RADIATION WORKER HANDBOOK

AND TRAINING MANUAL

FOR REMCOR INC.

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1. INTRODUCTION

This manual is intended to convey the minimum necessary information needed by personnel who work or intend to work with radioactive materials. This includes all NES personnel performing radiological work.

The manual presents the basic definitions, terms, and responsibilities which are inherent in radiation work. It is intended to be used both by the novice and as a refresher for veteran radiation workers.

2. REFERENCES

1. Kaplan, "Nuclear Physics"; Addison-Wesley, Mass, 1962.

2. Fitzgerald, et.al., "Mathematical Theory of Radiation Dosimetry"; Gordon & Breach, New York, 1967.

3. Miner(ed), "Ionizing Radiation and the Cell"; New York Academy of Sciences.

4. Title 10, Code of Federal Regulations, Part 19, "Notices, Instructions, and Reports to Workers; Inspections".

5. Title 10, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation".

6. Title 29, Code of Federal Regulations, Chapter XX, "Occupational Safety and Health Administration, Dept. of Labor", Part 1910.

7. NES, "Emergency Actions Procedure".

8. NES, "Surface Contamination Program".

3. A SHORT COURSE IN NUCLEAR PHYSICS

An elementary knowledge of the nature of matter and radiation will aid in the understanding of where radiation comes from and how to control it. It has often been observed that certain basic misconceptions lead to incorrect application of instruments, data, or risk assessment.

While details of atomic structure and elementary particle physics are not required here, a basic idea of the structure of the atom limited to our needs shall be presented. The atom consists of a small nucleus within a larger cloud of electrons. Electrons are negatively charged particles of small mass. The nucleus is composed of protons (positively charged) and neutrons (no charge) whose masses are close to each other, but are approximately 1800 times more massive than an electron.

Atoms can be presented by the following shorthand.

$_{92}U^{235}$ = Uranium
92 protons
235-92=143 neutrons
235 units of total weight
(electron weight is insignificant)

The same chemical element can have several isotopes, which vary only in the number of neutrons.

ex: $\left.\begin{matrix} U^{233} \\ U^{235} \\ U^{238} \end{matrix}\right\}$ **All uranium, with 92 protons, but they have 141, 143 and 146 neutrons each.**

Some isotopes are naturally unstable and become more stable (decay) by emitting radiation. Other isotopes can be made to be unstable and also decay by emission of radiation.

The types of decay radiation to be considered are:

beta	-	negatively charged, with a mass of an electron
alpha	-	positively charged, a package composed of 2 protons and 2 neutrons
gamma	-	electromagnetic radiation of no charge or appreciable mass
neutron	-	no charge, essentially an escaping particle from a nucleus which has too many to be stable

After an isotope emits radiation of these types it is more stable. It may emit any combination of the above radiations, and may do so simultaneously or in a series. The resulting atom still may be relatively unstable and perform further decay. This leads to the formation of a series of "daughters" which ultimately lead to a stable (non-radioactive) isotope.

Each isotope decays at a constant rate. The time it takes for 1/2 of the original substance to decay into another substance is called its half-life. The radiation emitted during this decay is always the same both by type and energy for a given isotope. This combination of data is used to measure and guard against the radiation emitted in this process.

If radioactive material is inhaled, swallowed, or otherwise ingested, it will have a specific biological half-life. That is, a period of time after which the body has excreted one half of the original amount. The effective biological half-life can be represented as a combination of radioactive and biological reduction in the quantity of internally deposited material as follows:

$$T\ 1/2\ \text{eff.} = \frac{(\text{BIO } T\ 1/2)\ (\text{RAD. } T\ 1/2)}{(\text{BIO } T\ 1/2) + (\text{RAD. } T\ 1/2)}$$

Where

T 1/2 eff. = effective half-life of a radioactive substance in the body

Bio T 1/2 = biological half-life of the substance

RAD T 1/2 = radioactive half-life of the substance

4. DEFINITIONS

Activity — The number of nuclear transformations (disintegrations) occurring in a given quantity of material per unit time. (See Curie)

Alpha Particle — A charged particle emitted from the nucleus of an atom having a mass and a charge equal in magnitude to a helium nucleus; i.e., two protons and two neutrons. (Symbol: α)

Analyzer, Pulse Height Multi-channel — An electronic circuit which sorts and records pulses according to height (also known as an MCA).

Atom — The smallest unit of an element that retains the chemical properties of that element.

Beta Particle — Charged particle emitted from the nucleus of an atom, with the mass and charge equal in magnitude to that of the electron. (Symbol: β)

Calibration — Determination of variation from standard, or accuracy, of a measuring instrument needed to ascertain necessary correction factors.

Chamber, Ionization — An instrument designed to measure a quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

Contamination, Radioactive — Deposition of radioactive material in any place where it is not desired, particularly where its presence may be harmful. This may interfere with an experiment or a procedure or be a source of biological hazard to personnel.

Controlled Area — Only applies to controlled surface contamination areas, to an area which contains one or more controlled surface contamination area(s), or an area which is established as a Special Area per Reference 8.

Count (Radiation Measurement) The external indication of a device designed to enumerate ionizing events. It may refer to a single detected event or to the total number registered in a given period of time. The term is often erroneously used to designate a disintegration, ionizing event, or voltage pulse.

Note: Spurious count - In a radiation counting device, a count caused by any agency other than radiation.

Counting Ratemeter An instrument which gives a continuous indication of the average rate of ionizing events.

Curie The special unit of activity. One curie equals 3.700×10^{10} nuclear disintegrations per second, abbreviated Ci. Several fractions of the curie are in common usage:

Microcurie: One-millionth of a curie (3.7×10^4 disintegrations per second), abbreviated μCi.

Millicurie: One thousandth of a curie (3.7×10^7 disintegrations per second), abbreviated mCi.

Nanocurie: One-billionth of a curie (37 disintegrations per second), abbreviated nCi.

Picocurie: One-millionth of a microcurie (3.7×10^{-2} disintegrations per second or 2.22 disintegrations per minute), abbreviated pCi.

Decay, Radioactive Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons.

Detector, Radiation Any device for converting radiant energy to a form more suitable for observation. An instrument used to determine the presence and the amount of radiation.

Disintegration A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus. When numbers of nuclei are involved, the process is characterized by a definite half-life. (Symbol: dis or DIS)

Dose A general form denoting the quantity of radiation or energy absorbed. For special purposes it must be appropriately qualified. If unqualified, it refers to absorbed dose.

Absorbed Dose: The energy imparted to matter by ionizing radiation per unit of irradiated material at the place of interest. The unit of absorbed dose is the Rad. One rad equals 100 ergs per gram. (See Rad)

Cumulative Dose (radiation): The total dose resulting from repeated exposures.

Dose Equivalent A quantity used in radiation protection. It expresses all radiations on common scale for calculating the effective absorbed dose. It is defined as the product of the absorbed dose in rads and certain modifying factors. (The unit of dose equivalent is the Rem)

Dose Rate Absorbed dose delivered per unit time.

Efficiency (Counters) A measure of the probability that a count will be recorded when radiation is incident on a detector. Usage varies considerably, so it is best to ascertain which factors (window transmission, sensitive volume, energy dependence, geometry, etc.) are included in a given case.

Error, Statistical Errors in counting due to the random time-distributions of disintegrations.

Exposure A measure of the ionization produced in air by "X" or gamma radiation. The special unit of exposure is the roentgen. (Abbreviated R) Several fractions of the roentgen are in common usage.

Microroentgen: one-millionth of a roentgen. (Abbreviated μR)

Milliroentgen: one-thousandth of a roentgen. (Abbreviated mR)

Fission The process by which the nucleus of an atom is split into 2 or more other atoms, which releases energy.

Fusion The process by which 2 or more light atomic nuclei combine to form another heavier nucleus.

Gamma Ray Short wavelength electromagnetic radiation (range of energy from approximately 10 keV to 9 MeV) emitted from the nucleus. Also referred to as photons. (Symbol: γ)

Geometry Factor The fraction of the total solid range about the source of radiation that is subtended by the face of the sensitive volume of a detector.

Quality Factor The quality factors for various types of radiation are simply proportionality factors that relate the biological effects, as expressed in rem, to the actual radiation energy absorbed.

Half-life, Radioactive Time required for half the amount of a radionuclide to decay into another nuclide. Each radionuclide has a unique half-life.

Ion A positively or negatively charged atom or particle.

Isotopes Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore the mass number. Almost identical chemical properties exist between isotopes of a particular element. The term should not be used as a synonym for nuclide.

Stable Isotope: A non-radioactive isotope of an element.

Milliroentgen (mR) A submultiple of the roentgen, equal to one-thousandth of a roentgen. (See Roentgen)

Monitoring Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in a region.

Area Monitoring: Routine monitoring of the radiation level or contamination of a particular area, building, room or equipment.

Personnel Monitoring: Monitoring any part of an individual for exposure to external radiation or of physical deposition of radioactive materials.

Nuclide A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons (Z), number of neutrons (N), and energy content; or alternatively, by the atomic number (Z), mass number A = (N + Z), and atomic mass.

Rad Amount of any radiation which will deposit 100 ergs of energy per gram of material.

Radiation (1) The emission and propagation of energy through space or a material medium in the form of waves. For example, energy in the form of electromagnetic waves. The term radiation or radiant energy usually refers to electromagnetic radiation and is commonly classified according to frequency, as Hertzian, infrared, visible (light), ultra-violet, x-ray and gamma ray.

(2) By extension, corpuscular emissions, such as alpha and beta radiation, or rays of unknown or mixed type, as cosmic radiation.

Background Radiation: Radiation arising from a radioactive source other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present.

External Radiation: Radiation from a source outside the body- the radiation must be capable of penetrating the skin.

Internal Radiation: Radiation from a source within the body (as a result of deposition of radionuclides in body tissues).

Ionizing Radiation: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

Radioactivity — The property of certain nuclides to spontaneously emit particles or gamma radiation or of emitting "X" radiation following orbital electron capture or of undergoing spontaneous fission.

Artificial Radioactivity: Man-made radioactivity produced by particle bombardment or electromagnetic irradiation, as opposed to natural radioactivity.

Induced Radioactivity: Radioactivity produced in a substance after bombardment with neutrons or other particles. The resulting activity is "natural radioactivity" if formed by nuclear reactions occurring in nature, and "artificial radioactivity" if the reaction was caused by man.

Rem — Amount of radiation which will cause damage to the tissue of our bodies equivalent to the damage that would be caused by absorbing 100 ergs of X-ray or gamma radiation per gram of body tissue. The rem accounts for the biological damage caused by different types of radiation.

Roentgen (R) — Amount of X-ray or gamma radiation which will deposit 88 ergs of energy in one gram of dry air or 100 ergs of energy in one gram of body tissue.

Spectrum, Energy A visual display or a plot of the distribution of the intensity of radiation of a given kind as a function of its energy.

Standard, Radioactive A sample of radioactive material, usually with a long half-life, in which the number and type of radioactive atoms at a definite reference time is known. It may be used as a radiation source for calibrating radiation measurement equipment. Standards are traceable to those of the National Bureau of Standards.

Survey, Radiological Evaluation of the radiation hazards incident to the production, use or existence of radioactive materials or other sources of radiation under specific conditions. Such an evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that may be involved, and sufficient knowledge of processes using or affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.

X-ray Penetrating electromagnetic radiations whose wave lengths are shorter than those of visible light. In nuclear reactions, it is customary to refer to photons originating in the extranuclear part of the atom as x-rays.

5. RIGHTS AND RESPONSIBILITIES

Radiation workers are protected by certain standards of the Federal Government. These standards are defined in Title 10, Code of Federal Regulations, Parts 19 and 20. Conventional worker safety is controlled at the Federal level by standards published by the Occupational Safety and Health Administration (OSHA).

In accordance with 10 CFR 19, copies of both 10 CFR 19 and 10 CFR 20 must be posted in the workplace. These documents present details of the following summarized standards. These standards are Federal law.

Each employee has the right to know what his yearly exposure to radiation has been upon request. This request shall be made in writing. The worker also has the right to know his exposure at other times besides yearly (i.e., termination of a job, etc.)

In accordance with these regulations, a radiation worker has a professional obligation to notify his supervisors and/or superiors of conditions or actions which he feels are in violation of these acts and endanger the safety of company personnel and/or the general public.

In accordance with 10 CFR 20, radiation exposure to workers is limited to those as summarized below:

1. Whole body: head, trunk, active blood forming organs, lens of eyes, or gonads....1,250 mRem/calendar quarter

2. Hands and forearms, feet and ankles....18,750 mRem/calendar quarter

3. Skin of whole body....7,500 mRem/calendar quarter

Also, the total whole body dose (Rems) shall not exceed:

5 x (N-18) where N = age of worker

NRC Form #4 shall keep account of a person's lifetime dose (amount plus when and where received). In addition to exposure, 10 CFR 20 also addresses inhalation and/or ingestion of radioactive materials. Exposure to minors and the amount of permissible radiation in uncontrolled areas (i.e., to the general public) are also addressed.

Furthermore, 10 CRF 20 addresses radiation operating practices, sign postings, waste material release limits, and certain packaging limitations.

6. RISK

Radiation of various types is commonly used in medical practices (x-ray, cancer therapy) and the benefits derived are judged to exceed the risks involved. Radiation exposure to radiation workers not medically oriented is considered to entail risk increasing with dose and shall be limited by NES to doses as low as reasonably achievable (ALARA).

The risk from radiation varies with the amount, type, and energy of the radiation. It also varies with where on the body you receive it. Since your fingers and toes contain no vital organs or major blood producing areas, you can safely receive more gamma radiation there than is permitted to the trunk of the body.

Radiation damages cells. Enough radiation will damage enough cells to make you feel sick. Enough will kill you. Refer to Table 1 for a listing of effects at increasing dosage. Note that the level at which damage is first detectable is <u>substantially</u> larger than the amount you may be allowed to receive legally.

Radiation damage can be related by analogy to any number of common injuries. If you are hit by a baseball or by particle radiation (beta, alpha, neutron) you will be harmed. If you stay in the sun too long or receive gamma radiation, you will be harmed. The <u>degree</u> of harm is what matters in risk assessment. In both conventional and radiation injury, the body will repair itself to a degree. For example, if you lose a small amount of blood you will self-repair; if you receive a slight sunburn, you will self-repair. At low levels of blood loss (i.e., a cut finger) or low levels of radiation (i.e., below the legal limit) no noticeable harm is done to the person as a whole. Although there is a limit below which no detectable damage from radiation occurs, regulatory agencies have assumed conservatively that damage always occurs at any level of exposure.

The natural radiation background (sunlight, soil, food, air) exposes you to small amounts of radiation daily. It is thought this is where man has obtained his ability to repair low level radiation damage; we are subject to it all our lives. A comparison of common sources of exposure is shown in Table 2. The damage from radiation measured or anticipated in the following tables indicates that such harm is an accumulation of probabilities. While the effect of individual particles or waves of radiation on a single cell may be calculated, the cumulative effect on a specific individual can only be estimated by comparison with known results of exposures to large populations.

The damaging effects of radiation fall into two categories:

Somatic - harm to the individual
Genetic - harm to future generations

In addition, the amount of time over which a radiation dose occurs determines the degree of damage:

Acute exposure - a large amount in a short time
Chronic exposure - a small amount over a long time

The effects of radiation damage generally are referred to by one of the following terms:

latent - damage showing up after time has elapsed (i.e., cancer, genetic damage)
immediate - damage showing up after or during exposure.

TABLE 1

EFFECTS OF RADIATION

Level, Rem (Acute Exposure)	Probable Effect
0 to 50	No obvious effect, except possibly minor blood changes.
80 to 120	Vomiting and nausea for about 1 day in 5 to 10 percent of exposed personnel. Fatigue but no serious disability.
130 to 170	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 25% of personnel. No deaths anticipated.
180 to 220	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 50 percent of personnel. No deaths anticipated.
270 to 330	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness. About 20 percent deaths within 2 to 6 weeks after exposure; survivors convalescent for about 3 months.
400 to 500	Vomiting and nausea in all personnel on first day, followed by other symptoms of radiation sickness. About 50 percent deaths within 1 month; survivors convalescent for about 6 months.
500 to 750	Vomiting and nausea in all personnel within 4 hours from exposure, followed by other symptoms of radiation sickness. Up to 100 percent deaths; few survivors convalescent for about 6 months.
1000	Vomiting and nausea in all personnel within 1 to 2 hours. Probably no survivors from radiation sickness.
5000	Incapacitation almost immediately. All personnel will be fatalities within 1 week.

TABLE 2
SOURCES OF RADIATION
(1 rem = 1000 millirem)

	Annual Radiation Exposure (millirem/yr)
I. Natural Radiation Sources	
A. Cosmic (from outer space)	
Connecticut and Massachusetts	40
Colorado	120
B. Terrestrial (from the earth's surface)	
Connecticut	60
Massachusetts	75
Colorado	105
C. Food Consumed and the human body itself	25
Subtotal	
Connecticut	125
Massachusetts	140
Colorado	250
II. Technologically Enhanced Exposures to Natural Sources	
A. Radioactivity in Building Materials (varies from wood frame to brick to stone)	12-34
B. Air Travel (round trip cross country)	4
C. Natural Gas (randon-222)	
Cooking (lung)	15
Heating (lung)	54

TABLE 2 (continued)

SOURCES OF RADIATION

(1 rem = 1000 millirem)

			Annual Radiation Exposure (millirem/yr)
	D.	Smoking (1 pack/day) - certain areas of lung	Up to 2000
		- whole body	2 to 20
III.	Man-made Sources		
	A.	Medical Uses of Radiation for Diagnosis (per capita)	103
		One Chest X-ray	30 to 70
	B.	Global Fallout from Nuclear Weapons Testing	2
	C.	Consumer Products (TV)	0.15 x hrs/day
	D.	Nuclear Power Station (within 50 miles)	0.1
		At Site Boundary	1 to 3

TABLE 3

Comparative Occupational Risks

	Observed Fatal Injuries Per Million Worker-Years(1)	Observed Deaths From Occupational Diseases Per Million Worker-Years
All Industry	100	50 to 1,000(4)
Chemical	60	N/A
Electric Utilities	160	N/A
Construction	340	N/A
Lumber	360	N/A
Mining, Underground Coal	1,160	2,000 to 6,000
Mining, Surface	260	N/A
Underground Metal Miners(2)	N/A	12,400
Shipbuilding	60	N/A
Steel	120	5,700(5)
Transit	100	N/A
Wood Products	160	N/A
Asbestos Insulation Workers(3)	N/A	3,650
Uranium Miners(2)	N/A	2,320
Smelter Workers(2)	N/A	1,930
Commercial Nuclear Power Industry (Radiation related effects only)	None	From 40 to 80 (not observed, but based on statistical calculations)

N/A = Data Not Available

1 From "Work Injury Rates" (1977), National Safety Council.

2 "The President's Report on Occupational Safety and Health", Commerce Clearing House, May 22, 1972, pages 11 and 128.

3 Irving J. Selikoff and William J. Nicholson, "Deaths Among 17,800 Asbestos Insulation Workers in the United States and Canada, January 1, 1967 through January 1, 1977," National Institutes of Health, 1978.

4 From U.S. HEW and U.S. NRC Staff Analysis of NRDC Petition PRM-2-6 to lower occupational radiation limits, July 1978. The most probable numbers are from 50 to 110.

5 Dr. Carol Redmond, University of Pittsburgh.

TABLE 4

Risks Which Increase Chance of Death By 1 in 1,000,000

Smoking 1.4 cigarettes	Lung cancer, heart disease
Drinking 1/2 liter of wine	Cirrhosis of the liver
Spending 1 hour in a coal mine	Black lung disease
Living 2 days in New York or Boston	Air pollution
Traveling 6 minutes by canoe	Accident
Traveling 10 minutes by bicycle	Accident
Traveling 300 miles by car	Accident
Flying 1,000 miles by jet	Accident
Flying 6,000 miles by jet	Cancer caused by Cosmic radiation
Living 2 months with cigarette smoker	Lung cancer, heart disease
Eating 40 tablespoons of peanut butter	Liver cancer caused by aflatoxin B
Drinking 30 12 oz. cans of diet soda	Cancer caused by saccharin
Eating 100 charcoal broiled steaks	Cancer from benzopyrene
Radiation exposure of 10 millirem (0.01 rem)	Cancer caused by radiation

TABLE 5

Average Risk of Fatality By Various Causes

Type of Event	Total Number Per Year [1]	Individual Chance Per Year [2]
Death (All Causes)	1,898,000	1 in 110
All Accidents	100,761	1 in 2,100
Motor Vehicle	47,038	1 in 4,600
Falls	14,136	1 in 15,000
Burns	6,338	1 in 34,000
Firearms	2,059	1 in 105,000
Electrocution	1,148	1 in 188,000
Lightening	160	1 in 1,400,000
Radiation effect 0.8 rem	None observed	1 in 12,500
Radiation effect 2.5 rem	None observed	1 in 4,000
Radiation effect 4 rem	None observed	1 in 2,500
Nuclear Power Plant		
Routine Release Health Effect Site Boundary Resident (50 yrs at 2 mrem/yr.)	None observed	1 in 5,000,000 (potential calculated)
Resident within 10 miles (50 years at 0.2 rRem/yr)	None observed	1 in 50,000,000 (potential calculated)

(1) Data from non-radiation effects is from 1979 World Almanac and is based on a U.S. population of 216,000,000.

(2) Chances for radiation effect fatalities are calculated. Chances for non-radiation fatalities are based on observed data.

TABLE 6

Chronic Individual Lifetime Chance of Fatality

Event Duration	20 Years	40 Years
Motor Vehicle	1 in 230	1 in 115
Falls	1 in 750	1 in 375
Radiation dose of 0.8 rem/yr	1 in 625	1 in 313
Radiation dose of 1.5 rem/yr	1 in 333	1 in 167(1)
Radiation dose of 2 rem/yr	1 in 250	1 in 125
Radiation dose of 2.5 rem/yr	1 in 200	1 in 100
Radiation dose of 3 rem/yr	1 in 167(1)	1 in 84
Radiation dose of 4 rem/yr	1 in 125	1 in 63

(1) The total dose of 3 rem/yr for 20 years is 60 rem. Any lifetime dose of 60 rem (i.e., 4 rem/yr for 15 years or 1.5 rem/yr for 40 years) causes the same lifetime risk.

TABLE 7

Sources of Information on Risk of Cancer from Radiation

Type of Cancer	Cause of Exposure or X-ray Treatments	Exposure Date	Years After Exposure Considered	Number of Subjects	Average Dose (rem)
Leukemia	A-bombs, Japan	1945	5-25	23,979	130
	Spondylitis	1935-54	0-25	14,554	372
Bone	Ra^{226} intake	1915-35	11-56	775	17,000
	Ra^{226} treatments	1944-64	4-25	925	4,410
	Spondylitis	1935-54	6-27	14,654	372
Breast	A-bombs, Japan	1945	16-25	12,000	125
	Fluoroscopy	1940-49	10-30	243	121
Lung	Uranium mines	1920-63	6-50	4,146	4,680
	Fluorspar mines	1935-63	11-33	800	2.770
	metal mines		16-37	1,759	1,720
	Spondylitis	1935-54	6-27	14,554	400
	A-bombs, Japan	1945	16-25	19,472	133
Gastro-intestinal	A-bombs, Japan	1945	25	23,979	130
	Spondylitis	1935-54	11	14,554	375
Leukemia age 0-9	A-bombs, Japan	1945	6-24	4,507	112
	Thymus X-rays	1926-57	0-35	1,451	65
	Tinia capitis	1940-49	0-22	2,043	30

Reference: National Academy of Sciences, 1972, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," (NAS 72).

7. RADIATION MEASUREMENT AND CONTROL

7.1 RADIATION MEASUREMENT

The device issued to radiation workers for the purpose of measuring radiation is the thermoluminescent dosimeter (TLD). A TLD consists of: a holder, filters, and a teflon card that has the thermoluminescent material in it. The filters allow us to tell the difference between beta and gamma radiations. The teflon card contains material that is thermoluminescent; that is, the material gives off a small amount of light when it is heated, after having been exposed to ionizing radiation. The amount of light is proportional to the amount of exposure to radiation for the TLD.

In conjunction with the TLD we use a direct (self-reading) pocket dosimeter (SRPD). This device enables us to determine at a glance how much exposure we have accumulated. The SRPD is worn next to the TLD on the upper front portion of the body. By holding the SRPD up to your eye, such that the end with the lens is toward your eye, and the end with the recessed pin is toward a light source, you can observe a scale. The scale is crossed at some point by a movable hairline. As the SRPD is exposed to radiation, the hairline moves up the scale.

Remember to wear these devices whenever handling radioactive material and each and every time you enter a radiologically controlled area. Unless told otherwise by Radiological Control personnel, wear them on the upper front trunk portion of the body. Other dosimetry devices will be issued by Radiological Control personnel when needed.

To determine your dose with a SRPD, you subtract the initial reading from the final reading. That is, if a SRPD reads 10 mrem when you enter an area and reads 30 mrem when you exit, then your dose is 20 mrem.

The three most important methods to minimize your exposure in fulfillment of ALARA objectives are the proper use of time, distance, and shielding. Each of these items is discussed in detail below.

7.2 TIME

The less time you spend in radiation areas, the less exposure to radiation you will receive. To fully utilize the time that is spent in radiation areas, all jobs should be pre-planned. Such pre-planning should include:

1. Making sure you have all the tools and equipment required for the job prior to entering the area.

2. Being familiar with the equipment either through job mock-up training or referring to a repair manual or plans prior to entering the area.

3. Knowing the radiation levels as well as component location prior to entering the area, and having stand-by personnel wait in low dose rate areas until needed.

4. Determining the Stay Time value.

7.2.1 Calculation of Stay Time

To determine your anticipated exposure prior to entering a radiation area, multiply the area radiation level by the amount of time to be spent in the area. Your exposure can thus be controlled by limiting the time you spend in the area:

Exposure = exposure rate x time

Stay Time is defined as the maximum amount of time a worker is allowed to stay in a specific radiation area. The Stay Time depends on ALARA considerations and the individual's present accumulated exposure. For example, John Smith

Quarterly exposure limit = 1250 mR
Present Quarterly Exposure = 1000 mR
Remaining Quarterly Exposure = 250 mR

Worker Area Radiation Level = 100 mR/hr
Safety Factor = 50 mR/hr

Stay Time = $\frac{250 - 50}{100}$ = 2.0 hours maximum

7.3 DISTANCE

By keeping as much distance between yourself and sources of radiation as possible, you can reduce the amount of exposure to radiation you will receive. Here are some suggestions:

1. Work at arm's length from hot spots whenever possible.

2. Use long-handled tools if possible.

3. Remove item to be worked on to an area lower in dose rate.

7.3.1 Radiation Exposure Reduction

Uniformly distributed radiation from a point source decreases approximately as the square of the distance. For example:

Assume a dose rate from a point source at 1 ft = 1 rem/hr

Then, at 2 ft the dose rate = 250 mR/hr
at 4 ft the dose rate = 63 mR/hr

Radiation from a line source, like a long pipe, decreases approximately linearly with distance. For example:

Assume a dose rate from a line source at 10 ft = 500 mR/hr

Then, at 20 ft the dose rate = 250 mR/hr
at 40 ft the dose rate = 125 mR/hr

Summary:

a. Point (infinite)

$$\text{Dose Rate}_2 = \frac{\text{Dose Rate}_1 \times (\text{Dist}_1)^2}{(\text{Dist}_2)2}$$

b. Line (within 1/2 length)

$$\text{Dose Rate}_2 = \frac{\text{Dose Rate}_1 \times \text{Dist}_1}{\text{Dist}_2}$$

c. Plane (within 0.7 radius)

$$\text{Dose Rate}_1 = \text{Dose Rate}_2$$

7.4 SHIELDING

The third method of controlling/minimizing radiation exposure is by means of shielding. Generally, this is the preferred method because it results in intrinsically safe working conditions, whereas reliance on distance and/or time of exposure may involve continuous administrative control over workers.

The amount of shielding required depends on the type of radiation, the activity of the source and on the dose rate which is acceptable outside the shielding material.

The installation of the shielding material could be of the permanent type or of the temporary type.

Examples:

- Construction walls - permanent shielding
- Pre-design pipe wall thickness - permanent shielding
- Concrete blocks - temporary shielding
- Lead sheets/blankets - temporary shielding
- Lead shot - temporary shielding

If the shielding installation is of the temporary type, radiation workers shall be cautioned never to move the temporary shield without the approval of the Radiological Controls Supervisor.

7.4.1 Effectiveness of Shielding

The following paragraphs provide shielding effectiveness for α, β and γ radiation particles.

Alpha (α) particles are easily absorbed. A thin sheet of paper is usually sufficient to stop alpha particles and so they never present a shielding problem.

Beta (β) radiation is more penetrating than alpha radiation. In the energy range which is normally encountered (1-10 MeV) beta radiation requires shielding of up to 0.4 inches of aluminum for complete absorption.

One important problem encountered when shielding against beta radiation concerns the emission of secondary X-rays, which result from the rapid slowing down of the beta particle. This X-radiation is known as bremsstrahlung. In order to reduce the amount of bremsstrahlung, beta shield should be constructed of materials of low mass number (e.g., aluminum).

Gamma (γ) radiation is attenuated exponentially when it passes through any material. The dose rate to γ-radiation emerging from a shield can be written as:

$$D_t = D_o \exp(-\mu t)$$

Where

D_t = dose rate after passing through a shield of thickness t
D_o = dose rate without shielding
μ = linear absorption coefficient of the shielding material
t = thickness of shielding material

Half-Value Layer (HVL): The half thickness or half-value layer for a particular shielding material is the thickness required to reduce the intensity to one half its incident value. Writing the HVL as t 1/2, the previous equation becomes:

$$\frac{Dt}{D_o} = 0.5 = \exp(-\mu t\ 1/2)$$

$$t\ 1/2 = \frac{0.693}{\mu}$$

Tenth Value Layer (TVL): The tenth thickness or tenth-value layer is simply the thickness required to reduce the intensity of a beam of gamma radiation to one-tenth its incident value. By a calculation similar to that carried out above it can be shown that:

$$t\ 1/10 = \frac{2.303}{\mu}$$

Some typical values of t 1/2 and t 1/10 for lead, iron and water are given in Table 6.3.1.

TABLE 6.3.1

APPROXIMATE VALUES OF t 1/2 AND t 1/10

γ - radiation	inches of lead		inches of iron		inches of water	
energy (MeV)	t 1/2	t 1/10	t 1/2	t 1/10	t 1/2	t 1/10
0.66 (Cs-137)	0.4	1.0	1.4	2.75	7.5	25.0
1.25 (Co-60)	0.78	1.8	1.9	3.7	15.0	27.0

7.5 AREA DESIGNATIONS

All controlled areas at work sites are divided into area categories as defined below. Categorization of areas allows workers to know what kind of environment they are entering and provides written warning of radiological hazards at entrances to the specific areas.

- Radiation Area 1-100 mR/hr general field
- High Radiation Area >100 mR/hr general field
- Surface Contamination Area >50 pci/100CM^2 alpha
  >450 pci/100CM^2 beta/gamma
- Airborne Radioactivity Area >2 x 10^{-11}uCi/ml alpha (based on U^{238})
  >1 x 10^{-10} uCi/ml beta/gamma (based on Cs^{137})

8. CONTAMINATION MEASUREMENT AND CONTROL

8.1 CONTAMINATION

Contamination (Radioactive) - is the deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence may be harmful. Contamination may destroy the validity of an experiment or a procedure, make equipment unusable, or actually be a source of harm to personnel.

Contamination (Fixed) - is that radioactive contamination that remains on tools and equipment and is not reduced by normal decontamination techniques. An item is considered to have fixed contamination if there is detectable alpha contamination as measured with an alpha survey meter or beta/gamma contamination > 100 counts per minute as measured within ½ inch with a PPA-2 pancake G-M probe or equivalent.

Contamination (Loose Surface) - is that radioactive contamination that is removable from tools and equipment by normal decontamination techniques.

8.2 DETECTING CONTAMINATION

When a sensitive radiation detection instrument is used to locate contamination, that is called frisking (the instrument is referred to as a frisker).

After each exit from a contaminated area, you are required to pass a sensitive probe slowly over your body - frisk. Normally, you will not find contamination on your body. If you do find contamination, stay where you are, and notify a Radiological Control Technician. If necessary, they shall wash the contamination off, using soap and lukewarm water. After cleaning you will again be frisked to check for contamination. For example, if only a hand is contaminated, then washing only the hands would be required. If simple cleaning does not work, more abrasive methods are employed.

If you place a contaminated tool next to the frisker you will see a response on the meter. The tool can be washed to remove the contamination (just like removing any dirt or grease).

You cannot use a frisker in an area where the radiation levels are elevated. The radiation in an area, which is called background radiation, will cause a large meter response. This situation leaves two choices: take the person or item to be frisked to an area low in radiation levels, or use what is called the swipe technique to detect removable contamination.

A swipe is a piece of dry filter paper which is wiped over a surface and then measured for radioactivity. This method detects removable or loose surface contamination. The limits for loose surface contamination, requiring the use of protective clothing are:

1. 1,000 dpm alpha, beta, gamma/100 cm^2 removable - determined by wiping the area with dry filter paper and testing the filter paper with an appropriate survey meter.

NOTE: The limits are applied and tested for independently for alpha and for beta, gamma.

Even though an item has been swiped, and no contamination detected, the item still needs to be frisked. Certain porous items can have contamination fixed to them.

In a situation where airborne contamination is present, or an individual has possibly ingested contamination (as in cases of facial contamination), a whole body count will be required for the contaminated individual. This will tell just how much, if any, radioactive material is in the body, and from that, a calculation of the worker's dose can be made.

Airborne materials may occur as dust, fumes, smoke, vapor, or gas. The most common measurements are taken of particulate matter by suction onto filter paper. This air sampling may be divided into 'spot' or 'continuous' sampling, depending upon the collection time spent. Due to naturally occurring radioactive gases in the atmosphere (Ra,Th) and their particulate daughters, a correction in the counted activity is made based on the short half-life of the naturally occurring gases involved.

The estimated long-life activity count rate is determined by the following formula:

$$C_{LL} = \frac{C_2 - 0.271\, C_1}{0.729}$$

when C_{LL} = long lived count rate
$C1$ = counter after 4 hours of decay
$C2$ = counts after 24 hours of decay

8.3 GUIDELINES FOR WORK IN CONTAMINATED AREAS

1. Do not eat, smoke, chew, or drink in controlled areas.

2. Do not enter an area that is contaminated without Radiological Control's approval.
3. Always wear protective clothing for work in contaminated areas.
4. Avoid contact on your face with any contaminated items (do not scratch your nose while in protective clothing).
5. Always be aware of actions that could cause airborne contamination (even if they are not your actions).
6. Contain contamination to as small an area as possible by:
   - observing contamination postings.
   - using proper protective clothing removal procedures.
   - placing all contaminated tools and equipment in their proper places.
   - keeping the areas as clean as possible by practicing good housekeeping.
7. Persons with open sores, wounds, or bleeding of any degree will not be allowed in contaminated areas.
8. Always wear respirators when required by posted signs or by Radiological Control instructions.

The following shall be the procedure for donning and removal of the full face, air purifying respirator:

Prior to use, the mask should be visually inspected for defects, e.g., straps, viewing shield and exhaust port. Next - remove the filter canister and inspect that portion of the filter element visible through the filter connector pipe. If there is any evidence of deformity - replace with a new filter (after inspecting new filter). Now - connect filter canister to mask - ensuring that connector is tight (canister is not free to move). Next - adjust straps so mask may be donned. Place mask on head, tighten straps snugly (do not pull straps too tight).

Clear mask by exhaling, and then - holding hands tightly against filter intake ports - inhale and hold for 5-10 seconds. The mask should collapse tightly around face. This indicates a snug fit and that mask is ready for use. If mask does not collapse readjust straps and test again. Eye glasses will not be worn with the mask as a tight seal of the mask around the head and face is not possible when glasses are worn. Prescription lense inserts are the responsibility of the individual rad worker. When removing the mask - simply lean forward (bend at the waist), grasp mask around the area of the mask and filter connection - disengaging the chin from the chin recess in the mask and sliding the mask forward and off the head. This method will minimize the possibility of becoming contaminated by "loose" contamination falling off the mask outer surfaces and on to the wearer.

8.4 AREAS SURVEYS

Survey maps are posted for your reference prior to entry to controlled areas. These surveys indicate contamination and radiation levels in the area, as well as identifying "hot spots".

8.5 RESPIRATORS

In most cases, when respiratory protection is required, a full face air purifying respirator will be used. However, steps are taken to eliminate the need for respiratory protection by minimizing airborne contaminants. Some of these steps include:

- The use of physical boundaries such as doors and tents to localize airborne contaminants.
- The use of filtered ventilation to remove contaminants from the air.
- The decontamination of grossly contaminated areas to prevent airborne contamination being caused by work in the area.

Here is a list of some specific cautions that are applicable to respirator use:

1. Contact lenses cannot be worn with respirators.
2. If dentures are worn while qualifying for respirators, they must be worn while working in a respirator.
3. Remember also that full face, air purifying respirators do <u>not</u> supply oxygen. Do <u>not</u> wear them into atmospheres that are immediately dangerous to your health, or into any area that may be deficient in oxygen.
4. Do not use air purifying respirators to fight fires.

5. Beards are not permitted if a respirator is to be worn. (This includes wearing a respirator in the respirator test booth.)
6. If you are in an area, and for any reason your respirator fails to supply you air - remove the respirator and quickly exit the area.
7. Always wear the type of respirator prescribed by Radiological Control.
8. Perform a negative pressure test each time a respirator is put on, prior to entering the work area. Radiological Control personnel shall assist you in assuring a good fit.

8.6 MINIMIZING WASTE VOLUME

1. Radwaste receptacles are for contaminated trash only. Do not throw clean trash into these containers.

2. Do not dump solvents and oils down floor drains; as oil and solvents shorten the life of liquid radwaste treatment equipment and result in larger amounts of waste that are more difficult to process.

3. Notify your supervisor if you notice excessive leakage from pumps or valves.

4. All tools and equipment removed from Contaminated Areas must be surveyed by Radiological Control personnel prior to removal to determine if they are contaminated. Contaminated tools and equipment should be stored for future use, and contaminated trash should be disposed of as radwaste. Tools, equipment, and trash that are frisked "clean" may be stored or discarded as everyday non-radioactive material.

5. Whenever possible, use tools and equipment that are already contaminated. Re-use of contaminated tools and equipment will reduce the amount of radioactive material generated. If you do not know where to get tools that are to be used in contaminated areas - ASK your supervisor.

6. Do not put cloth type protective clothing (PC) in waste receptacles. If PC's are placed with radwaste, they will be disposed of as radwaste.

7. Be neat! By using drop cloths, catch bags and by picking up tools you can reduce the spread of contamination and thus reduce the amount of material required for area cleanup and decontamination.

8. Use only the materials required to clean the area. An excessive amount of bags, rags and solvent add to radwaste.

9. Use Type A boxes correctly:

   1) Do not put aerosol cans in boxes. These cans should be placed in special drums designated for that purpose.
   2) Do not place bags or cans of water or any other fluid in boxes, ask Radiological Controls for guidance in such cases.
   3) Unless you are told to by Radiological Controls, do not throw usable contaminated tools in boxes.
   4) For use at this site, boxes will be Type A containers.

9. EMERGENCY ACTIONS

9.1 CONTINUOUS AIR MONITOR ALARM

If a continuous air monitor alarm sounds in the area you are in, you should:

- Stop all work, and cover work area.
- Warn all others in the area.
- Leave the area and proceed to the designated area.
- Notify a Radiological Control Technician.

9.2 AREA RADIATION MONITOR ALARM

If you are in an area and an area radiation monitor alarm sounds, here is what you should do:

- Leave the area immediately, making sure that all others in the area are aware of the alarm and leave also.
- Secure access to that area.
- Notify Radiological Control Technician.
- Check your dosimeter.

9.3 PHYSICAL INJURY

Good sense must be applied when a first aid situation arises. You should not drag a slightly injured man out of a contaminated area and thereby contaminate other areas unnecessarily. Neither do we want a man to bleed to death by following normal dressing and frisking procedures. Notify Radiological Control personnel!

All emergency response measures in controlled areas shall be carried out in accordance with the Emergency Actions Procedure.

APPENDIX C

RADIOLOGICAL CONTROL PLAN

HARVARD AVENUE SITE