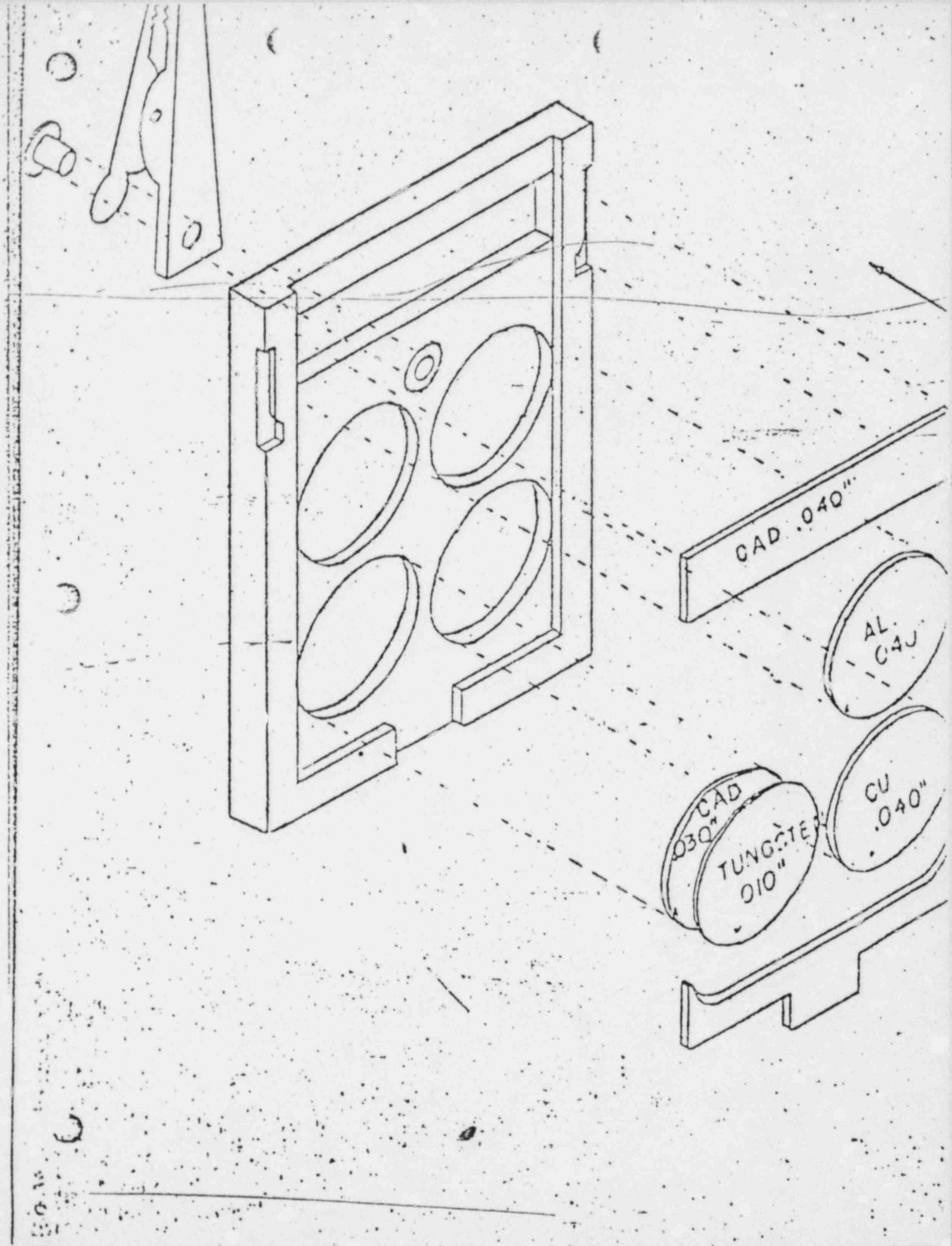
JUST BECAUSE IT'S SO SIMPLE

DON'T GET OFF GUARD

CALIBRATION OF DOSE AND EQUIPMENT
MUST BE DONE EVERY DAY

MONITORING OF RADIATION LEVELS
MUST BE DONE TODAY

LABORATORY HOUSEKEEPING
SHOULD HAVE BEEN DONE YESTERDAY



CAD .040"
AL .04J
CAD .030"
TUNGSTE
.010"
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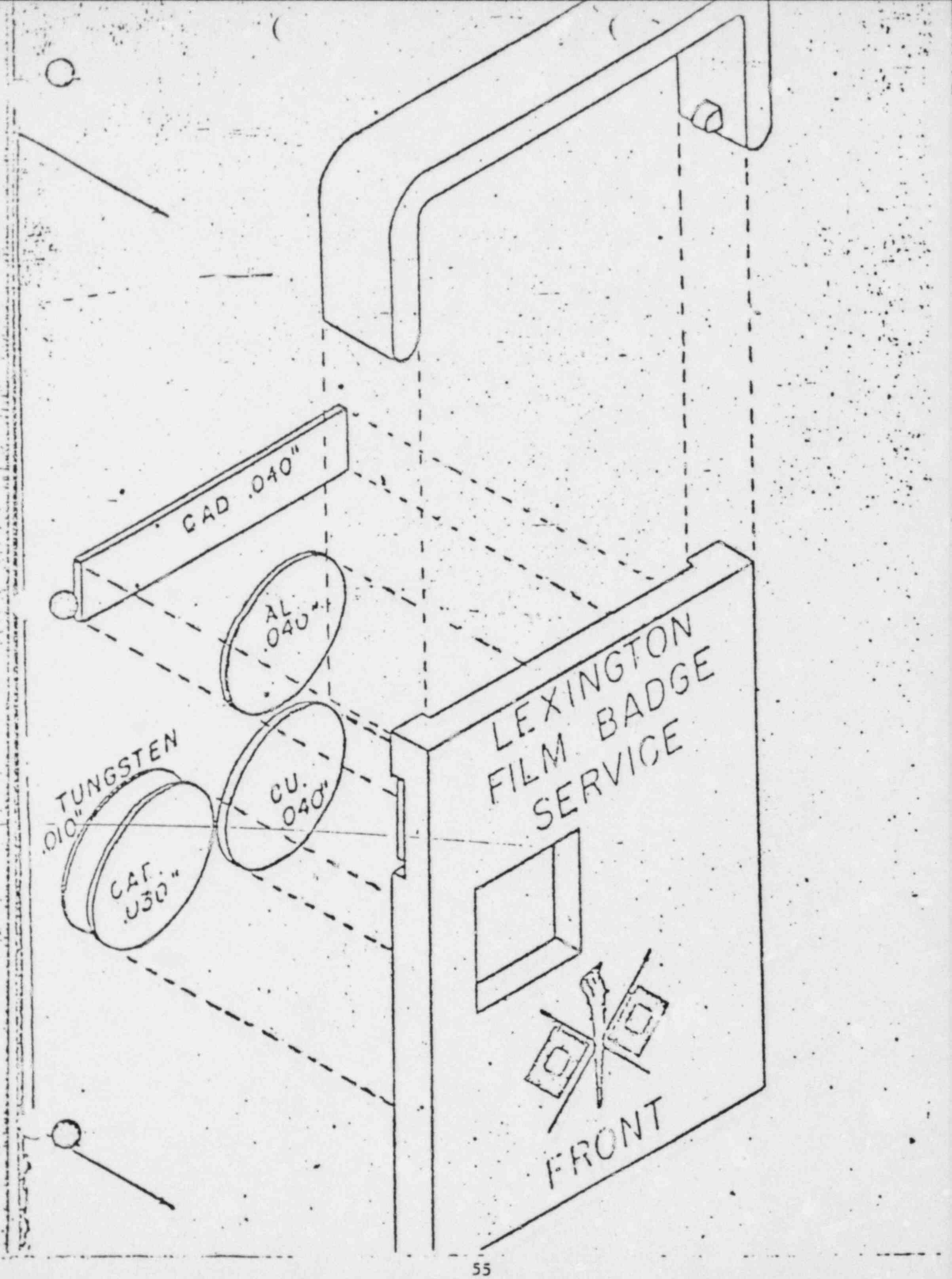
CAD .040"
AL .040"
TUNGSTEN .010"
CAT. .030"
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LEXINGTON
FILM BADGE
SERVICE
FRONT

NAME: ______________________________ DATE: ______________

SSN: ____________________

HARRY DIAMOND LABORATORIES
2800 POWDER MILL ROAD
ADELPHI, MD

DELHD -SA

QUIZ
SAFETY ASPECTS OF IONIZING RADIATION SOURCE USE

PART I - INTRODUCTION, TERMINOLOGY, & PHYSICS REVIEW

A. Match the following with the correct definition

1. Alpha Radiation (α)	______	Particles of nuclear origin having properties identical to electron ($_{\pm 1}e^0$)
2. Beta Radiation ($\beta^{\pm}$)	______	A measure of energy imparted to matter by ionizing radiation and particles per unit mass of irradiated material at the place of interest (=100 erg/g).
3. Gamma Ray (γ)	______	Penetrating electromagnetic radiation originating in the extra-nuclear portion of the atom. May be produced by machines.
4. X-Ray	______	Particles of nuclear origin having properties identical to helium nucleus (^4_2He).
5. Roentgen (R)	______	High-energy electromagnetic radiation of nuclear origin which is very penetrating.
6. rad	______	That dose of ionizing radiation which elicits the same biological effect as one (1) R of standard (250 keV) X-ray.
7. rem	______	That quantity of X or γ radiation which will produce one statcoulomb of negative ions in one cubic centimeter (0.001293 g) of air at 0°C and 760 mm of Hg pressure.
8. Unit of Exposure	______	rem
9. Unit of Absorbed Dose	______	Roentgen (R)
10. Unit of Biological Dose	______	rad
11. Neutron	______	Elementary nuclear particle with a mass approximately the same as that of a hydrogen atom and electrically neutral; its mass is 1.008982 mass units.

B. Answer the following TRUE or FALSE

12. ______ Health Physics is a profession devoted to the protection of man and his environment from unwarranted radiation.

13. ______ HDL Regulation 385-20 prescribes procedures and safe work practices which must be observed by personnel engaged in operations involving ionizing radiation sources.

14. ______ All transfers of radioactive material to or from HDL must be coordinated with the HDL Radiation Protection Officer.

15. ______ Biological half life refers to the amount of time it takes for a radionuclide to decay once inside the body.

C. Complete the following:

16. The symbol ${}^{12}_{6}C$ means that the carbon nucleus being described contains ______ protons, ______ neutrons, and has an atomic mass of ______ a.m.u.

PART II - EXTERNAL RADIATION PROTECTION

Complete the following:

1. What are the three basic means of external radiation protection
   a. ______________________
   b. ______________________
   c. ______________________

2. The approximate exposure rate to gamma radiation from external sources may be calculated from a formula. Complete the statement of this formula.

   R/hr at 1 meter $\cong$

3. Match the below listed radiation with the appropriate shielding material.

a. Alpha	______	Best shielded by dense material.
b. Beta	______	Best shielded by less dense material of suitable thickness.
c. Gamma	______	Will be completely stopped by a sheet of paper.

4. If you were to select an area for the storage of high-intensity gamma source, which area would be the most desirable from a safety view point?
   a. A high shelf (approximately 5 feet above the floor) in a storage cabinet.
   b. A desk located within the laboratory area.
   c. A shelf in a remote area of the lab at waist height
   d. A location that assures an exposure rate of 0.25mR/h will not be exceeded in adjacent work areas.

5. Which of the following is NOT good practice in the external protection from ionizing radiation when working with radioisotopes?

   a. Use mirrors for viewing purposes.

   b. Use remote handling devices.

   c. Work with adequate shielding between radioactive source and experimenter.

   d. Work quickly when working with radioactive material.

   e. Add radioactive material early in the experimental procedure.

   f. Rehearse the experiment with non-radioactive material to gain familiarity with the procedure.

PART III - BASIC MATHEMATIC MANIPULATIONS

1. Perform the indicated operations and express the results in terms of scientific notation (powers of 10):

   a. 18,000 + 2000 = __________

   b. 0.0036 - 0.0006 = __________

   c. 480,000 ÷ 800 = __________

   d. 16,000 x 0.002 = __________

2. Solve the following problems (show your work):

   a. How long can a man work in a 200 mR/h field if we wish to limit his exposure dose to 50 mR/h?

      (1) 15 minutes

      (2) 4 hours

      (3) 30 minutes

      (4) None of the above

   b. Given: Source O----------------X----------------------X (point 1 at X, point 2 at X)

      Distance to point 1 = 1 foot
      Distance to point 2 = 5 feet
      Intensity at point 2 = 4 mR/h

      Find: Intensity at point 1

      Solution:

      (1) 16 mR/h

      (2) 25 mR/h

      (3) 0.25 mR/h

      (4) 100 mR/h

Solve the following problems and circle the correct answer:

c. A man has received 100 mrem thus far for the present film badge exchange period. How long can be work in an area that would expose him to 200 mrem/hr without exceeding his monthly allowable exposure as established for radiation workers at HDL?

   a. 60 minutes
   b. 30 minutes
   c. 15 minutes
   d. 90 minutes

d. A man is working at a distance of one foot from a 10 mCi unshielded Co-60 source. What will be the intensity of the radiation field he will be working in? Co-60 emits photons of 1.17 & 1.33 Mev everytime it disintegrates.

   a. 150 R
   b. 150 mR/hr
   c. 120 mR
   d. 120 mR/hr

e. A woman needs to do some work on a lab bench that is two feet away from a radioactive storage area. She sees the sign on the storage area that states the radiation intensity is one R/hr at 1 ft from the storage area. What will be the radiation intensity at her lab bench?

   a. 4 R/hr
   b. 250 R/hr
   c. 4 mR/hr
   d. 250 mR/hr

f. You will be working next to a storage area where I-131, Cs-137, Na-22 and Na-24 are stored. The I-131 is giving off an intensity of 10 mR/hr, the Cs-137 is giving off 2 mR/hr, the Na-22 is giving off 20 mR/hr, and the Na-24 is giving off 8 mR/hr. If you are working in the area for 10 hours during the month and the rest of the time you are not working around radioactivity, what total dose should your film badge show? (Radiation intensity given at point you are working -- discount decay).

   a. 400 mR/hr
   b. 4 R
   c. 400 mR
   d. 4 R/hr

g. You will be working in an area with an extremely high radiation intensity. If you put three (3) half value layers of a material between you and the source, you will:

   a. Increase the intensity by 8 times.
   b. Decrease the intensity by 1/6 th.
   c. Increase the intensity by 6 times.
   d. Decrease the intensity by 87.5%
   e. The intensity does not change where you are by the addition of half value layers.

3. Define (as powers of 10) the following:

EXAMPLE: Megacurie = 10^6 curies

Picocurie = ________ curies

Millicurie = ________ curies

Nanocurie = ________ curies

Microcurie = ________ curies

4. Solve the following mathematical expressions:

a. $10^2 \times 10^3$ = ________

b. $10^9 \times 10^{-6}$ = ________

c. $1 \times 10^3 + 2 \times 10^4$ = ________

PART IV - LIMITS OF RADIATION EXPOSURE

1. ________ is the formula used to compute the maximum allowable accumulated lifetime exposure to ionizing radiation for radiation workers.

2. ________ is the maximum allowable accumulated whole body exposure to an external source of ionizing radiation for radiation workers during any one calendar quarter.

3. ________ is the maximum allowable annual whole body exposure to external sources of ionizing radiation for any individual in the general public (non-occupationally exposed).

4. Radiation workers must be at least ______ years of age.

5. A "Radiation Area" is defined as any area accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of ______ millirem, or in any 5 consecutive days a dose in excess of ______ millirem.

PART V - INTERNAL RADIATION PROTECTION

Complete the following:

1. The four modes of entry of radioisotopes into the body are:

a. ________________

b. ________________

c. ________________

d. ________________

2. Complete the following chart with the appropriate words or symbols (Alpha - α; Beta - β; Gamma - γ):

	EXTERNAL HAZARD	AS AN INTERNAL HAZARD
MOST HAZARDOUS		
LEAST HAZARDOUS		

3. In evaluating the potential internal hazard from a radioisotope, which of the following should be considered?

   a. The type of radiation emanated.
   b. The chemical form of the radioisotope.
   c. The physical form of the radioisotope.
   d. The maximum permissible body burden.
   e. The critical organ.
   f. The experimental procedure.
   g. All of the above should be considered.
   h. None of the above should be considered.

PART VI - NUCLEAR INSTRUMENTATION AND PERSONNEL MONITORING

Multiple Choice - Circle the most correct answer.

1. What is the purpose of the film badge?

   a. Provide a temporary record of the dose of ionizing radiation received.
   b. Protect the individual from ionizing radiation.
   c. Provide a permanent record of individual exposure to ionizing radiation.
   d. None of the above.

2. Beta radiation can be measured in the field by:

   a. Using a special thermometer and recording the temperature change in a fallout sample.
   b. Using a self-reading pocket dosimeter.
   c. Observing the color change in a film badge.
   d. Using a Geiger-Mueller tube survey meter with the beta shield open.

3. The wrist film badge has:

   a. The same type film packet as the whole body badge.
   b. A different type of film packet than the whole body beta-gamma film badge.
   c. Different filters than the whole body beta-gamma film badge.
   d. None of the above.

4. The purpose of the filters in the film badge is to:

   a. Make it possible to determine the energy of the incident radiation.
   b. Shield the film badge from cosmic rays.
   c. Aid in establishing electron equilibrium.
   d. All of the above.
   e. None of the above.

5. HDL personnel who are occupationally exposed to ionizing radiation due to the nature of their work at HDL:

   a. Are required to report suspected over-exposure to ionizing radiation immediately after the occurrence to their supervisor.
   b. Must obtain a film badge from the HDL Radiation Protection Officer and wear it while working with ionizing radiation sources.
   c. Must have an appropriate medical examination prior to beginning work with radiation sources.
   d. Have a right to be advised of their exposure to radiation or radioactive materials as shown in records maintained by HDL.
   e. All of the above.

6. If you were required to enter a gamma radiation field of unknown intensity, you should carry which of the following instruments for monitoring?

   a. A film badge.
   b. A high-range Geiger-Mueller tube survey meter.
   c. A liquid scintillation counter.
   d. A non-self-reading R chamber.

7. Dosimeters are used to supplement film badges when:

   a. The badge has been left at home.
   b. The badge has been exposed and it is not yet time to change badges.
   c. The individual is working in an area where he might receive a significant exposure in a short period of time.
   d. There are doubts concerning the accuracy and precision of the film badge.

PART VII - SAFE HANDLING PRACTICES

Answer the following <u>TRUE</u> or <u>FALSE</u>.

1. ______ Organic solvents should be used to clean hands after working with radioisotopes.

2. ______ Unwanted radioactive material may be disposed of by placing it in the office waste basket.

3. ______ Radioactive materials need not be stored in locations which are identified by appropriate radiation signs.

4. ______ Rubber gloves and separate laboratory attire should be worn when working with unsealed radioisotopes.

5. ______ Fume hoods (or other ventilation control) should be used for dusty or aerosol generating operations involving radioisotopes.

6. ______ There is no reason why touch up cosmetics should not be used in a laboratory where radioisotopes are used.

7. ______ Eating, smoking, and drinking should be permitted where radioisotopes are used.

8. ______ It is permissible to pipet radioactive material by mouth if the activity is known.

9. ______ Radioactive items should be checked for removable contamination within 18 hours after they arrive at HDL.

10. ______ All accidental exposure to ionizing radiation sources should be reported to the HDL Radiation Protection Officer.

11. ______ If radioisotopes are to be used, it is generally a good idea to cover all work surfaces with disposable absorbent materials.

12. ______ Age and sex have no bearing on the personnel exposure limits set for radiation workers.

PART VIII - BIOLOGICAL EFFECTS

Complete the following:

1. The biological effects of ionizing radiation may be broadly categorized as ____________________ effects and ________________________ effects.

2. Which of the following factors influence biological response of individuals exposed to ionizing radiation?

   a. Total dose.
   b. Dose rate.
   c. Continuous exposure.
   d. Interrupted exposure.
   e. Health of the individual.
   f. All of the above.
   g. None of the above.

3. Radiation sickness occurs as the result of exposure to high doses of radiation. The dosage ranges given below suggest that the observed symptoms would result primarily from damage to what tissues (organs)?

DOSAGE RANGE	TISSUES (ORGANS) PRIMARILY AFFECTED
100-1000 rad	
1000-5000 rad	
5000-∞ rad	