NRC FORM 313 (5-1997) 10 CFR 30, 32, 33 34, 35, 36, 39 and 40

U. S. NUCLEAR REGULATORY COMMISSION

APPROVED BY OMB: NO. 3150-0120 EXPIRES: 7/31/1999

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APPLICATION FOR MATERIAL LICENSE

INSTRUCTIONS: SEE THE APPROPRIATE LICENSE APPLICATION GUIDE FOR DETAILED INSTRUCTIONS FOR COMPLETING APPLICATION. SEND TWO COPIES OF THE ENTIRE COMPLETED APPLICATION TO THE NRC OFFICE SPECIFIED BELOW.

APPLICATION FOR DISTRIBUTION OF EXEMPT PRODUCTS FILE APPLICATIONS WITH:

DIVISION OF INDUSTRIAL AND MEDICAL NUCLEAR SAFETY
OFFICE OF NUCLEAR MATERIALS SAFETY AND SAFEGUARDS
U S NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

ALL OTHER PERSONS FILE APPLICATIONS AS FOLLOWS:

IF YOU ARE LOCATED IN:

CONNECTICUT, DELAWARE, DISTRICT OF COLUMBIA, MAINE, MARYLAND, MASSACHUSETTS, NEW HAMPSHIRE, NEW JERSEY, NEW YORK, PENNSYLVANIA, RHODE ISLAND, OR VERMONT, SEND APPLICATIONS TO:

LICENSING ASSISTANT SECTION
NUCLEAR MATERIALS SAFETY BRANCH
U.S. NUCLEAR REGULATORY COMMISSION, REGION I
475 ALLENDALE ROAD
KING OF PRUSSIA, PA 19406-1415

ALABAMA, FLORIDA, GEORGIA, KENTUCKY, MISSISSIPPI, NORTH CAROLINA, PUERTO RICO, SOUTH CAROLINA, TENNESSEE, VIRGINIA, VIRGIN ISLANDS, OR WEST VIRGINIA, SEND APPLICATIONS TO:

ATLANTA FEDERAL CENTER
U. S. NUCLEAR REGULATORY COMMISSION, REGION II
61 FORSYTH STREET, S.W., SUITE 23T85
ATLANTA, GEORGIA 30303-3415

IF YOU ARE LOCATED IN:

ILLINOIS, INDIANA, IOWA, MICHIGAN, MINNESOTA, MISSOURI, OHIO, OR WISCONSIN, SEND APPLICATIONS TO:

MATERIALS LICENSING SECTION
U.S. NUCLEAR REGULATORY COMMISSION, REGION III
801 WARRENVILLE RD
LISLE, IL 60532-4351

ALASKA, ARIZONA, ARKANSAS, CALIFORNIA, COLORADO, HAWAII, IDAHO, KANSAS, LOUISIANA, MONTANA, NEBRASKA, NEVADA, NEW MEXICO, NORTH DAKOTA, OKLAHOMA, OREGON, PACIFIC TRUST TERRITORIES, SOUTH DAKOTA, TEXAS, UTAH, WASHINGTON, OR WYOMING, SEND APPLICATIONS TO:

NUCLEAR MATERIALS LICENSING SECTION
U.S. NUCLEAR REGULATORY COMMISSION, REGION IV
611 RYAN PLAZA DRIVE, SUITE 400
ARLINGTON, TX 76011-8064

PERSONS LOCATED IN AGREEMENT STATES SEND APPLICATIONS TO THE U.S. NUCLEAR REGULATORY COMMISSION ONLY IF THEY WISH TO POSSESS AND USE LICENSED MATERIAL IN STATES SUBJECT TO U.S.NUCLEAR REGULATORY COMMISSION JURISDICTIONS.

1. THIS IS AN APPLICATION FOR *(Check appropriate item)*

- [X] A. NEW LICENSE
- [ ] B. AMENDMENT TO LICENSE NUMBER ______
- [ ] C. RENEWAL OF LICENSE NUMBER ______

2. NAME AND MAILING ADDRESS OF APPLICANT *(Include Zip code)*

Refer to Accompanying Supplemental Information

3. ADDRESS(ES) WHERE LICENSED MATERIAL WILL BE USED OR POSSESSED

4. NAME OF PERSON TO BE CONTACTED ABOUT THIS APPLICATION

TELEPHONE NUMBER

SUBMIT ITEMS 5 THROUGH 11 ON 8-1/2 X 11" PAPER. THE TYPE AND SCOPE OF INFORMATION TO BE PROVIDED IS DESCRIBED IN THE LICENSE APPLICATION GUIDE

5. RADIOACTIVE MATERIAL
a. Element and mass number; b. chemical and/or physical form; and c. maximum amount which will be possessed at any one time.

6. PURPOSE(S) FOR WHICH LICENSED MATERIAL WILL BE USED.

7. INDIVIDUAL(S) RESPONSIBLE FOR RADIATION SAFETY PROGRAM AND THEIR TRAINING EXPERIENCE

8. TRAINING FOR INDIVIDUALS WORKING IN OR FREQUENTING RESTRICTED AREAS.

9. FACILITIES AND EQUIPMENT.

10. RADIATION SAFETY PROGRAM.

11. WASTE MANAGEMENT.

12. LICENSEE FEES *(See 10 CFR 170 and Section 170.31)*

FEE CATEGORY | AMOUNT ENCLOSED $

13. CERTIFICATION. *(Must be completed by applicant)* THE APPLICANT UNDERSTANDS THAT ALL STATEMENTS AND REPRESENTATIONS MADE IN THIS APPLICATION ARE BINDING UPON THE APPLICANT.

THE APPLICANT AND ANY OFFICIAL EXECUTING THIS CERTIFICATION ON BEHALF OF THE APPLICANT, NAMED IN ITEM 2, CERTIFY THAT THIS APPLICATION IS PREPARED IN CONFORMITY WITH TITLE 10, CODE OF FEDERAL REGULATIONS, PARTS 30, 32, 33, 34, 35, 36, 39 AND 40, AND THAT ALL INFORMATION CONTAINED HEREIN IS TRUE AND CORRECT TO THE BEST OF THEIR KNOWLEDGE AND BELIEF.

WARNING: 18 U.S.C. SECTION 1001 ACT OF JUNE 25, 1948 62 STAT. 749 MAKES IT A CRIMINAL OFFENSE TO MAKE A WILLFULLY FALSE STATEMENT OR REPRESENTATION TO ANY DEPARTMENT OR AGENCY OF THE UNITED STATES AS TO ANY MATTER WITHIN ITS JURISDICTION.

CERTIFYING OFFICER – TYPED/PRINTED NAME AND TITLE	SIGNATURE	DATE
Richard J. Timbo, Principal	Richard J. Timbo	12-2-04

FOR NRC USE ONLY

TYPE OF FEE	FEE LOG	FEE CATEGORY	AMOUNT RECEIVED	CHECK NUMBER	COMMENTS
			$		
APPROVED BY				DATE	

B-1

SUPPLEMENTAL INFORMATION

RICHARD BARRY MARKETING GROUP
APPLICATION FOR RADIOACTIVE MATERIAL LICENSE

ITEM 1. THIS IS AN APPLICATION FOR

A new radioactive materials possession/use license in accordance with 10 CFR 30, §30.33.

ITEM 2. NAME AND ADDRESS OF APPLICANT

Richard Barry Marketing Group (RBMG)
81 Ruckman Road
Closter, NJ 07624-2102

ITEM 3. ADDRESS WHERE LICENSED MATERIAL WILL BE USED OR POSSESSED

81 Ruckman Road
Closter, NJ 07624-2102

ITEM 4. NAME OF PERSON TO BE CONTACTED ABOUT THIS APPLICATION

Michael Shane Brightwell, MS, CHP
Application Preparer
Professional Radiation Consulting, Inc.
267-B East 29th Street #444
Loveland, CO 80538
631-278-0610 (phone)
720-294-1153 (fax)
proradcon@aol.com

Richard J. Timbo
Applicant Certifying Official
Applicant Radiation Safety Officer
81 Ruckman Road
Closter, NJ 07624
201-750-8000 (phone)
201-750-8444 (fax)
rbmg@luminox.com
www.luminox.com

SUPPLEMENTAL INFORMATION

ITEM 5. RADIOACTIVE MATERIAL

A. ELEMENT AND MASS NUMBER	B. CHEMICAL OR PHYSICAL FORM	C. MAXIMUM AMOUNT THAT WILL BE POSSESSED AT ANY ONE TIME
Hydrogen-3 (Tritium).	Sealed Gaseous Tritium Light Sources (GTLS); (mb-microtec Models X00/A, X00/B, and X00/C)	25 mCi per timepiece 5 mCi per hand 15 mCi per dial 50,000 Ci total activity (200,000 timepieces)

ITEM 6. PURPOSES FOR WHICH RADIOACTIVE MATERIALS WILL BE USED

Pursuant to the general provisions of 10 CFR 30, §30.33, this license is intended to facilitate the receipt, storage, and initial transfer of devices listed in Item 5 incident to the distribution to persons exempt from licensing in accordance with an Exempt Distribution License issued pursuant to 10 CFR 30, §32.14 and §30.15.

ITEM 7. INDIVIDUAL(S) RESPONSIBLE FOR RADIATION SAFETY PROGRAM AND THEIR TRAINING EXPERIENCE

- Michael Shane Brightwell, MS, CHP, of Professional Radiation Consulting, Inc. (Application Preparer), will implement the Basic Radiation Safety Training program. Mr. Brightwell's resume is in **Attachment 1**.
- Richard J. Timbo, Applicant Radiation Safety Officer (RSO) – Mr. Timbo will be trained using the Basic Radiation Safety Training (BRST) document (**Attachment 2**). Successful completion will be demonstrated by examination with a minimum passing score of 80%. Additionally, Mr. Timbo will be observed to perform or simulate performance of all required licensed activities as appropriate.
- Any person(s) proposed to be an Authorized User (AU) will be trained per **Attachment 2**; demonstrate adequate knowledge (testing minimum passing score of 70%), skills, and abilities (performance or simulated performance of all applicable licensed activities); and the person's credentials will be submitted to NRC for approval as an AU.

SUPPLEMENTAL INFORMATION

ITEM 8. TRAINING FOR INDIVIDUALS WORKING IN OR FREQUENTING RESTRICTED AREAS

The BRST will be used to train AUs and general employees who may frequent restricted areas (**Attachment 2**).

ITEM 9. FACILITIES AND EQUIPMENT

All devices are scheduled to be received at the facility in final individual packages, which are bulked packaged into boxes. These boxes will either be stored or opened for necessary individual package inventorying and or to satisfy QC requirements. Individual packages will also be stored similar to bulk packages.

The facilities and equipment dedicated to the receipt, handling, storage, and packaging for transfer of devices listed in Item 5 include:

- Pallet forklifts, floor lifts, and floor trucks.
- Lockable storage rooms to which access will be limited to and under the supervision of Authorized Users (Item 8).
- Inspection and repackaging facilities such as tables, floor space, boxes, etc.

Attachment 3 is a floor plan if the facility, showing areas where licensed devices will be received, handled, stored, and packaged for transfer. All packages will be received through the back door, transferred to the packing and shipping room for inventory, and then stored in the stock room. Packages are taken from the stock room to the packing and shipping room for as orders are filled, then shipped through the back door. Products/packages are not typically handled in the administrative and office area and are locked in the stock room during storage.

ITEM 10. RADIATION SAFETY PROGRAM

Operational

The licensed radioactive materials proposed under this license are limited to sealed source devices (SSDs), each containing no more than 25 mCi of ^3H in gaseous form, packaged in their final distribution packaging. Any release of the radioactive materials from the individual SSD results in insignificant (if measurable) internal dose equivalent to any exposed individual. Activities do not include any routine removal of the SSDs from their final packaging at the facility except as required during QC inspections. These SSDs are manufactured and packaged at the manufacturer's facility in accordance with the QC requirements specified in the associated exempt distribution license (EDL).

The licensed activities planned under this license are limited to

- receipt of bulk packaged (palletized boxes) of SSDs;
- storage of bulk and individual packages of SSDs;
- quality control checks of a fraction of individual SSD packages;
- repackaging of final individual packages, and
- shipping of bulk boxes and individual packages of SSDs.

Based on the types of radioactive materials and associated planned licensed activities, the reasonable extent of radiation safety requirements are essentially limited to proper inventory control, including control requirements inherent in the QC inspections specified in the associated EDL. These control requirements are specified in earlier sections of this application and in the associated EDL.

ITEM 11. WASTE MANAGEMENT

Due to the inherent nature of the GTLSs used in these SSDs, combined with the limitations on the licensee to only manage SSDs in assembled and packaged form, the generation of potentially radioactive waste will be limited to SSDs that contain failed GTLSs in-place. Therefore, the licensee will follow the protocol of collecting and returning all damaged SSDs and SSDs with failed GTLSs (that have not been previously distributed to persons exempted from licensing) to the overseas manufacturing facility, where they will be repaired under that facility's program.

ITEM 12. LICENSE FEES

Fee Gategory ≡ 3.B.
Amount Enclosed = $2,800

Michael Shane Brightwell

Certified Health Physicist

Professional Radiation Consulting, Incorporated

TECHNICAL EXPERTISE

- Radiological Program Management
- Radiological Investigations, Remediation, and Decommissioning
- Radioactive Materials Licensing
- Radioactive Waste Management

PROFESSIONAL EXPERIENCE

11 Years

EDUCATION

MS/(b)(6)/Health Physics, Texas A&M University

BS/(b)(6) Nuclear Engineering, Texas A&M University

PROFESSIONAL REGISTRATIONS

Certified in the Comprehensive Practice of Health Physics (CHP), American Board of Health Physics, 1999

Licensed Senior Reactor Operator, Texas A&M University, 1989

PROFESSIONAL PROFILE

Mr. Brightwell specializes in radiological program management, applied health physics, nuclear engineering, and reactor operations. His areas of expertise include: radiation safety officer duties, site decontamination and decommissioning, dose modeling, radioactive materials licensing, project management, work plan development, radiation detection instrumentation, environmental and reactor health physics, audits/inspections, radioactive materials shipping, and radioactive waste management.

REPRESENTATIVE PROJECTS

RADIOLOGICAL PROGRAM MANAGEMENT

Mr. Brightwell's radiological experience includes site investigations and remedial program design and implementation. Specifically, he has been involved in:

- Comprehensive program development/implementation;
- material licensing;
- regulatory compliance/negotiation;
- radiological investigations;
- soil sampling, and
- report preparation.

Mr. Brightwell has been the Radiation Safety Officer for programs including developing licensing procedures, training personnel, monitoring/assessing dose (personnel and environmental), maintaining instrumentation, handling radioactive materials, and auditing radiation safety programs.

<u>Applicable Projects:</u>

- Former Sylvania Electric Products Incorporated Facility
- Lite Pro, LLC
- Dow Chemical / Umetco
- Phelps Dodge / Western Nuclear

RADIATION SAFETY OFFICER

- State of New York
- State of Florida
- State of Colorado

Radiation Safety Officer and Certified Health Physicist for a former AEC-licensed fuel fabrication facility – The 10-acre site was impacted by low level radionuclides (uranium and thorium) as well as industrial solvents (PCE and TCE) and metals. Extensive soil testing was conducted and 3-dimensional maps of the contaminant plumes were compiled. Numerous remedial approaches were considered to handle the multiple contaminants in the soil. A large-scale remediation, over 60,000 cubic yards of impacted soils, is being conducted. The excavation is being conducted under structures, all samples are barcoded, and the impacted soils are placed in Lift-Liner™ bags and transported off-site for disposal at a remote low-level radioactive waste disposal facility.

NRC approved Radiation Safety Officer for exempt commercial product distribution licensees, including sealed source device (SSD) safety evaluations, NRC SSD registration, SSD distributor's facility possession license for the distribution of a product containing gaseous tritium light sources (GTLS), and ultimate NRC exempt SSD distribution licensing.

Radiation Safety Officer for decommissioning uranium heap leach and mill tailing facilities, an environmental/radiochemistry laboratory, and an environmental remediation construction company.

Applicable Projects:

- Former Sylvania Electric Products Incorporated Facility
- Lite Pro, LLC
- Dow Chemical / Umetco

SENIOR ENGINEER/HEALTH PHYSICIST

Field manager for the remediation of several uranium mill-tailing sites. Work included large-scale earth moving operations, management of quality assurance/quality control (QA/QC) program, monitoring for wind-blown radionuclide contamination, large-scale land area and rail bed surveys using radiation measurement/ global positioning system (RM/GPS) technology, and supervision of waste shipments.

Contract Radiation Safety Officer for a full service environmental laboratory. Radiation safety program implementation and maintenance, including licensing, developing procedures, training personnel, monitoring/assessing dose (personnel and environmental), maintaining instrumentation, and handling radioactive materials.

Developed and performed a comprehensive decontamination and decommissioning program of a radiochemistry laboratory. Program included using MARSSIM and other applicable regulatory guidance as well as performing site-specific dose modeling using RESRAD Family of Codes.

Contract Radiation Safety Officer for two mineral mining facilities during remediation and license termination.

Michael Shane Brightwell

Certified Health Physicist

Professional Radiation Consulting, Incorporated

Applicable Projects:

- Barringer Laboratories
- Dow Chemical / Umetco
- Phelps Dodge / Western Nuclear

TECHNICAL SERVICES MANAGER

- Management of the environmental and trace characterization laboratory at Texas A&M Nuclear Science Center.

- Designed and engineered nuclear reactor experiments for medical, commercial, industrial, and military applications. Regulatory compliance, QA/QC.

SENIOR REACTOR OPERATOR

Responsible for start up, training, and daily operations of a 1-Megawatt TRIGA research reactor. Involved in research related to radioisotope production.

PROFESSIONAL TRAINING

- OSHA 40-Hour Safety Training and 8-Hour Refresher
- Radiation Safety Officer, 40-hour Training
- Ludlum Measurements Inc., 40-hour Training
- Oak Ridge Associated Universities MARSSIM Training
- Argonne National Lab Environmental Assessment Division RESRAD/RESRAD-BUILD Deterministic and Probabilistic Dose Assessment Training
- Health Physics Society Summer Schools on Decommissioning and Restoration of Nuclear Facilities, and Radiation Instrumentation
- Radiation Safety and the Use of Nuclear Gauges
- AAHP Course in Statistics and Decommissioning
- Duratek Advanced Radioactive and Hazardous Material Transportation Training
- Canberra Gamma Spectroscopy Training on System Management and Algorithms
- Senior Reactor Operator Training
- Navy Nuclear Power Program

Michael Shane Brightwell

Certified Health Physicist

Professional Radiation Consulting, Incorporated

PROFESSIONAL AFFILIATIONS

- Registered Qualified Expert in the State of Colorado
- American Academy of Health Physics
- Health Physics Society
- Texas A&M Corps of Cadets (b)(6)

SELECTED PUBLICATIONS

- Brightwell, M.S. 2001. "Radiation Detection Instrumentation Used In Decommissioning." Radiation Instruments. Textbook of and Lecture at the Health Physics Society Summer School, Findlay, Ohio, June 2001.

- Brightwell, M.S. and Reece, W.D. 1999. "Fast Neutron Flux Irradiation Device for a 1-MW TRIGA Research Reactor." Proceedings of and Presentation at the 32nd Midyear Topical Meeting of the Health Physics Society, Albuquerque, New Mexico, January 1999.

- Fiske, L.E., Doyle, S., Johnson, J.A., and Brightwell, M.S. 1999. "Orphaned Radioactive Sources." Proceedings of the 1999 Conference of the Solid Waste Association of North America, Tucson, AZ.

- Herrold, J.F., Brightwell, M.S. 1998. "Using Regulatory Guidance in Decommissioning Under an NRC Broad-Scope Byproduct Material License." RSO Magazine 3:17-23.

- Landau, M.S., Brightwell, M.S., and Johnson, J.A. 1998. "Schwartzwalder Mine Haul Road Radiation Survey." Proceedings of and Presentation at the Spectrum '98 International Conference on Decommissioning and Decontamination and on Nuclear and Hazardous Waste Management, Denver, Colorado, September 1998.

- Brightwell, M.S. 1995. "Minimizing the Production of Unwanted Activation Products in the Argon-40/Argon-39 Dating Method." Thesis, Texas A&M, Department of Nuclear Engineering.

BASIC RADIATION SAFETY TRAINING

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I. INTRODUCTION

A. Purpose

1. Understanding radiation and radiation risks
2. Understanding terminology
3. Understanding biological effects of radiation
4. Put radiation risks in perspective
5. Familiarity with radiation detection instrumentation
6. Understanding radiation safety regulations
7. Familiarity with occupational exposures to radiation
8. Understanding the problem of indoor radon

B. Content

1. Basic radiation physics
2. Terminology and units
3. Biological effects
4. Sources of radiation exposure
5. Principal methods of detection
6. Radiation safety regulations
7. Typical occupational exposures and basic radiation safety techniques
8. Origin and health effects of radon and its progeny

II. NATURE OF RADIOACTIVITY

A. Structure of the Atom - Review

1. Basic particles: protons, neutrons, electrons
2. Nucleus: protons + neutrons
3. Electrons in orbit around nucleus

B. Terminology and Shorthand

1. Atomic number (Z) = number of protons
2. Atomic mass (A) = number of nucleons (protons + neutrons)

3. Terminology and abbreviations

$^{12}_{6}C$ carbon 6 protons + 6 neutrons

$^{14}_{6}C$ carbon 6 protons + 8 neutrons

$^{238}_{92}U$ uranium 92 protons + 146 neutrons

C. Radioactivity (Figures 1, 2, and 3)

1. When the nucleus of an atom has excess energy it gets rid of it by emitting radiation - radioactive decay.

2. Line of stability

3. Types of ionizing radiation

a.) Particulate

i.) Alpha particles - ^{4}He nuclei

ii.) Beta particles - electrons/positrons originating from nucleus

b.) Electromagnetic

i.) Gamma photons - originate from nucleus

ii.) X-rays - originate from outside nucleus
Bremsstrahlung
Characteristic x-rays

c.) Neutrons

Radiation Type	Mass (amu)	Charge	Energy Distribution Range	Penetrability	Specific Ionization (ip/μm)
Alpha (α)	4	+2	Monoenergetic 4-8 MeV	Low	4000
Beta (β)	0.000549	-1 +1	Spectral 0.018-2.3 MeV	Moderate	10–100
Gamma (γ)	0	0	Monoenergetic 0.1-3 MeV	High	N/A
X-ray	0	0	Spectral <50 keV -2 MeV	High	N/A

Figure 1. Electromagnetic Spectrum

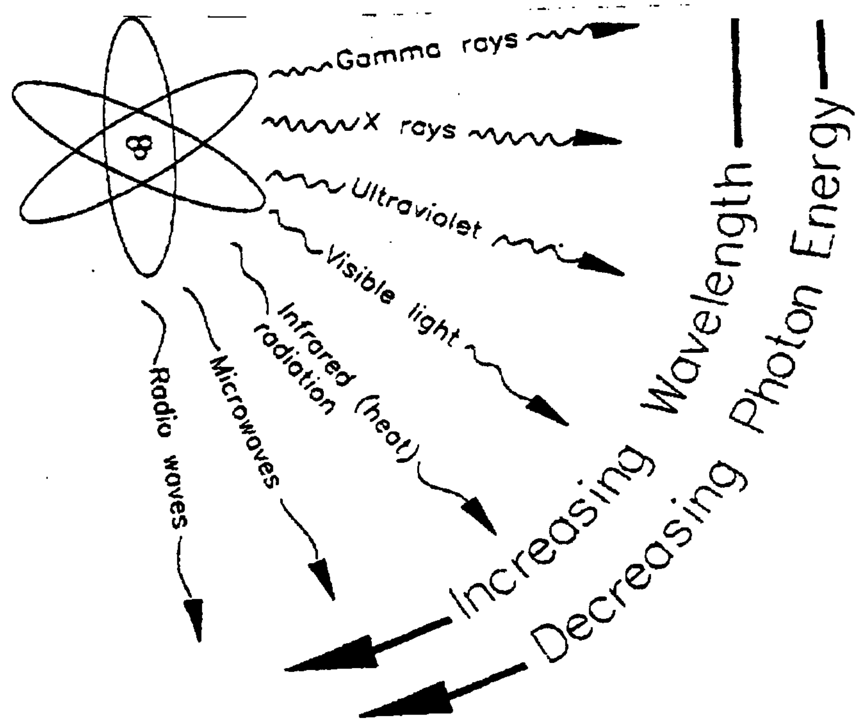


Figure 2. Line of Stability

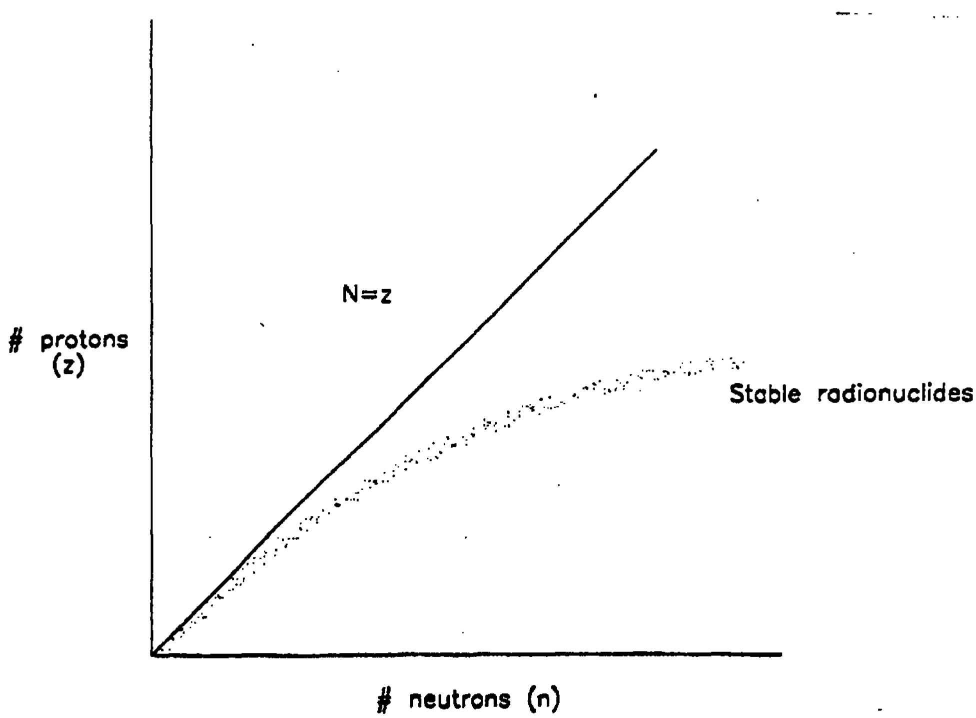
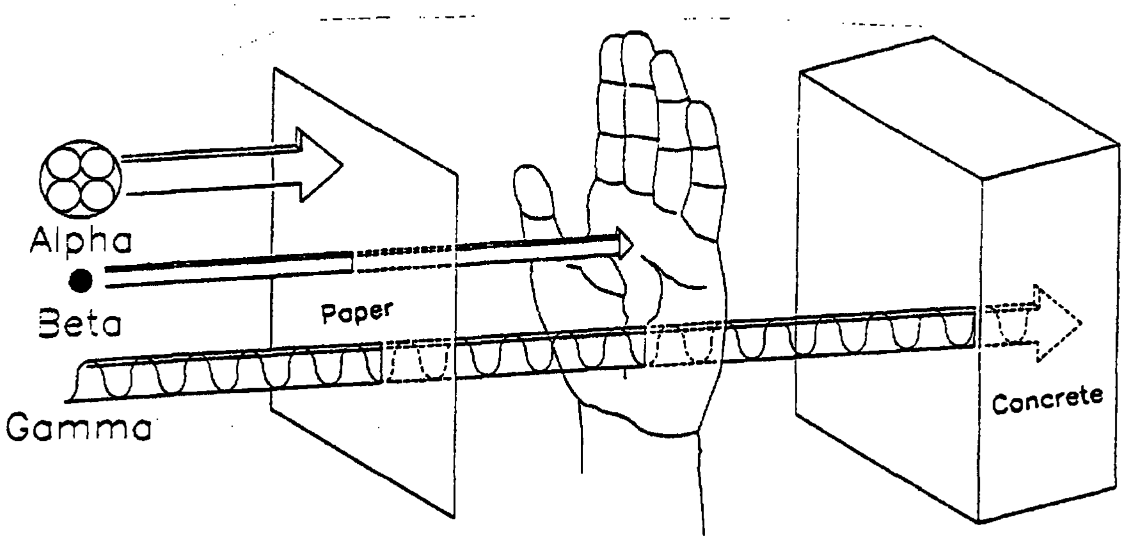


Figure 3. Penetrability of Different Types of Radiation



D. Characteristics of Different Types of Radiation

Determine biological effects and usefulness as well as methods of detection

1. Alpha particles - high energy; low penetrability; can be stopped by a sheet of paper or layer of dead skin cells.

2. Beta particles - moderate penetrability; several centimeters to several meters in air; less than one centimeter in tissue.

3. Gamma photons and X–rays - very penetrating; lead or concrete can be used to shield them.

E. Radioactive Decay

Radioactive decay is a random process. The probability of any radioactive atom decaying in a given period is defined as the *decay constant*. While it is impossible to predict when any one radioactive atom will decay, it is possible to predict the fraction of atoms that will decay in any given time interval.

$-dN/dt = \lambda N$ where λ = decay constant

$A = -dN/dt$

$-dN/dt = \lambda N$

$-\int dN/N = \lambda \int dt$

$\ln N = -\lambda t + I$ where I = constant of integration at $t = 0 \qquad I = \ln N_0$

$\ln N = -\lambda t + \ln N_0$

$\ln N - \ln N_0 = -\lambda t$

$\ln N/N_0 = -\lambda t$

$N/N_0 = e^{\lambda t}$

F. Half-life

The half-life is the time it takes for half of the radioactive atoms present to decay.

$\ln N/N_0 = \ln 0.5 = -\lambda T_{1/2}$

$\ln 0.5 = -0.693 = -\lambda T_{1/2}$

$T_{1/2} = 0.693 / \lambda$

Half-life is characteristic of a given radionuclide and cannot be changed by chemical or physical means.

Half-lives of common radionuclides:

^{238}U	4.5 billion years
^{239}Pu	24,000 years
^{14}C	5,700 years
^{226}Ra	1,600 years
^{3}H	12.3 years
^{222}Rn	3.8 days
^{214}Po	0.000164 seconds

G. Typical Decay Equations, Characteristics

1. Particulate
   a. α decay $\qquad ^{238}U \Rightarrow {}^{234}Th + {}^{4}He\ (\alpha)$
   b. β decay $\qquad ^{14}C \Rightarrow {}^{14}N + \beta$
2. Electromagnetic
   a. γ $\qquad ^{214}Bi \Rightarrow {}^{214}Po + \beta + \gamma$
   b. X-ray
      1. Characteristic - results from change in orbital electron shell reconfiguration following particulate decay.
      2. Bremsstrahlung ('braking radiation") - results from reduction in energy of free electron as it passes in vicinity of nucleus and bound orbital electrons.

H. Interaction of Radiation With Matter (Figures 4 and 5)

1. Charged Particle (Particulate)
   a.) Excitation - electrons raised to excited state
   b.) Ionization - electrons stripped from the atom to form ion pair
2. Electromagnetic radiation interactions with matter
   a.) Photoelectric interaction
   b.) Compton interaction
   c.) Pair production

Figure 4. Particulate Radiation Interaction with Matter

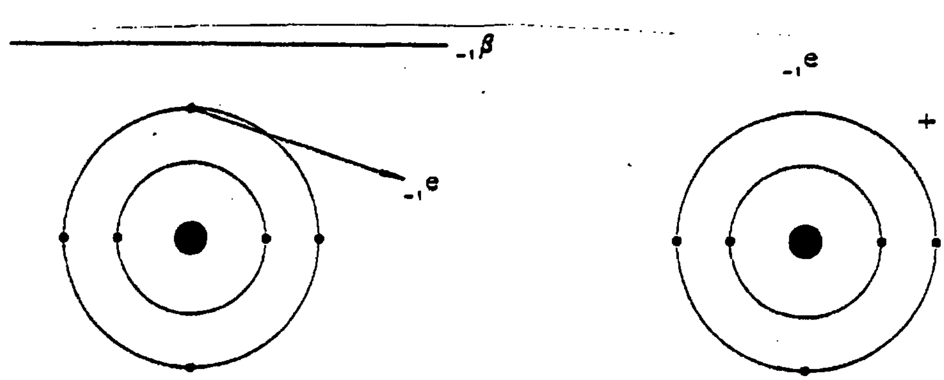
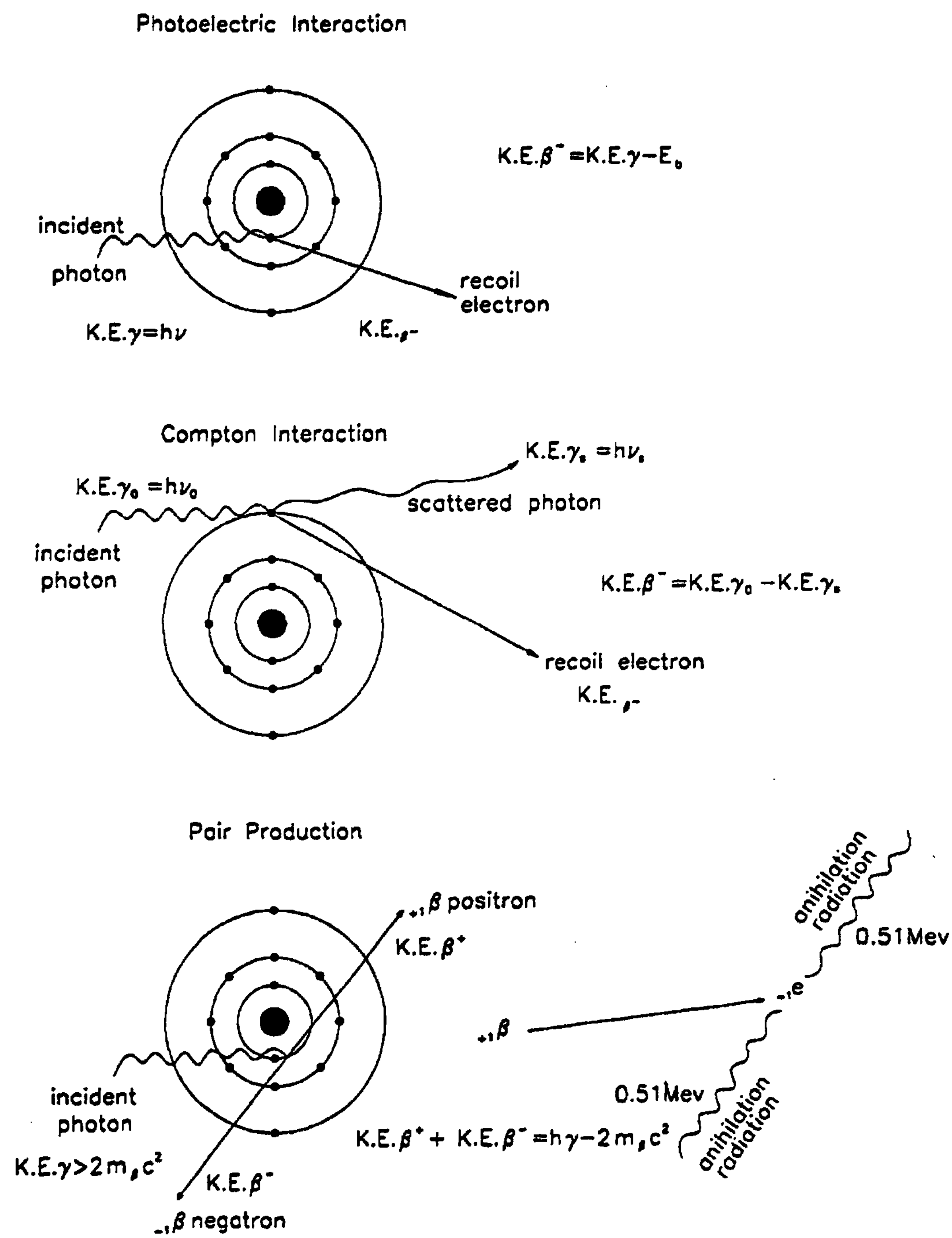


Figure 5. Electromagnetic Radiation Interaction with Matter



III. TERMS AND UNITS OF RADIATION

A. Definitions

Radiation <ionizing radiation> - alpha particles, beta particles, gamma rays, x-ray, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. *Radiation,* as used in this document, does not include non-ionizing radiation, such as such as radio- or microwaves, visible, infrared, or ultraviolet light.

Gray (Gy) - the SI unit of *absorbed dose.* One *gray* is equal to an *absorbed dose* of 1 J/kg (100 *rads*).

Rad (rad) - the special unit of *absorbed dose.* One *rad* is equal to an *absorbed dose* of 100 ergs/g or 0.01 J/kg (0.01 *gray*).

Rem (rem) - the special unit of any of the quantities expressed as *dose equivalent.* The *dose equivalent* in *rems* is equal to the *absorbed dose* in *rads* multiplied by the *quality factor* (1 *rem* = 0.01 *sievert*).

Sievert (Sv) - the SI unit of any of the quantities expressed as *dose equivalent.* The *dose equivalent* in *sievert* is equal to the *absorbed dose* in *grays* multiplied by the *quality factor* (1 *sievert* = 100 *rems*).

Stochastic Effects - health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of the *dose* without threshold. Hereditary effects and cancer incidence are examples of *stochastic effects.*

Nonstochastic Effects - health effects, the severity of which vary with *dose*, and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a *nonstochastic effect* (also called a deterministic effect).

Activity (A) - rate of disintegration (transformation) or decay of radioactive material. The units of *activity* are the curie (Ci) and the becquerel (Bq).

Exposure (X) - being exposed to ionizing radiation or radioactive material.

Dose **or** ***Radiation Dose*** - a generic term that means *absorbed dose*, *dose equivalent*, *committed dose equivalent*, *effective dose equivalent*, *committed effective dose equivalent*, or *total effective dose equivalent*, as defined below.

Absorbed Dose (D) - the energy imparted by ionizing radiation per unit mass of irradiated material. The units of *absorbed dose* are the rad (rad) and the Gray (Gy).

Quality Factor (Q) - the modifying factor that is used to derive *dose equivalent* from *absorbed dose.*

Dose Equivalent (H_T) - the product of the *absorbed dose* (in tissue medium), *quality factor*, and all other necessary modifying factors at the location of interest. The units of *dose equivalent* are the *rem* and the *sievert.*

Weighting Factor (w_T) – the proportion of the risk for an organ or tissue (T) of *stochastic effects* resulting from irradiation of that organ or tissue, to the total risk of *stochastic effects* when the whole body is irradiated uniformly.

Committed Dose Equivalent ($H_{T,50}$) - the *dose equivalent* to organs or tissues of reference (T) that will be received, from an intake of radioactive material by an individual, during the 50-year period following the intake.

Effective Dose Equivalent (H_E) - the sum of the products of each *dose equivalent* (H_T) to an organ or tissue (T) and the applicable organ or tissue *weighting factor.*

Committed Effective Dose Equivalent ($H_{E,50}$) – the sum of the products of the *weighting factor* applicable to each organ or tissue (T) irradiated and the *committed dose equivalent* applicable to each organ or tissue.

Deep-dose Equivalent (H_d) – the *dose equivalent* at a tissue depth of 1 cm (1000 mg/cm^2); applies to external whole-body *exposure.*

Total Effective Dose Equivalent (TEDE) – the sum of the *deep-dose equivalent (H_d)* for external exposures and the *committed effective dose equivalent ($H_{E,50}$)* for internal exposures.

B. Units of Activity

1. Curie (Ci) = 3.7×10^{10} disintegrations-per-second (dps) = 3.7×10^{10} becquerel (Bq)

   millicurie (mCi) = 3.7×10^7 dps
   microcurie (μCi) = 3.7×10^4 dps
   picocurie (pCi) = 0.037 dps

2. Becquerel = 1 dps = 2.7×10^{-11} Ci

3. Useful Conversion Factors

   1 pCi = 0.037 Bq = 2.22 disintegrations-per-minute (dpm)
   1 Bq = 27 pCi = 60 dpm

C. Units of Exposure - Roentgen - Charged Produced in Air Due to Radiation

1. Roentgen applies only to x-rays and gamma radiation

2. Roentgen (R) = 2.58×10^4 coulombs/kg in dry air

D. Units of Absorbed Dose (D) - Energy of the Radiation Absorbed in a Medium

(In radiation safety, the medium generally considered is tissue.)

1. 1 rad = 100 ergs/g

2. 1 Gy = 1 J/kg

3. 1 Gy = 100 rads

E. Units of Dose Equivalent (H_T)

1. $H_T = D \times Q \times n$

   where n is a modifying factor which is rarely used

   a.) rem = rad x Q

   b.) Sv = Gy x Q

2. Quality Factors

Type of Radiation	Quality Factor (Q)	Dose Equivalent of Absorbed Dose (D) =1 ($H_T = D \times Q$)
X-ray, γ, β radiation	1	1
α particles, multiple-charge particles, fission fragments, heavy particles of unknown charge	20	20
Neutrons of unknown energy	10	10
High-energy protons	10	10

F. Effective Dose Equivalent (H_E)

1. $H_E = H_T \times w_T$

2. ***Weighting Factor (w_T)*** - varies according to the organ affected and is a measure of the sensitivity of a particular organ. The risk of fatality due to radiation is less if only one organ is irradiated compared to the risk if the whole body is irradiated.

Organ or Tissue (T)	w_T
Gonads	0.25
Breast	0.15
Red Bone Marrow	0.12
Lung	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder[1]	0.30
Whole Body	1.00

[1] 0.30 results from 0.06 for each of the five "remainder" organs (excluding the skin and lens of the eye) that receive the highest doses.

IV. RADIATION BIOEFFECTS

A. Radiation Exposure

1. External - source of radiation remains outside the body as with medical x-rays.

   a.) α Particles - because they cannot penetrate the layer of dead skin cells, alpha particles are not typically a hazard outside the body.

b.) β Particles - can cause damage to the skin from outside the body but cannot reach other major organs.

c.) γ– and x-rays - can penetrate to any part of the body to cause damage to major organs.

2. Internal - radioactive material inside the body

   a.) Routes of entry

      i.) Inhalation - most common

      ii.) Ingestion - common

      iii.) Absorption through the skin – less common

      iv.) Injection – least common

   b.) Deposition in body organs depends on the nuclide and chemical form; is generally independent of radiological characteristics.

   c.) Alpha particles are approximately 20 times more hazardous (Q=20) than beta particles and gamma photons per unit of energy absorbed.

      i.) High Linear Energy Transfer (LET) (high concentration of ion pairs)

      ii.) Greater concentration of damage to cells in a small volume of tissue

B. Cellular Effects of Radiation Dose

1. None - incident radiation has no interaction/effect in cell
2. Cell Repair - cell completely repairs damage
3. Cell Killing - cell is damaged to the extent that it cannot reproduce
4. Cell Transformation - cell is damaged but retains the ability to reproduce; mechanisms that control cell replication may be damaged so that cell divides in an uncontrolled fashion

C. Acute Effects of Radiation Dose

1. Types of exposures

   Chernobyl firemen
   Nuclear war
   Criticality accidents
   Other accidents (Brazil, Mexico, etc.)

2. Acute radiation sickness - cell killing

   a.) Hematopoietic syndrome
   b.) Gastro-intestinal syndrome
   c.) Central Nervous System (CNS) effects

3. Effect of fractionation of dose

D. Chronic Effects of Low Level Radiation Dose (Figures 6 and 7)

1. Chronic effects of radiation have not been observed in human populations
   a.) Inferred from animal studies
   b.) Epidemiological studies of populations exposed at relatively high radiation levels
      i.) Hiroshima and Nagasaki
      ii.) Medically irradiated patients
2. Increased risk of cancer is the principal concern with chronic exposure to radiation
   a.) Mechanism - radiation damages the cell and causes it to reproduce in an uncontrolled manner.

   b.) Dose response relationship - it is assumed that the increase in cancer risk is a linear function of incremental dose (linear-non-threshold assumption).

   c.) Risk estimates based on studies of Hiroshima and Nagasaki survivors.

3. Genetic effects
   a.) Genetic effects have not been observed in human populations but have been inferred from animal studies.

   b.) British studies have shown an increased risk of childhood leukemia among children whose fathers worked in a nuclear plant. However, this effect has not been seen in other populations such as the A-bomb survivors and individuals in areas with abnormally high background radiation levels. Most experts in radiation safety generally discount this effect.

   c.) Current wisdom: Genetic effects are not as significant as once believed to be.
4. Effects on the fetus
   a.) Birth defects seen at Hiroshima and Nagasaki at relatively high radiation doses (10-50 rads).

   b.) Increased risk of childhood leukemia among children irradiated in utero.

   c.) Increased risk of spontaneous abortion seen in female veterinary personnel who used diagnostic x-rays in their practices during pregnancy (two studies).

Figure 6. Direct and Indirect Effects of Radiation on Cells

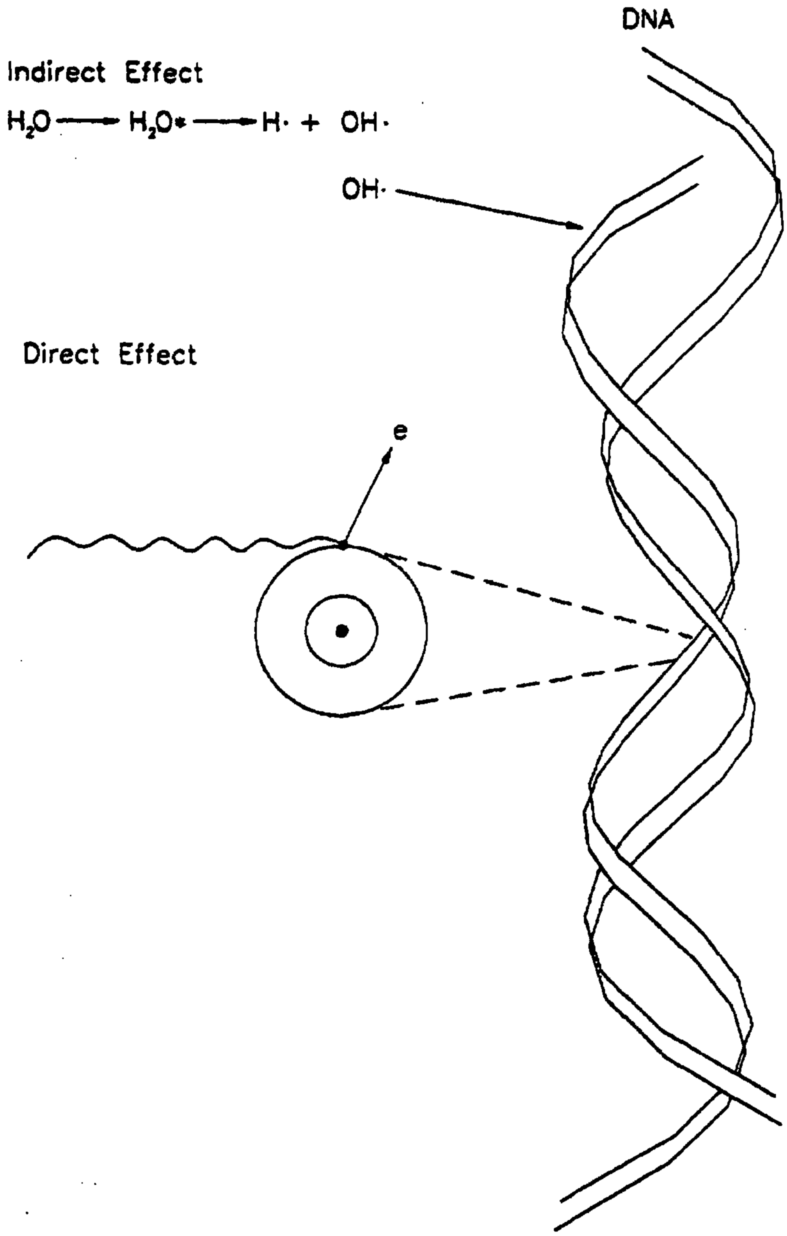
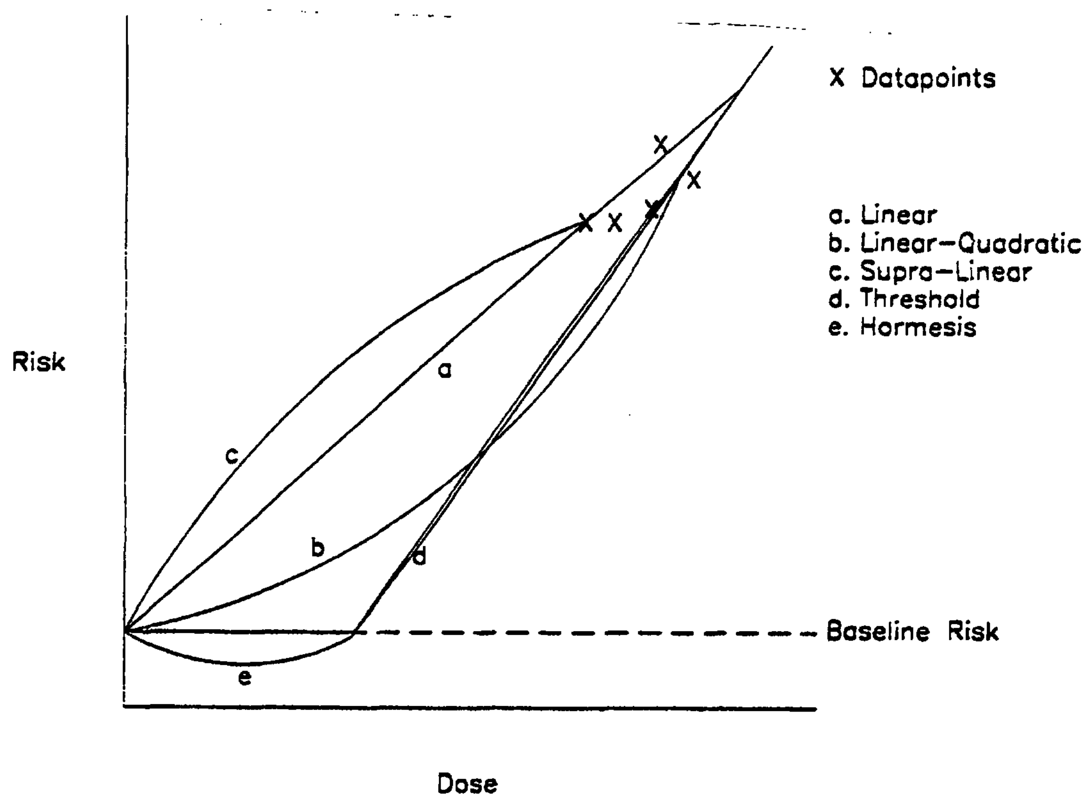


Figure 7. Radiation Dose Response Models



V. SOURCES OF RADIATION

A. Natural Background

Radiation has been a part of the environment since the world was formed. It comes from earth's crust, outer space, and internally deposited, naturally occurring radionuclides.

1. Cosmic Radiation - Comes from outer space; levels increase with altitude because there is a thinner blanket of atmosphere to absorb the radiation.

   Levels in Denver are twice the national average
   Levels in Leadville are twice the levels in Denver.

2. Terrestrial Radiation - naturally occurring radionuclides in the earth's crust.

   a.) Uranium series

   b.) Thorium series

   c.) ^{40}K

3. Internal radiation

   a.) Uranium series

   b.) ^{40}K

   c.) Other radionuclides (^3H, ^{14}C, etc.)

B. "Man-made" Radiation

1. Fallout from nuclear bomb testing and nuclear accidents
2. Medical x-rays
3. Consumer products - smoke detectors, TV screens, lenses
4. Reactors

C. Technologically Enhanced Radiation

Natural radioactivity which has been brought to the surface or used in a way which increases radiation dose to people.

1. Uranium mill tailings and other mining and milling waste
2. Indoor radon - shelter, energy conservation

D. Natural Background Radiation Levels

1. Background radiation levels depend on the location of residence, life-style factors.

Radiation Type	Average Annual Background Dose (mrem/yr)	
	U. S. Average	Denver
Cosmic	28	50
Terrestrial	28	82
Internal	39	39
Indoor Radon	200	400
Total	**295**	**571**

2. Other doses from natural background

   a.) Cross-country airplane flight - 2 mrem

   b.) One week of skiing at 10,000 ft. - 1 mrem

   c.) Living at 6,000 ft. rather than 5,000 ft. - 7 mrem/yr

   d.) Cigarette smoking: 1,300 mrem/yr

E. Typical Medical X-rays

1. Annual average - 50-100 mrem/yr
2. Chest x-ray - 10 mrem
3. Dental x-ray series - 5-10 mrem

F. Environmental and Occupational Doses

1. Mean for radiation worker - 100-200 mrem/yr
2. Limit for radiation worker - 5,000 mrem/yr
3. Excess Dose at the boundary of Rocky Flats - 1 mrem/yr

VI. COMPARISON OF VARIOUS LEVELS OF RADIATION DOSE

A. Acute Dose

1. Acute Radiation Sickness

   a.) Blood abnormalities observed - 50-100 rad

   b.) LD_{50}: 300-350 rad

   c.) Acute radiation sickness

      i.) Hematopoietic syndrome - >100 rad
      ii.) GI tract syndrome - >300 rad
      iii.) CNS effects - 1,000 rad

2. Fractionated doses or partial body irradiation reduces the severity of acute effects

B. Chronic Doses

1. Typical natural background: 0.2-0.3 rem/yr (including indoor radon)
2. Typical diagnostic x-rays: 0.01-1 rem
3. Maximum permissible dose to worker - 5 rem/yr
4. Maximum allowable dose to a member of the general public: 0.1 rem/yr
5. Maximum allowable dose to the fetus: 0.5 rem
6. Indoor radon: 0.1-10+ rem/yr

   Average U.S.: 0.2 rem/yr
   Average Colorado: 0.4 rem/yr

VII. RADIATION RISKS

A. Fatal Cancer

Risk coefficient calculated on the basis of Hiroshima and Nagasaki studies = 8×10^{-4} per rem

Risk coefficient adjusted for dose-rate effectiveness and non-fatal detriments = 6.2×10^{-4} per rem.

B. Genetic Effects (in first two generations)

1×10^{-4} per rem

C. Risk in Perspective

Estimated annual risk of fatality due to common activities

All risks from smoking	3.0 in 10^3
Cancer risk from smoking	1.2 in 10^3
Work in agricultural jobs	6.0 in 10^4
Motor vehicle accidents	2.4 in 10^4
Home accidents	1.1 in 10^4
Work in service and government jobs	1.1 in 10^4

Average lifetime risk from one year of exposure:

Indoor radon

Smoker	2.0 in 10^4
Non-smoker	3.0 in 10^5

Natural background (excluding radon)

Colorado	7.0 in 10^5
U.S. Average	4.0 in 10^5

EPA acceptable risk level for environmental contaminants (lifetime risk of 1 in 1,000,000)

Annual acceptable risk	2.0 in 10^8

VIII. RADIATION DETECTION

A. Gas Ionization (Figures 8 and 9)

Incident radiation produces ions in a gas; electrons are collected on an anode to produce an electrical pulse or a current.

1. Ionization Chambers - all ions produced directly by the radiation are collected on the anode to produce a pulse that is equal to the amount of energy deposited in the chamber. Pulse can be converted to current.

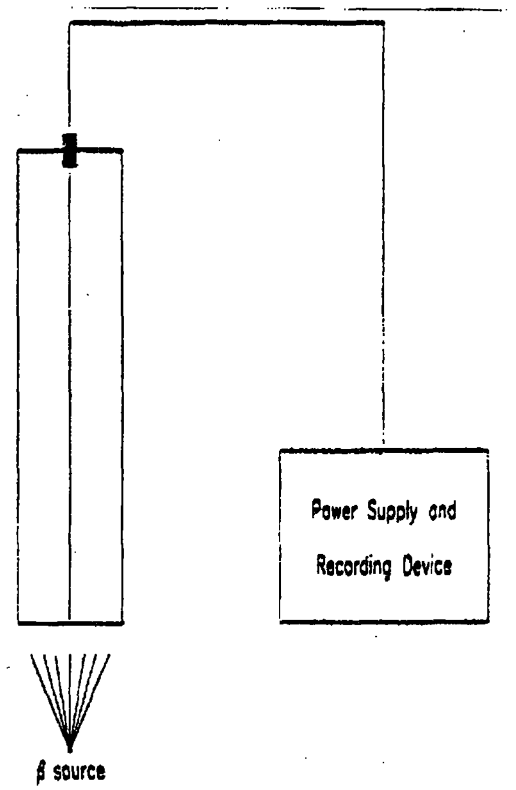
2. Proportional Counters - when the voltage on the anode is great enough, the electrons produced initially by the radiation may be given sufficient energy to cause "secondary" ionization.

   With proportional counters, alpha particles can be detected in the presence of betas.

3. GM Counters - when the voltage on the anode is high enough, the chamber may be saturated. That is, the size of the pulse is independent of the energy initially deposited in the chamber or tube by the radiation. As long as one ion pair is formed in the tube, the size of the pulse will be equal to the maximum. GM counters cannot discriminate between different types of radiation.

GM counters are much more efficient for detecting betas than gammas and are usually used for detecting and quantifying surface contamination or activity of a sample.

Figure 8. Radiation Detection by Gas Ionization



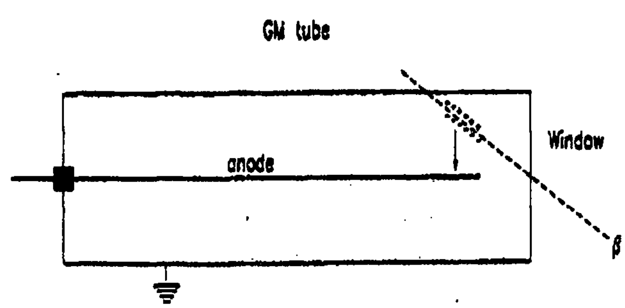
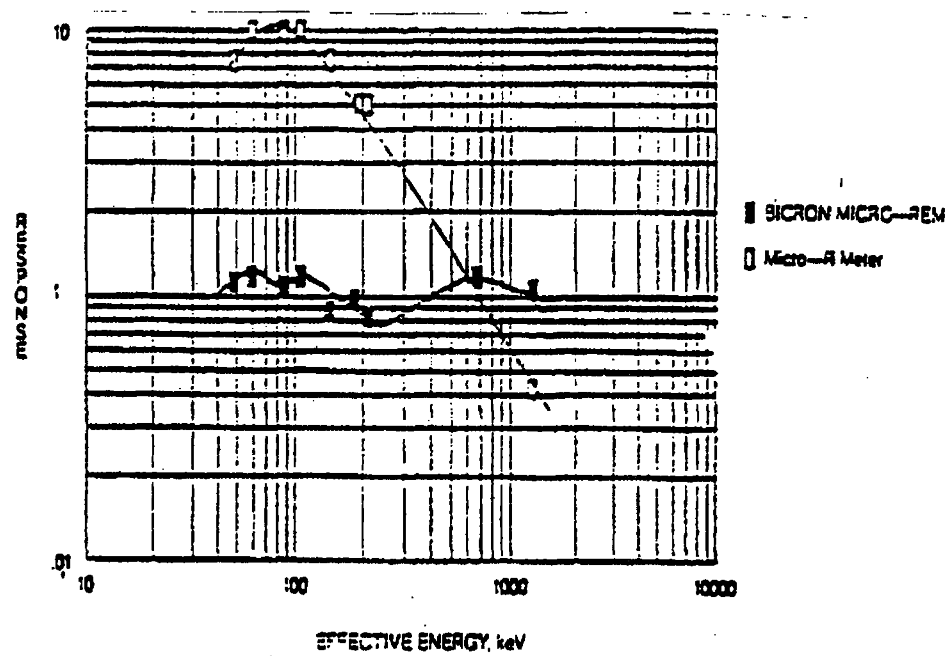


Figure 9. Log Scale Efficiency Chart



B. Scintillation (Figures 10, 11, 12 and 13)

Electrons in a crystal exist in a specific energy state (ground state) unless they are excited to a higher energy level. Radiation passing through a crystal can raise crystal electrons to the excited state in proportion to the amount of energy deposited in the crystal.

When excited electrons in certain crystals drop back down to the ground state they release light photons. These photons can be converted to an electrical pulse by the use of a photomultiplier tube. The size of the pulse is directly proportional to the amount of energy absorbed by the crystal.

1. Gamma and X-ray Survey Meters (NaI crystals)
   a.) Gamma scintillometer - moderate to high energy gammas and x-rays
   b.) Thin crystal scintillometers - low energy x-rays and gammas
2. Alpha Survey Meters (ZnS Crystal)
3. Gamma Spectrometers (NaI Crystals)
4. Liquid Scintillation Counters

C. Personal Monitors

1. Purpose
   a. Integrated measurement of radiation doses from various types of radiation
   b. Provide documented radiation exposure records
2. Types
   a. Film Badges - α, β, n
   b. Thermoluminescent Dosimeters (TLDs) – γ, X-ray, n
   c. Workspace/Breathing Zone Air Particulate Detectors – various emissions; physical collection medium

D. Semi-Conductors

1. GeLi Detectors - γ Spectroscopy
2. Surface Barrier Detectors - α Spectroscopy

Figure 10. Radiation Detection by Scintillation

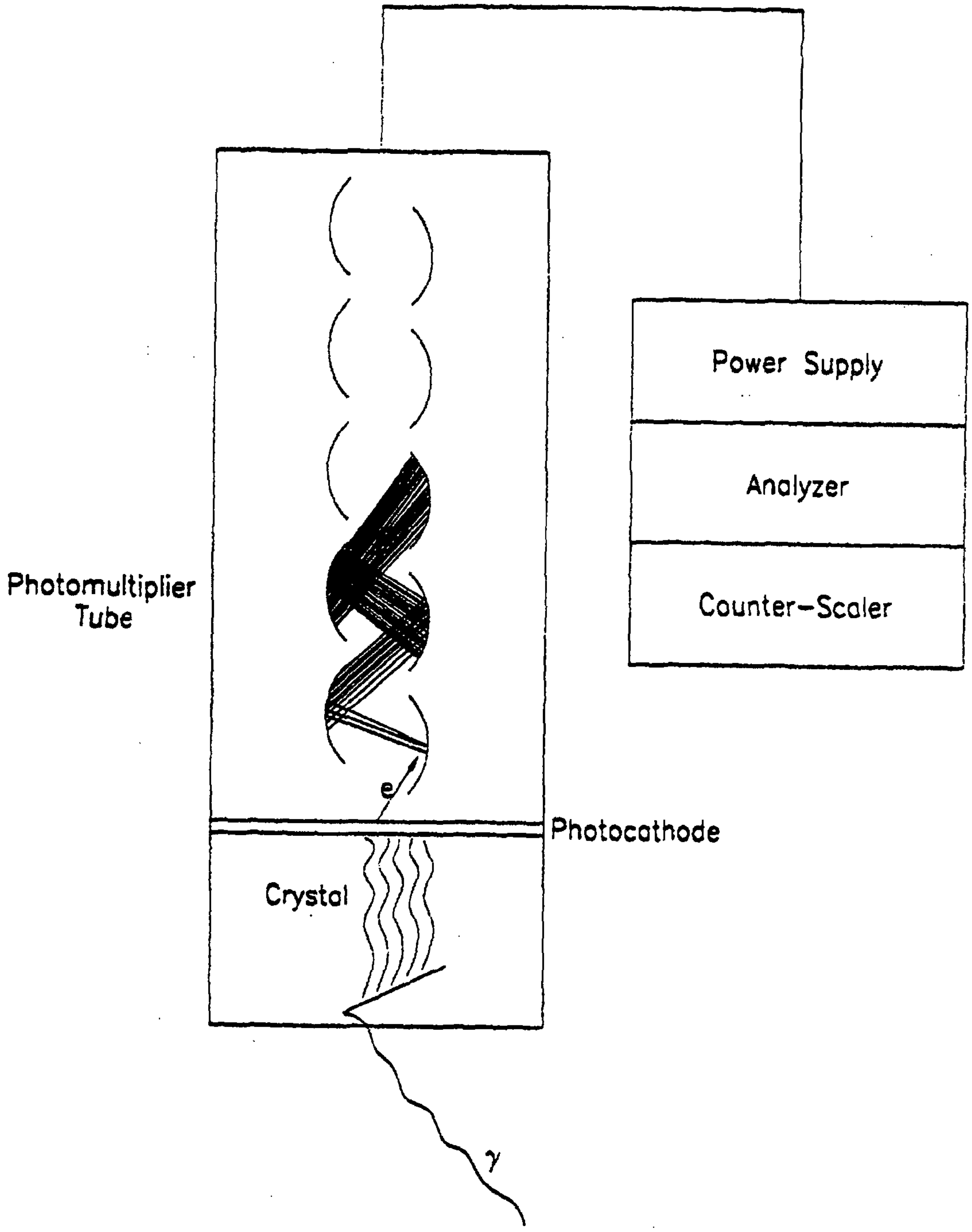


Figure 11. Pulse Size versus Voltage

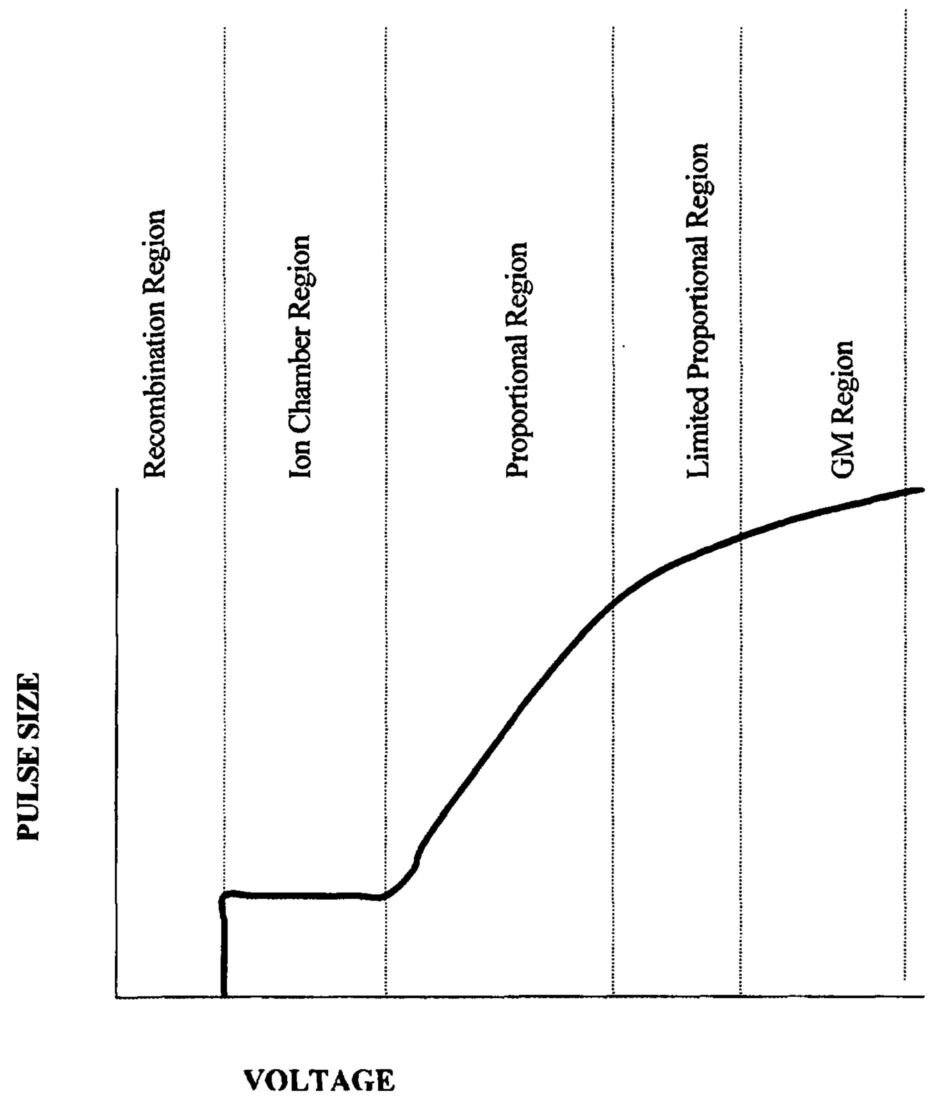


Figure 12. Typical Alpha Spectrum

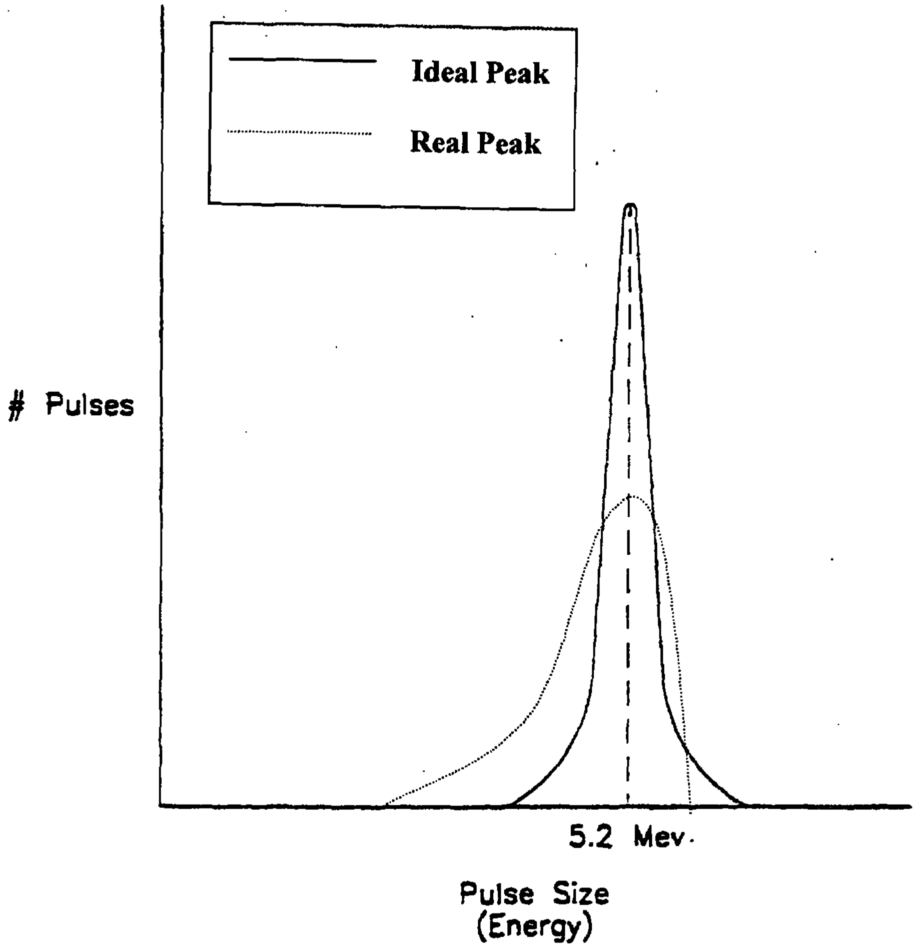
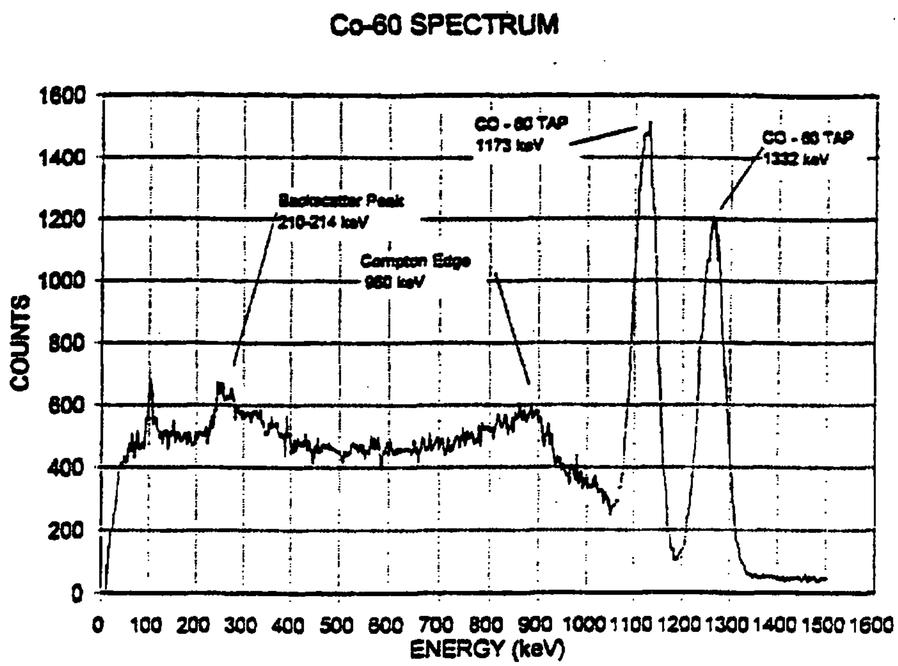
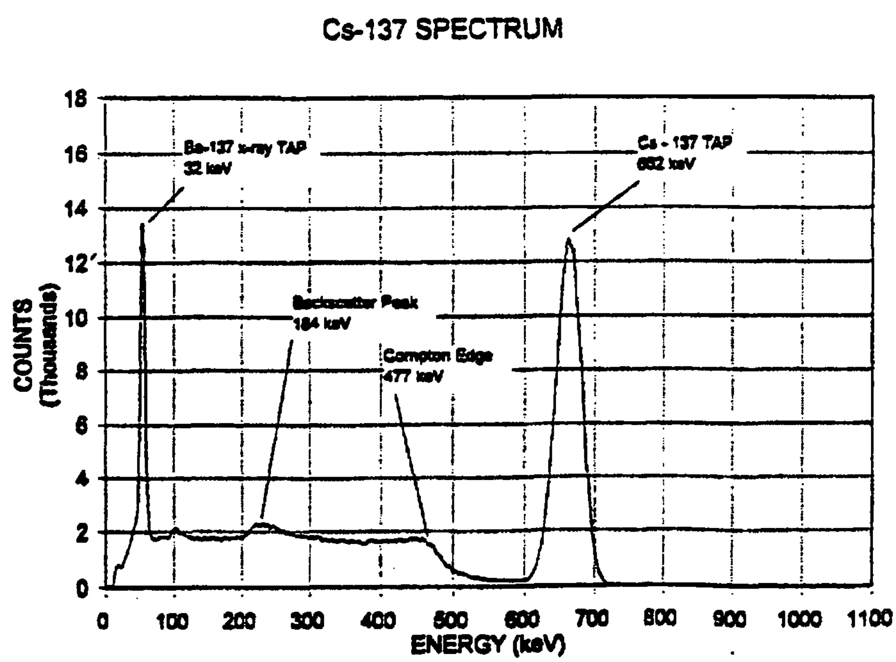


Figure 13. Typical Gamma Ray Spectrum





IX. STANDARDS AND REGULATIONS

A. Process

1. EPA provides guidance that is binding on other regulatory agencies - recommends radiation safety standards.

2. Nuclear Regulatory Commission (NRC) regulates "byproduct" and "source" material - issues licenses for use of radioactive materials.

3. Agreement States accept the responsibility for regulating the use of radioactive materials in place of the NRC.

   a.) Florida is an Agreement State

   Florida Department of Health, Bureau of Radiation Control
   Executive Director - ______________________________
   Radioactive Materials Section Director - ______________

   b.) Wyoming is not an Agreement State - NRC regulates use of radioactive materials.

4. Radiation producing machines such as x-ray machines are generally regulated by the state.

5. Nuclear reactors are regulated by the NRC.

B. Regulations

1. Federal - 10 CFR 20

   Based on the 1977 recommendations of the International Commission on Radiological Protection (ICRP). The ICRP revised its 1977 recommendations in 1991. It will be at least 10 years before the new recommendations are implemented in the United States.

2. State – Florida Radiation Control Regulations (64E-5)

   State regulations must conform to a standard set by the Conference of Radiation Control Directors (CRCPD). State standards must be at least as stringent as NRC standards.

C. Table of Radiation Safety Standards

Radiation Worker	Component(s)	Dose Equivalent
Total Effective Dose Equivalent[1]	$H_d + H_{E,50}$	5 rem/year
Single Organ Dose Equivalent	Organ $H_d + H_{T,50}$	50 rem/year
Lens of the Eye	Lens Dose Equivalent	15 rem/year
Skin or any Extremity	Shallow Dose Equivalent	50 rem/year
Worker Under 18	TEDE	0.5 rem/year
Fetus (Declared Pregnant Worker)[2]	TEDE	0.5 rem/gestation period
Annual Limit of Intake[3]	ALI	Nuclide Specific
Derived Air Concentration[4]	DAC	Nuclide Specific
General Public		
Any member	TEDE	0.1 rem/year
Specific member with prior approval of the regulatory agency	TEDE	0.5 rem/year

(1) Total Effective Dose Equivalent (TEDE) is the sum of the internal effective dose equivalents and the external dose equivalents.

(2) The worker must declare the pregnancy in writing to the employer in order for the dose limit to the fetus to be implemented.

(3) Annual Limit of Intake is that intake of a radionuclide that will result in a committed effective dose equivalent of 5 rem for a worker or 100 mrem for the general public.

(4) Derived Air Concentration (DAC) is that concentration of a radionuclide in air which will result in a committed effective dose equivalent to a worker of 5 rem if inhaled for 2,000 hours/year or a committed effective dose equivalent of 100 mrem to a member of the general public if inhaled for 8,760 hours/year.

X. BASIC RADIATION SAFETY

A. Basic Principles of Radiation Safety

1. Justification
2. Optimization

   ALARA - keep doses As Low As Reasonably Achievable, social and economic factors being taken into account.

3. Limitation

B. Protection Against External Radiation

1. Time of exposure
2. Distance from the source
3. Shielding
   a.) Types
      - Concrete walls
      - Lead aprons and gloves

   b.) Reduction in dose due to shielding is an exponential function with shielding thickness.

C. Protection Against Internal Radiation
(same as for any contaminant)

1. Prevent ingestion
2. Prevent inhalation
3. Prevent absorption/injection through the skin
4. Control methods
   a.) Isolation - ventilation, hoods, shielding
   b.) Substitution
   c.) Good housekeeping
   d.) Administrative controls
   e.) Personal protective devices - respirators, gloves, anti-Cs

XI. COMMONLY USED CALCULATIONS

A. Specific Activity (activity per unit mass)

$$A = \lambda N$$

where:

$A \equiv$ activity (Bq/g)
$\lambda \equiv$ decay constant $= \ln 2/T_{1/2}$
$N \equiv$ number of atoms present
$T_{1/2} \equiv$ nuclide half-life

B. Decay

$$A_t = A_0 e^{-\lambda t}$$

where:

A_t	≡ activity at time t
A_o	≡ activity at time zero
λ	≡ decay constant = ln $2/T_{1/2}$
$T_{1/2}$	≡ nuclide half-life
t	≡ time

C. Inverse Square Law

Exposure from a source is inversely proportional to the square of the distance from the source. This is applicable to a photo-emitting source whose largest dimension is small with respect to its distance from the exposure point.

$$X_1/X_2 = (d_2/d_1)^2$$

XII. RADON

A. Natural Radioactivity in the Earth's Crust

1. ^{40}K
   - a.) Natural abundance - 0.0119%
   - b.) Total in the body - 140 g (0.12 μCi)
2. Uranium
   - a.) Decay scheme (Figures 14 and 15)
   - b.) Concentration in the earth's crust - 4 ppm
   - c.) Concentration in typical ore - 0.2%
   - d.) Concentration of radium in soil
     - i.) Background: 1-5 pCi/g
     - ii.) Limits for clean-up of contaminated sites

       5 pCi/g in the first 15 cm
       15 pCi/g below the first 15 cm
3. Thorium
   - a.) Decay scheme (Figure 16)
   - b.) Concentration in the earth's crust ~ 10 ppm

B. Radon Gas - Decay Product of Uranium

1. History
   - a.) Occupational exposure

     1500s - Central Europe - lung disease in miners noted

1879 - Miners' disease recognized as cancer

1932 - Radon gas implicated as the cause

1954 - Prospective study of US miners initiated

1960s - Radon daughters generally accepted as the causative agent

b.) Residential exposure (indoor radon)

1970s - Health physics profession expressed concern due to energy conservation
Scandinavian studies published

1984 - Watras house in Pennsylvania - Reading Prong

1986 - EPA guidelines published

1990s - Building regulations

c.) Terminology

i.) Working Level (WL) - 100 pCi / L radon in equilibrium with its short-lived daughters or any combination of daughters with an equivalent energy potential (1.3×10^5 MeV total alpha energy through complete decay)

ii.) Working Level Month (WLM)

WLM = WL x hours exposed / 170 hours / month

d.) Regulations and guidelines

i.) Occupational

Current MSHA - 4 WLM / yr

Proposed MSHA - 1 WLM / yr

NIOSH recommendation - 1 WLM / yr

Average for underground uranium miners in the 1980s - 1 WLM / yr

ii.) Indoor radon (occupational and residential)

EPA Guideline - 4 pCi / L - 0.8 WLM / yr

NCRP Recommendation - 2 WLM / yr

Mean US - 0.2 WLM / yr (1 pCi / L)

Mean Denver - 0.5 WLM / yr (2.5 pCi / L)

C. Biological Effects of Inhalation of Radon Daughters

1. Deposition of daughters attached to particulates in upper bronchial tree
2. Deposition of unattached daughters in the upper respiratory tract
3. Irradiates bronchial epithelium (basal cells)
4. Cancer induction in the upper bronchial region

Figure 14. Decay Scheme for Uranium 238

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities†		
			α	β	γ
$^{238}_{92}U$	Uranium I	4.51×10^{9}y	4.15 (25%) 4.20 (75%)	---	---
$^{234}_{90}Th$	Uranium X_1	24.1d	---	0.103 (21%) 0.193 (79%)	0.063c‡ (3.5%) 0.093c (4%)
$^{234}_{91}Pa^{*}$ (99.87% / 0.13%)	Uranium X_2	1.17m	---	2.29 (98%)	0.765 (0.30%) 1.001 (0.60%)
$^{234}_{91}Pa$	Uranium Z	6.75h	---	0.53 (66%) 1.13 (13%)	0.100 (50%) 0.70 (24%) 0.90 (70%)
$^{234}_{92}U$	Uranium II	2.47×10^{5}y	4.72 (28%) 4.77 (72%)	---	0.053 (0.2%)
$^{230}_{90}Th$	Ionium	8.0×10^{4}y	4.62 (24%) 4.68 (76%)	---	0.068 (0.6%) 0.142 (0.07%)
$^{226}_{88}Ra$	Radium	1602y	4.60 (6%) 4.78 (95%)	---	0.186 (4%)
$^{222}_{86}Rn$	Emanation Radon (Rn)	3.823d	5.49 (100%)	---	0.510 (0.07%)
$^{218}_{84}Po$ (99.98% / 0.02%)	Radium A	3.05m	6.00 (~100%)	0.33 (~0.019%)	---
$^{214}_{82}Pb$	Radium B	26.8m	---	0.65 (50%) 0.71 (40%) 0.98 (6%)	0.295 (19%) 0.352 (36%)
$^{218}_{85}At$	Astatine	~2s	6.65 (6%) 6.70 (94%)	? (~0.1%)	---
$^{214}_{83}Bi$ (99.98% / 0.02%)	Radium C	19.7m	5.45 (0.012%) 5.51 (0.008%)	1.0 (23%) 1.51 (40%) 3.26 (19%)	0.609 (47%) 1.120 (17%) 1.764 (17%)
$^{214}_{84}Po$	Radium C'	164μs	7.69 (100%)	---	0.799 (0.014%)
$^{210}_{81}Tl$	Radium C"	1.3m	---	1.3 (25%) 1.9 (56%) 2.3 (19%)	0.296 (80%) 0.795 (100%) 1.31 (21%)
$^{210}_{82}Pb$	Radium D	21y	3.72 (.000002%)	0.016 (85%) 0.061 (15%)	0.047 (4%)
$^{210}_{83}Bi$ (~100% / .00013%)	Radium E	5.01d	4.65 (.00007%) 4.69 (.00005%)	1.161 (~100%)	---
$^{210}_{84}Po$	Radium F	138.4d	5.305 (100%)	---	0.803 (0.0011%)
$^{206}_{81}Tl$	Radium E"	4.19m	---	1.571 (100%)	---
$^{206}_{82}Pb$	Radium G	Stable	---	---	---

Figure 15. Decay Scheme for Uranium 235

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities†		
			α	β	γ
$^{235}_{92}$U	Actinouranium	7.1 ×10^{8}y	4.37 (18%) 4.40 (57%) 4.58c‡ (8%)	---	0.143 (11%) 0.185 (54%) 0.204 (5%)
$^{231}_{90}$Th	Uranium Y	25.5h	---	0.140 (45%) 0.220 (15%) 0.305 (40%)	0.026 (2%) 0.084c (10%)
$^{231}_{91}$Pa	Protoactinium	3.25x10^{4}y	4.95 (22%) 5.01 (24%) 5.02 (23%)	---	0.027 (6%) 0.29c (6%)
$^{227}_{89}$Ac 98.6% 1.4%	Actinium	21.6y	4.86c (0.18%) 4.95c (1.2%)	0.043 (~99%)	0.070 (0.08%)
$^{227}_{90}$Th	Radioactinium	18.2d	5.76 (21%) 5.98 (24%) 6.04 (23%)	---	0.050 (8%) 0.237c (15%) 0.31c (8%)
$^{223}_{87}$Fr	Actinium K	22m	5.44 (~0.005%)	1.15 (~100%)	0.050 (40%) 0.080 (13%) 0.234 (4%)
$^{223}_{88}$Ra	Actinium X	11.43d	5.61 (26%) 5.71 (54%) 5.75 (9%)	---	0.149c (10%) 0.270 (10%) 0.33c (6%)
$^{219}_{86}$Rn	Emanation Actinon (An)	4.0s	6.42 (8%) 6.55 (11%) 6.82 (81%)	---	0.272 (9%) 0.401 (5%)
$^{215}_{84}$Po ~100% .00023%	Actinium A	1.78ms	7.38 (~100%)	0.74 (~.00023%)	---
$^{211}_{82}$Pb	Actinium B	36.1m	---	0.29 (1.4%) 0.56 (9.4%) 1.39 (87.5%)	0.405 (3.4%) 0.427 (1.8%) 0.832 (3.4%)
$^{215}_{85}$At	Astatine	~0.1ms	8.01 (~100%)	---	---
$^{211}_{83}$Bi 0.28% 99.7%	Actinium C	2.15m	6.28 (16%) 6.62 (84%)	0.60 (0.28%)	0.351 (14%)
$^{211}_{84}$Po	Actinium C'	0.52s	7.45 (99%)	---	0.570 (0.5%) 0.90 (0.5%)
$^{207}_{81}$Tl	Actinium C"	4.79m	---	1.44 (99.8%)	0.897 (0.16%)
$^{207}_{82}$Pb	Actinium D	Stable	---	---	---

Figure 16. Decay Scheme for Thorium 232

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities†		
			α	β	γ
${}^{232}_{90}Th$	Thorium	1.41×10^{10}y	3.95 (24%) 4.01 (76%)	---	---
${}^{228}_{88}Ra$	Mesothorium I	6.7y	---	0.055 (100%)	---
${}^{228}_{89}Ac$	Mesothorium II	6.13h	---	1.18 (35%) 1.75 (12%) 2.09 (12%)	0.34c‡ (15%) 0.908 (25%) 0.96c (20%)
${}^{228}_{90}Th$	Radiothorium	1.910y	5.34 (28%) 5.43 (71%)	---	0.084 (1.6%) 0.214 (0.3%)
${}^{224}_{88}Ra$	Thorium X	3.64d	5.45 (6%) 5.68 (94%)	---	0.241 (3.7%)
${}^{220}_{86}Rn$	Emanation Thoron (Tn)	55s	6.29 (100%)	---	0.55 (0.07%)
${}^{216}_{84}Po$	Thorium A	0.15s	6.78 (100%)	---	---
${}^{212}_{82}Pb$	Thorium B	10.64h	---	0.346 (81%) 0.586 (14%)	0.239 (47%) 0.300 (3.2%)
${}^{212}_{83}Bi$ 64.0% 36.0%	Thorium C	60.6m	6.05 (25%) 6.09 (10%)	1.55 (5%) 2.26 (55%)	0.040 (2%) 0.727 (7%) 1.620 (1.8%)
${}^{212}_{84}Po$	Thorium C'	304ns	8.78 (100%)	---	---
${}^{208}_{81}Tl$	Thorium C"	3.10m	---	1.28 (25%) 1.52 (21%) 1.80 (50%)	0.511 (23%) 0.583 (86%) 0.860 (12%) 2.614 (100%)
${}^{208}_{82}Pb$	Thorium D	Stable	---	---	---

SUPPLEMENTAL INFORMATION

ATTACHMENT 3

Facility Floor Plan