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RADIATION SAFETY AND CONTROL MANUAL

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Health and Safety

RADIATION SAFETY AND CONTROL MANUAL

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Oak Ridge National Laboratory
Oak Ridge, Tennessee

CONTENTS

GLOSSARY

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

Alpha Particle, α – A positively charged particle emitted from a nucleus and composed of two protons and two neutrons.

Beta Particle, β – A charged particle emitted from a nucleus and having a mass and charge equal to those of the electron.

Bremsstrahlung – Secondary photon radiation produced by deceleration of charged particles passing through matter.

Decay – *Disintegration* of the nucleus of an unstable atom (nuclide, radioelement, radioisotope) by the spontaneous emission of charged particles and/or electromagnetic radiation.

Fission – The division of a heavy nucleus into two approximately equal parts with the emission of a relatively large amount of energy.

Half-Life – The time required for a radioactive substance to lose one-half its activity by decay.

Half-Value Layer – Amount of shielding material necessary to reduce radiation level by one half.

Isotope – One of several nuclides having the same number of protons in their nuclei and hence belonging to the same element but differing in the number of neutrons and therefore in mass number.

Neutron – Nuclear particle with a mass approximately the same as that of a hydrogen atom and electrically neutral.

Nucleus – That part of an atom in which the total positive charge and most of the mass are concentrated.

Nuclide – A species of atom characterized by the constitution of its nucleus.

Proton – Part of the nucleus holding a positive charge numerically equal to the charge of an electron.

Energy Units

ev – The amount of energy gained by an electron in passing through a potential difference of one volt.

kev – 1000 electron volts.

Mev – 1,000,000 electron volts.

FOREWORD

This manual is provided as a convenient source of information concerning Radiation Safety and Control. Laboratory policy requires that all operations must be performed in such a manner as to minimize personnel exposures, property losses from contamination, and environmental contamination.

It is a matter of specific responsibility for all supervisors and individuals engaged in work involving radioactivity to become familiar with Laboratory policies and approved radiation protection procedures and practices. Staff members of both Radiation Safety and Control and Applied Health Physics are available to aid in the evaluation of radiation hazards and to recommend safe procedures and protection measures.

F. R. Bruce, Director
Radiation Safety and Control

I. INTRODUCTION

The Laboratory follows the recommendations of the National Committee on Radiation Protection concerning permissible exposure limits for those working with radiation. A system of controls and regulations has been established which should ensure that no person at the Laboratory will receive more than the permissible exposure. This manual is intended to provide the minimum background necessary for intelligent cooperation with the regulations.

Since most of the potentially harmful radiation that will be encountered is detectable only by special instruments, control of exposure will involve monitoring to detect levels of radiation, the use of shielding, the control of contamination, and the budgeting of time spent in radiation fields. While expertness in these areas requires special training, the general principles are simple enough. Familiarity with them is essential in order to avoid personal overexposure and hazards to other persons.

Responsibilities

In addition to the obvious responsibility for the radiation safety of employees and visitors, the Laboratory has an additional responsibility to

> avoid exposing the general public to above the permissible levels of radiation;
>
> avoid releases of radioactive material which, even when causing no dangerous exposures, may interfere with Laboratory operations.

This requires careful control of operations under clearly understood regulations. While the responsibility for such control has been assigned to the divisions and operating supervisors, each individual should be aware of the variety of possible hazards and of what he can do to avoid accidents.

II. TYPES AND SOURCES OF RADIATION

The Atom as a Source of Radiation

The atom (see figure) is the smallest portion of an element that retains the chemical characteristics of that element. It is composed of a nucleus and lighter negatively charged particles, electrons, that move around the nucleus in definite orbits. The nucleus may be a

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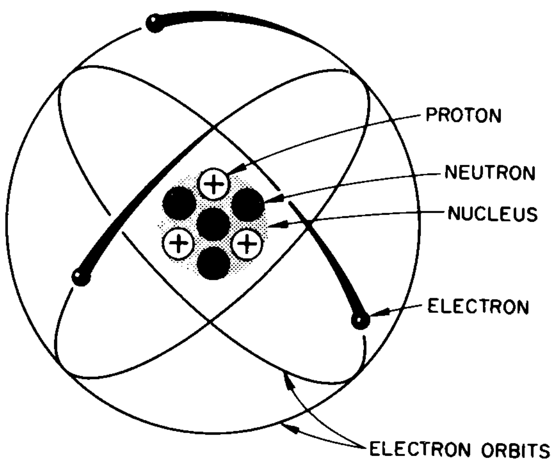
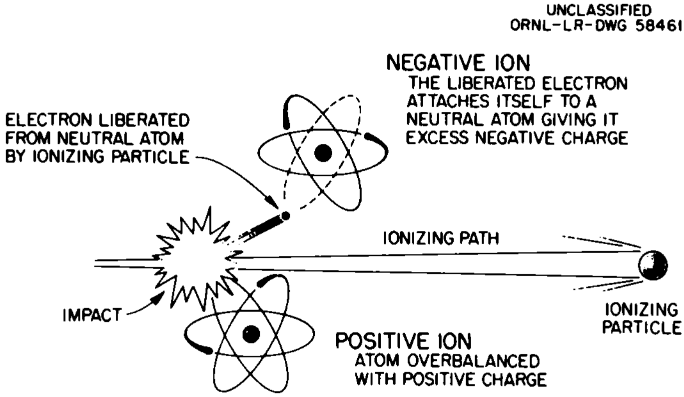


Structure of the Atom

single proton, positively charged, or a collection of protons and uncharged neutrons. These heavier particles have masses about 1835 times greater than that of the electron. In a neutral (or un-ionized) atom the numbers of protons and electrons are equal.

Ionization occurs when one or more of the orbiting electrons are removed (by the "impact" of radiation, for example) from the atom, which becomes electrically charged. In the case of the molecules, or chains of atoms, in the body, this ionization may cause a break by removing an electron link of the chain. The foreign materials formed by such breakage may then kill the



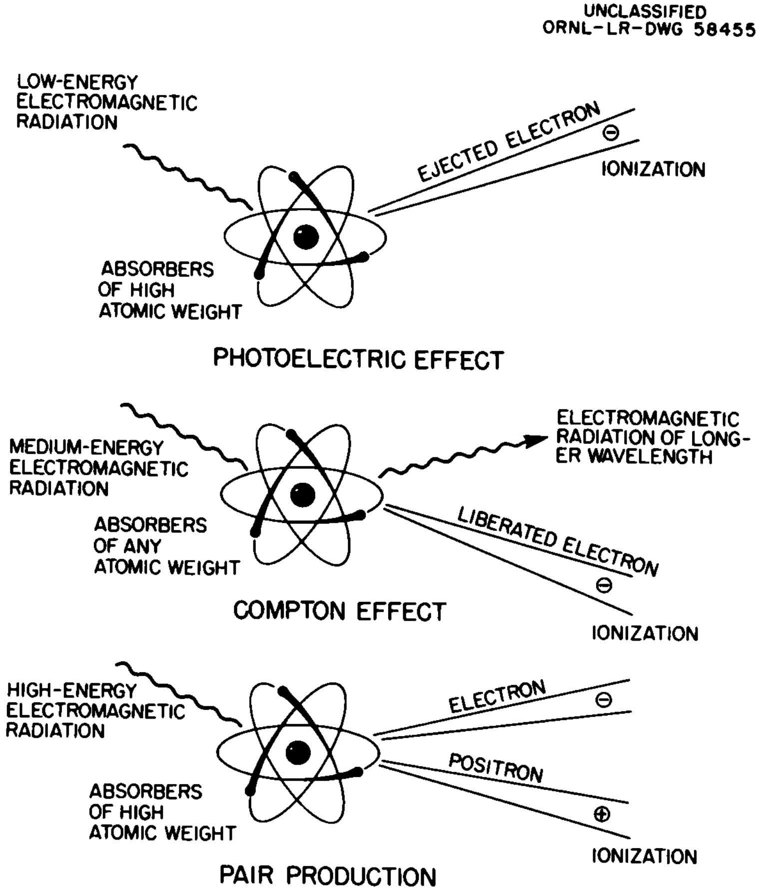
Ionization by Impact (Atomic Radiation – RCA Service Co.)

cell in which they were formed or cause damage in other parts of the body. This ability to ionize, then, is an important measure of the harmfulness of radiation.

The types of radiation described below are forms of energy emitted by excited or unstable atoms. These are atoms which – either as they are found in nature or because of some treatment by man – are in an unbalanced state and must alter their structure (disintegrate) and release energy to attain balance. Uranium and radium are naturally formed radioactive elements; examples of man-made radioisotopes are plutonium and the fission products formed by neutron bombardment of certain heavy elements in a nuclear reactor.

Radiation – in terms of radiation safety – is usually discussed as electromagnetic or corpuscular.

Electromagnetic radiation includes radio waves, infrared (heat radiation), visible light, ultraviolet radiation, x rays, and gamma radiation – listed here according to increasing energy. This increase of energy may be considered as an increased frequency of vibration of the waves, or, since the energy can act as if it were composed of particles, as an increase in the caliber of a bullet. All electromagnetic radiation travels with the speed of light.



The Ionizing Interactions of Electromagnetic Radiation (Atomic Radiation – RCA Service Co.)

A sufficient intensity (i.e., concentration of waves or particles) of any such radiation can be harmful. The radio waves very close to a high-powered transmitting antenna can cause severe burns, but their energy per wave is very low. The effect of ultraviolet radiation from the sun is familiar enough. The greater danger lies in the radiation (x and gamma) whose penetrating power is high enough to damage the deeper portions of the body *without any early signs appearing on the surface.* For this reason the external radiation exposure in need of careful control is often called "*penetrating radiation.*"

Corpuscular radiation or *emission* usually refers to the electrically charged alpha and beta particles emitted in the disintegration of radioactive atoms.

An *alpha particle* is a positively charged unit of two neutrons and two protons. Its range and penetration are very low; extremely high energies (7.5 million electron volts, Mev) are required for penetration of the skin. Although external irradiation by elements emitting alpha particles is not an appreciable hazard, such elements are capable of creating severe damage if they are taken into the body. This is because of the high ionizing power of alpha particles – almost a thousand times that of beta particles of equal energy. Alpha radiation is also difficult to detect.

A *beta particle* is a high-speed electron emitted from a disintegrating nucleus. It will travel several

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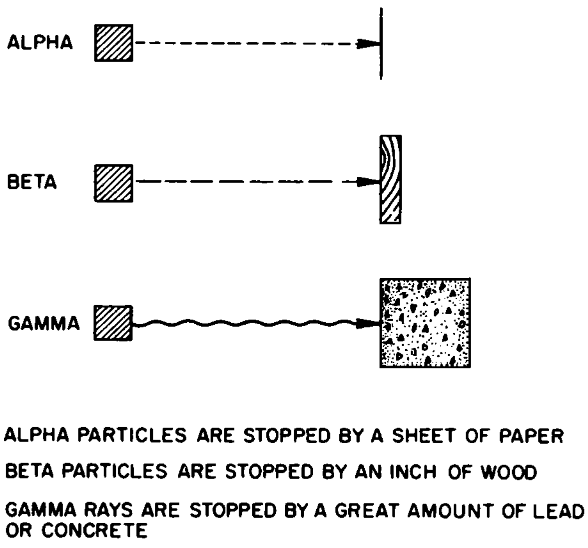

Radiation Shielding Materials (Nuclear Safety Principles and Practices – UCNC) hundred times farther in matter than an alpha particle of the same energy and is consequently an external radiation hazard. High-speed electrons also interact with matter and give off x radiation, whose penetrating power is much greater.

Neutrons are emitted in the disintegration of some artificially produced elements and in fission (the break-up of certain heavy elements under neutron bombardment). They cause ionization indirectly, and cause the

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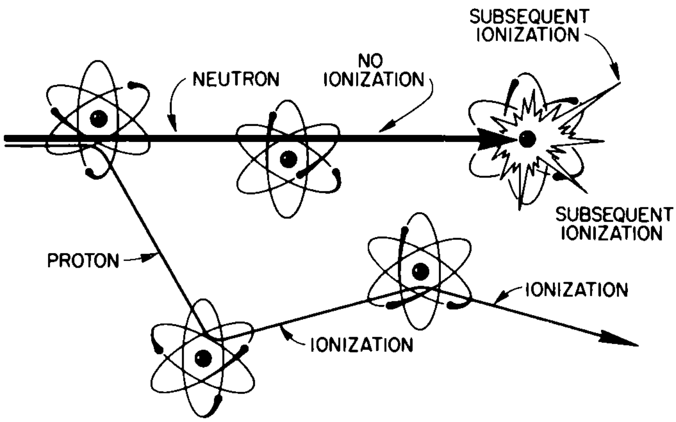


The Neutron, Unaffected by the Charge of Positive Nuclei, Penetrates Matter Until it Strikes a Nucleus; the Positive Proton is Affected and Moves Erratically (Atomic Radiation – RCA Service Co.)

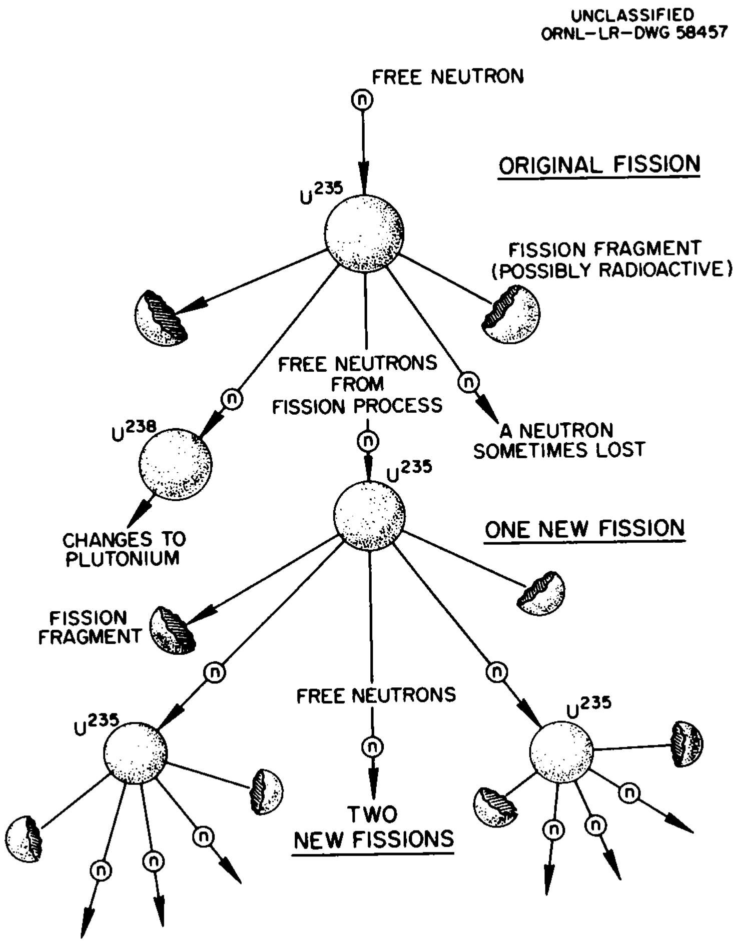
emission of high-energy gamma radiation on interaction with hydrogen. They may also produce ionizing protons and beta particles in the body and can cause some stable elements to become radioactive.

Other Sources of Radiation

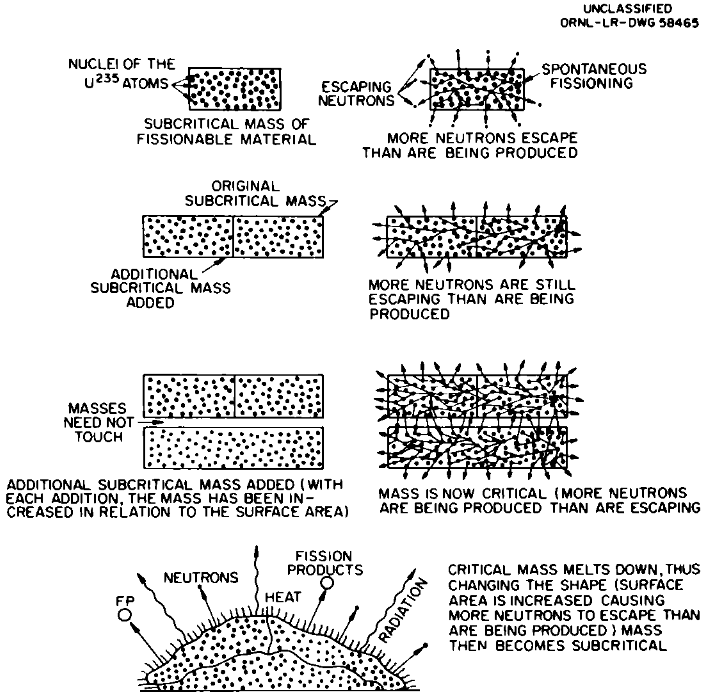
Ionizing radiation is also produced by x-ray machines, by particle accelerators such as the cyclotron, and by other special sources. The cyclotron is used to speed up charged particles which may then be used to activate other "target" materials. These materials, incorporated with others with which their own emissions may interact, then become special sources of radiation. Since accelerated particles produce radiation in several ways, the accelerators constitute a hazard when in operation, and precautions are necessary.

Criticality

When a sufficient amount of certain fissionable materials is assembled in such a shape that more



Schematic Representation of Chain Reaction (Nuclear Safety Principles and Practices – UCNC)



Critical Mass (Living with Radiation – AEC)

neutrons are being produced by fission than can escape from the surface of the mass, the amount is called a *critical mass.* The fissionable material must be one such as plutonium or uranium-235 which have the ability to keep up and to multiply fissions in a *chain reaction.* They do this because, upon being split into fragments (fission products) by spontaneously emitted neutrons, they emit 1 to 3 more neutrons which can go on to continue the process. When a critical mass is assembled, the multiplication of the chain reaction increases so that the burst of neutrons, gamma radiation, and often scattered fission products, is almost immediate.

Further details, and the precautions to be taken, will be given in the chapter on safe practices.

III. UNITS

Quantities of radioactive materials, levels of contamination or exposure, and accumulated doses are usually given in terms of four basic units. These are the curie, the roentgėn, the rad, and the rem.

Curie, c (millicurie, mc, is 1/1000 curie)

A quantity of a radioactive nuclide in which the number of disintegrations per second is 3.7×10^{10} ($3.7 \times 10{,}000{,}000{,}000$). Since the curie indicates only the number of disintegrations and nothing about the type or energies of the waves or particles emitted, it can be used as a measure of hazard only when the radioactive material is specified.

Roentgen, r

The exposure dose of x or gamma radiation — a measure of the radiation based on its ability to produce ionization at a certain place. The corpuscular emission associated with one roentgen produces, in one cubic centimeter of air at standard temperature and pressure, ions carrying one electrostatic unit of quantity of electricity. Note that the roentgen is properly applied only to x or gamma radiation.

Rad

The unit of absorbed dose; that is, the amount of energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest.

The rad may be applied to all ionizing radiation. Since the absorbed dose is a result of the interaction of radiation with matter, it depends upon the properties of the irradiated material as well as upon the radiation field. For example, an *exposure dose* of x or gamma radiation of 1 r will result in an *absorbed dose* of 0.887 rad per gram of air. The same exposure dose, however, will produce an absorbed dose of 1 rad in the soft tissue of the human body at a depth of 5 cm. In bone, the same exposure dose may produce from about 1 to almost 3 rads, depending on the energy of the radiation.

RBE

"Relative biological effectiveness" — a number expressing how much greater an absorbed dose of x or gamma radiation is needed to produce the same effect in human tissue as the radiation in question.

For example, the RBE of alpha radiation, 10, signifies that 1 rad of alpha radiation produces a particular biological response to the same degree as 10 rads of gamma radiation. The RBE of fast neutrons and alpha radiation is 10, of thermal neutrons 2.5, of gamma and beta radiation 1.

RBE Dose

The product of the absorbed dose in rads and the RBE with respect to a particular radiation effect. For mixed radiations the RBE dose is assumed to be equal to the sum of the products of the absorbed dose of each radiation and its RBE.

Rem

"Roentgen equivalent man" — the unit of RBE dose.

For example, an exposure of 30 mrads of gamma, 10 mrads of fast neutrons, and 8 mrads of thermal neutrons would result in a total RBE dose of 150 mrems:

$$\text{rads} \times \text{RBE's} = (30 \times 1) + (10 \times 10) + (8 \times 2.5) = 150 \text{ mrems} .$$

Dose Rate

Dose per unit time (mrem/hr, r/week, rad/hr, etc.).

If, in the example quoted above, the units were mrads/hr and the permissible limit 100 mrems/week, allowed working time would be 40 min/week. It is important that the units of dose rate and dose are not confused. The *intensity of a radiation field* is expressed in *dose rate units* (r/hr or rem/hr) since it determines the rate at which a dose will be accumulated in this field. The *actual accumulated dose*, the dose rate times the time of exposure (rem/hr × hr), is obviously expressed in *dose units* (rem).

Sample Calculations

Gamma. – If the number of curies of a specific radioisotope is known, the gamma exposure dose rate at a certain distance can be estimated. For a "point source" – that is, for a small source at a sufficient distance that it can be regarded as a point – the exposure dose rate, $R_{1\,ft}$, at 1 ft is given within ±20% by

$$R_{1\,ft} \cong 6cE \qquad r/hr ,$$

where c is curies and E is energy in Mev.

For example, the dose rate at 1 ft from a 1-curie cobalt-60 source, which emits a total of 2.5 Mev gamma per disintegration (as it decays to nickel-60), is

$$R_{1\,ft} \cong 6 \times 1 \times 2.5 \cong 15 \text{ r/hr} .$$

A rough approximation of the gamma exposure dose rate at other distances is given by the "inverse square law" which states that the intensity of radiation decreases with the square of the distance from the source.

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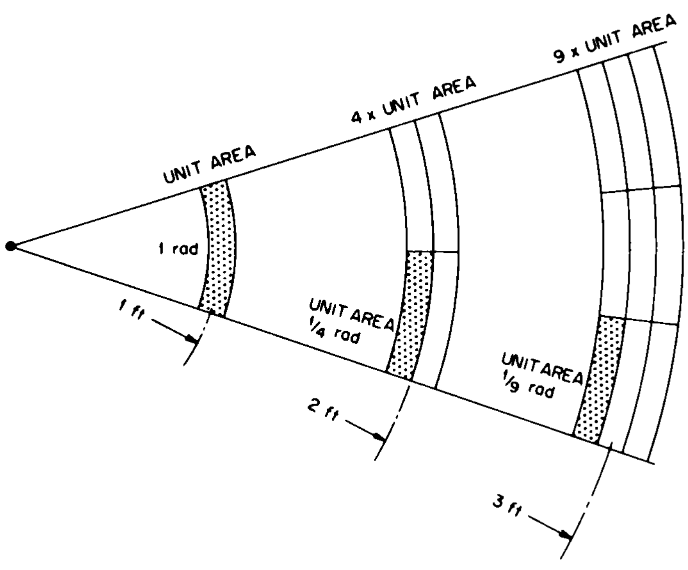


Illustration of Inverse Square Law

If the distance is doubled, the dose rate decreases to one fourth. Absorption by air and scattering of the radiation is neglected.

Beta. – An approximation of the dose rate at 1 ft from a beta-emitting point source is

$$R_{1\ ft} \cong 200\ c \qquad \text{rads/hr} .$$

The cobalt-60 used in the example above also emits a 0.31-Mev beta particle per disintegration; therefore 200 rads/hr of beta radiation should be added to the 15 r/hr of gamma at 1 ft.

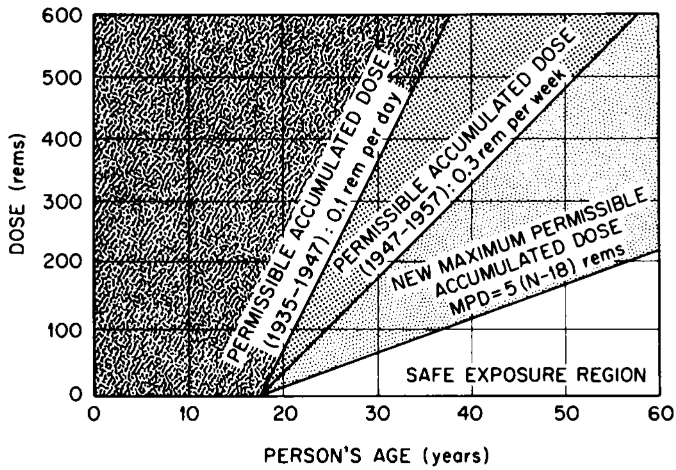
The 0.31-Mev beta particle has more than enough energy to penetrate the protective layer of the skin (only 0.07 Mev is required), and clearly adds to the hazard *at this distance.* However, its range in air (about 12 ft per Mev) would be only about 3.7 ft.

IV. PERMISSIBLE EXPOSURES – MAXIMUM AND RECOMMENDED AVERAGE

5(N – 18)

The maximum permissible occupational dose of ionizing radiation to the gonads, blood-forming organs, total body, head and trunk, and lenses of the eyes is based on the amount assumed to cause only negligible injury if accumulated over a working period of 47 years (i.e., from the age of 18 to 65). This amount is estimated as 235 rems and includes all ionizing radiation occupationally absorbed. It does not include medical and dental x rays, though these should be considered by the Health Division before approving an individual for radiation work.

It is important to recognize that this 235 rems is the total accumulated dose due to *continued* low-level exposure. Prorated over the average working lifetime of 47 years, it establishes 5 rems/yr as the recommended *average* annual maximum. That is, the maximum accumulated dose to age N years is 5(N – 18). By this rule, a 35-year-old individual should not have accumulated more than 5(35 – 18), or 85, rems.



Permissible Accumulated Dose – Radiation Workers (Nuclear Safety Principles and Practices – UCNC)

Dose Rate and Accumulated Dose

Annual. – The 235 rems acceptable as a long-term accumulated dose could, if taken as a single dose, cause hemorrhage, diarrhea, or – if complications should develop – even death. The *rate* at which a dose is received is therefore important. For this reason the recommended maximum annual dose is set at 12 rems. In pressing circumstances a deliberate single exposure of 12 rems could be sustained – except by women in the reproductive age. If this is done, and the dose when added to the already accumulated dose exceeds that permitted by the 5(N – 18) rule, future exposures must be so limited that the accumulated dose is reduced to the permitted level within 5 years.

Note that 12 rems/yr (see table) is a permissible maximum, even though 5 rems/yr is a *recommended average* maximum.

Quarterly. – The maximum accumulated dose in any 13 weeks is 3 rems. This is clearly not a recommended average, since continued exposure at this rate would lead to an annual dose of 12 rems.

Weekly. – The recommended average maximum weekly dose is 0.1 rem (100 mrems). Doses up to 300 mrems in a week – or in a single exposure if it is the only exposure in that week – may be approved by the operating supervisor, provided that adequate records and controls are maintained by the employee's division to ensure that the 3-rems/quarter limit is not exceeded.

Daily. – The daily recommended average dose for administrative purposes is 20 mrems. A Radiation Work Permit, properly approved, is required for work in radiation fields expected to result in an accumulated dose above this level.

The immediate supervisor may authorize as much as 300 mrems (see above) in a single day provided that he can ensure that the worker will not receive more than 300 mrems in that week. Where the worker is

Organ	Recommended Maximum Weekly Dose (rems)	Maximum Permissible Dose (rems)		
		Quarterly (13 weeks)	Annual	Age Proration Total
Total body, head and trunk, eye lens, gonads, bloodforming organs	0.1	3	12	$5(N - 18)$*
Skin of whole body, thyroid	0.6	10	30	$30(N - 18)$
Hands, forearms, feet, ankles	1.5	25	75	$75(N - 18)$

*N is age in years.

assigned to him for a single short job or a short period, the supervisor may – through the cooperation of Health Physics and the individual's foreman – approve an exposure leading to a total of less than 300 mrems for the week.

If the supervisor for any reason cannot exercise such control, he may authorize no more than 60 mrems in a work day without the specific approval of the Division Director of the exposed person. Division approval is also required for any accumulated dose above 300 mrems in one week.

A single exposure above one-third the maximum quarterly dose (i.e., an exposure of 1 rem) requires the approval of the Laboratory Deputy Director.

Accidental Doses. – An accidental dose of 25 rems to the whole body may be received only once in a lifetime; this means that the worker receiving such a dose must be protected from any possibility of a repetition. Future exposures must be adjusted so that the 5(N – 18) value is soon regained. However, such an adjustment may not be practical, and relatively complete removal from further risk is to be preferred – with the provision that, where competent medical authority agrees, a continued calculated risk may be endured if the alternative would handicap the individual in the pursuit of his career.

Dose Rate Controls

Special approvals are also required for exposures to certain *dose rates*. The accompanying table shows the approvals required.

MPC – Maximum Permissible Concentration

Internal exposure is controlled by limiting surface contamination and by setting maximum permissible concentrations of radioelements in air and water. The maximum permissible concentration of a particular radioelement is that which, if taken into the body by

Requirements for Entry into a Radiation Zone

Exposure Range (rems/hr)	Direct-Reading Monitoring Instruments Required	Health Physics Surveillance Required	Administrative Authority		
			Employee's Division Director	Health Physics Division Director	Laboratory Deputy Director
0.003–5*	X	X			
5–20	X	X	X		
20–50	X	X	X	X	
>50	X	X	X	X	X

*In the exposure range 0.003–5 rems/hr, the monitoring and surveillance requirements may be ignored if the anticipated exposure time is such as to result in an accumulated weekly dose of less than 0.1 rem.

inhalation or ingestion over a working lifetime, will deliver the maximum permissible dose to a *critical organ.* A critical organ is that organ whose damage by radiation results in the greatest damage to the body. (A table of the MPC's of certain radioelements is included in the Appendix to this manual.)

Adjustment of MPC for Emergency Operations. – If the 5(N – 18) dose is not exceeded, *and where no exposure has been received for the previous 13 weeks,* a person may work for one hour exposed to 1200 times the total-body MPC (in air for a 40-hr week), though the practice is not encouraged. Respirators should be used to minimize inhalation, and *no* exposure should be permitted for the following 13 weeks. Note that the 1200, which at first sight may seem excessively high, represents the one-quarter's (13-week) *ingested* dose raised by a factor that is the ratio, 12/5, of the *maximum* over the *average* dose in rems. That is,

$$40 \times 13 \times 12/5 \cong 1200 \ .$$

In general, the decreasing order of hazard for radioactive material taken into the body is:

1. contamination of a wound,
2. inhalation,
3. ingestion (of insoluble nuclides).

Adjustments of MPC for External Radiation and Overtime. – The MPC's in air and water must be adjusted in cases where (1) there is an external dose as well as an internal dose, (2) where the worker spends more than 40 hours per week in the controlled area. In case (1), if D rems is the quarterly internal dose to an organ due to a single element, and if external radiation delivers a dose of E rems per quarter to that organ, the MPC for that element based on the particular organ must be reduced by a factor of (D – E)/D. If the internal dose is due to a mixture of radionuclides, the MPC must be properly weighed and summed. In case (2), if the worker spends a 48-hr week in the controlled area, the MPC's which apply to a 40-hr week must be reduced by a factor of 40/48.

Deliberate Emergency Exposures

No official maximum exposures have been set for rescue teams or any other deliberately exposed persons for *extreme emergencies* such as criticality accidents, serious reactor accidents, or atomic warfare. No civilian regulations can cover what must be a matter of personal decision: the acceptance of a dangerous exposure in order to save a life or for national defense. In such cases those persons exposed should be made aware of the possible consequences before exposure. ***It is stressed that such exposures can be accepted only during extreme emergencies.***

Internal Exposure

Though the same maximum permissible doses apply to internal exposure as to external (or to combinations of the two), internal exposures are considered separately because of the greater uncertainties involved in the setting of minimum safety standards. Whether the material enters the body through a wound, through inhalation, or through ingestion by mouth, it establishes a source of radiation the victim cannot escape except by surgery or elimination by decay or natural processes. Some radioelements remain in the body for years, or for life.

V. EXPOSURE CONTROLS – DETECTION, TIME, DISTANCE, SHIELDING

The previous chapter outlined the limits within which work with radiation is assumed to involve an acceptable risk. The present chapter describes the methods used to ensure that all work is planned to be carried out within those limits.

Such controls require:

Use of instruments and alarms for detection and warning.

Establishment of Radiation and Contamination Zones where special precautions are necessary.

Establishment of procedures and regulations for hazardous operations.

Shielding of sources of radiation.

Budgeting of time spent in radiation fields.

Detection – Instruments

The purpose of protective radiation-detection instruments is to indicate the type and either the dose-rate, integrated (i.e., accumulated) dose, or relative intensity of harmful radiation. They are usually classified as:

Personnel Monitoring Instruments – such as the film badge or pocket chamber, carried on the person and used to indicate accumulated dose or to provide an alarm at a preset level.

Portable Survey Instruments – used to indicate levels of external radiation fields or radioactive contamination.

Area Monitoring Instruments – usually fixed in place; used to provide a record of radiation or contamination levels or warning of excessive radiation fields.

Examples are shown in the tables below and in the illustrations following.

Personnel Monitoring Instruments (Portable)

Instrument	Radiation Detected	Range	Application	Remarks
Film meter (badge)	γ, β, n_f, n_{th}	0.1–10,000 rads	Permanent record of dose of each type of mixed radiation. Au and In activated by criticality accident.	Film-density dependence on photon energy circumvented by filters. Orientation of film during exposure a problem.
Pocket chamber (indirect reading, Victoreen type)	γ	To 100 $\pm$ 5 mr To 200 $\pm$ 10 mr	Measurement of day-to-day gamma exposure.	Relatively energy independent for γ. Read by minometer.
Pocket chamber (direct reading)	γ n_{th} (when coated with boron enriched in B^{10})	To 200 mr; available with higher ranges	Visual check on gamma and, when modified, thermal neutron exposure.	Position of electrometer fiber read through magnifying lens.
Personal radiation monitor	γ, x, high-level β	Maximum audible warning at 0.5 r/hr; flashing light becomes continuous at 10 r/hr	Visible (light) and audible warning of radiation field.	Signal frequency proportional to radiation intensity. Available in higher rate ranges.
Chemical dosimeter	γ	5 to 2×10^6 rads	Measure gamma component of a mixed radiation field.	Being tested in film badges. Read by titration, measurement of conductivity change, measurement of pH colorimetrically or electrometrically.
Glass dosimeter	γ	5 to several thousand rads	Dose measurement of gamma exposure over a wide range.	Loosely bound electrons freed by radiation form photoluminescent centers with silver; centers excited by ultraviolet light emit photons (~6400 A). Should not be read for 1 hr after exposure unless specially calibrated.

Portable Survey Instruments

(Battery or electrostatically powered)

Instrument	Radiation Detected	Range (Nominal)	Application	Remarks
Cutie pie	γ, x High-energy β	5 to 10,000 mrads/hr	Dose-rate meter for γ and x (0.008 to 2 Mev) within 10%. With ORNL chamber measures with at least 50% efficiency the externally hazardous betas.	Most widely used instrument for these measurements. A "soft-shell" instrument (ORNL chamber) is made by cutting away sections from the detector housing and replacing them with a thin film. Adjusted to "zero" position through grid bias potentiometer.
Juno survey meter	α γ β	Three scales: 10,000, 100,000, and 1,000,000 dis/min Three scales: 50, 500, and 50,000 mr/hr	Dose-rate meter for γ and β; relative-intensity meter for α.	Maximum error 10% full scale. Manually positioned shields used. Should be warmed up 1 min and carefully zeroed. For γ measurement should be oriented as to calibrating source. Zero may be adjusted in high radiation fields.
Samson survey meter	α β, γ	Three scales: ×1, ×5, ×25 (500 counts/min, full-scale, ×1)	Rate meter for α; with probe, monitor for β, rate meter for γ.	Calibrated only for α although sensitive to β and γ radiation. Must be properly zeroed before use. Warmup time: 2–3 min. External shield should be used to determine if radiation other than α is present. Sensitive area should almost touch surface being surveyed.
Geiger-Mueller survey meter (Thyac and Nuclear 2610)	$\beta > 0.2$ Mev, γ	Three scales: ×1, ×10, ×100; ×1 may be 600–800 counts/min full scale	Detection instrument for $\beta > 0.2$ Mev and γ. Rate meter and audible pulse. Indicates *approximate* γ dose rates between 0.05 and 20 mr/hr.	Energy dependent. Should be used with earphones for faster response. Sliding shield for β-γ discrimination. Some models saturate above 50–100 mr/hr and will not indicate higher dose rates. Commercial instruments insensitive to low β energies, unless equipped with thin window counter.

Portable Survey Instruments (continued)

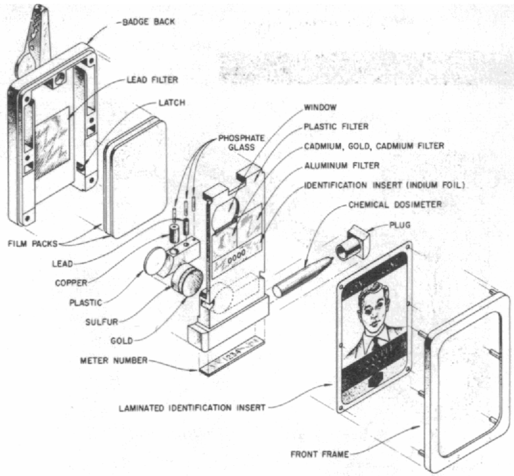
Instrument	Radiation Detected	Range (Nominal)	Application	Remarks
Alpha proportional counter (air) "Poppy"	α	May detect as little as 50 dis/min α in presence of 1 rad/hr γ	Analysis of mixed γ, β, and α radiation; discriminates between α and β-γ.	Less stable than the gas-flow instrument, particularly in area of high relative humidity. Probe face must be very near source of radiation, and moved slowly for low activities.
Alpha proportional counter (gas) (PAC-3G)	α	May detect as little as 50 dis/min α in presence of 1 rad/hr γ; range to 500,000 dis/min	Analysis of mixed γ, β, and α radiation; discriminates between α and β-γ.	More stable than air proportional counter. Reading not dependent on section of probe face receiving radiation, as with scintillation counter. Grade or type of gas used should not be changed without recalibration.
Alpha scintillation counter (Q 1975)	α	To ~500 counts/min	Assay of α emitters; registers accumulated counts. Audible signal and meter.	Requires less maintenance than proportional counter. Probe face must be very near source of radiation, and moved slowly for low activities.
Disk air sampler	α, β, γ (later counted)		Air drawn through filter by ac-operated blower.	Collection time and airflow rate should be noted.
Thermal neutron proportional counter (Q-2004)	n_{th}	20 to 20,000 $n_{th}/cm^2 \cdot sec$	Can discriminate against intense γ radiation (measure 200 $n_{th}/cm^2 \cdot sec$ in field of 10-rad/hr γ).	Employs $B^{10} + n \rightarrow Li^7 + \alpha$ reaction.
Fast neutron proportional counter (Rudolph)	n_f	0.1 to 100 mrads/hr	Measure first-collision tissue dose of n_f from 0.2 to 14 Mev. Discrimination a problem in γ fields above 2 r/hr.	Tissue-equivalent walls and gas.
Gamma scintillation counter	γ	Low-level	Used for very low-level γ monitoring, 0.001 to 1 mr/hr.	Sensitivity dependent on size of crystal.
Beta scintillation counter	β		Very few applications in portable instruments.	G-M tube generally preferable.
Neutron scintillation counter	n_f		Fast neutron detection where dose rate is not required.	

Personnel and Area Contamination Monitoring Instruments (Fixed)

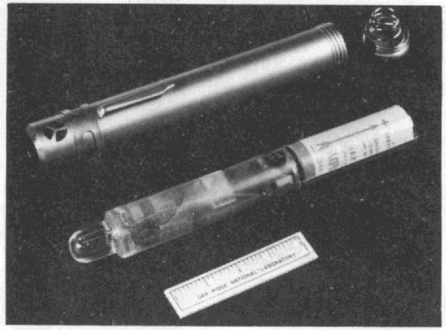
Instrument	Radiation Detected	Range	Application	Remarks
Hand and foot monitor	β, γ	Low-level	Simultaneous detection of β and γ contamination of hands and shoes. Will not detect α.	Most models have auxiliary probe for monitoring clothing.
Water effluent monitor	γ, β		Monitoring water wastes or coolants. May be connected to rate meter, recorder, and alarm systems, or to the check and diversion valves for control of water flow.	Thin films of water (or other material) will absorb α. Monitoring for any radiation may be complicated by silt, algae, radioactive contamination of the detector, variability in water flow rate and surface levels.
"Stack" monitors for gaseous effluents	Depends upon detectors chosen		Rough estimate of the radioactivity of effluent from a multi-use stack.	Requires complicated and expensive sampling, collecting, detecting, counting, and data-interpreting equipment.
Portal monitors (Quintector)	β, γ		Monitoring exits from areas of suspected contamination.	Slow passage through narrow portal required for maximum instrument response.

Area Monitoring Instruments

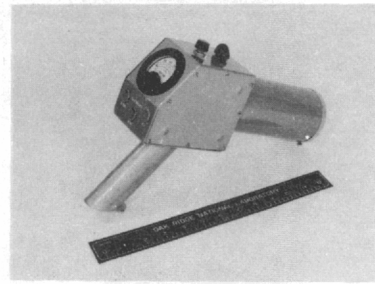
Instrument	Radiation Detected	Range	Application	Remarks
Continuous beta-gamma air monitor (particulate)	β, γ	Includes MPC level	Continuous recording of β-γ particulate radiation. Amber light and bell alarms for preset level.	Count-rate and strip-chart recorder incorporated. Does not distinguish between β and γ.
Continuous alpha-particulate air monitor	α, β		Provides alarm when permissible exposure is exceeded.	Alarm may be based on rate of increase of activity, rate of sample decay, change of normally constant α-β ratio due to radon decay. Radon is a problem.
Continuous gaseous air monitor	Tritium	1/100 to 10 × MPC for tritium	Tritium monitor	
Fast neutron dosimeter (Radsan)	n_f	From 1/10 permissible exposure	Fast neutron dosimetry. Insensitive to γ less than 5 r/hr.	Can be checked with internal α source. Tissue-equivalent chamber.
Monitron	γ if chamber is coated with carbon only; γ and n_{th} if coated with B^{10}-enriched boron	To 125 mr/hr	Dose-rate meter for γ background monitoring; measures only the relative intensities of n_{th}. Requires ac power input. Several ion chambers can be placed 150 ft or more from control unit.	Zero setting should be checked daily. Should be operated only on high-sensitivity setting unless users are warned of low-sensitivity setting. Where background permits, alarm should sound at 7.5 mr/hr. Calibrated with Ra source.
Threshold detector unit	n_{th}, n_f	High-intensity neutron flux	Provides data which, when analyzed with special counting equipment, gives the dosage of high-intensity neutron bursts.	Should supplement, but never be substituted for, alarm-type instruments which warn of dose rate, but which do not measure dose.
Alpha gas-flow proportional counter	α and β-γ	May detect as little as 0.1 dis/min α	Analysis of mixed γ, β, and α radiation; discriminates between α and β-γ.	Requires timer and scaler for power. Contamination of counter walls and loop electrode a problem.



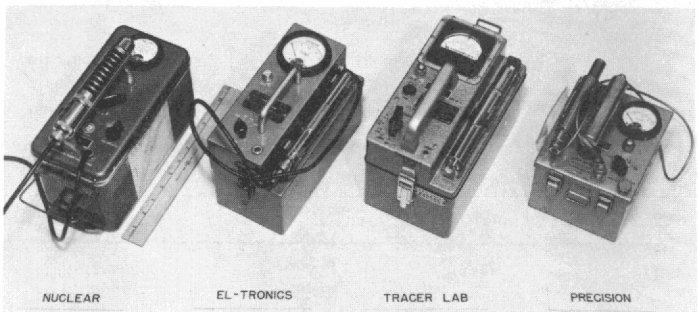
ORNL Badge Meter Model II



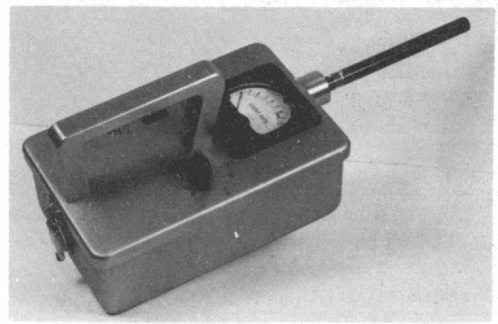
Personal Radiation Monitor



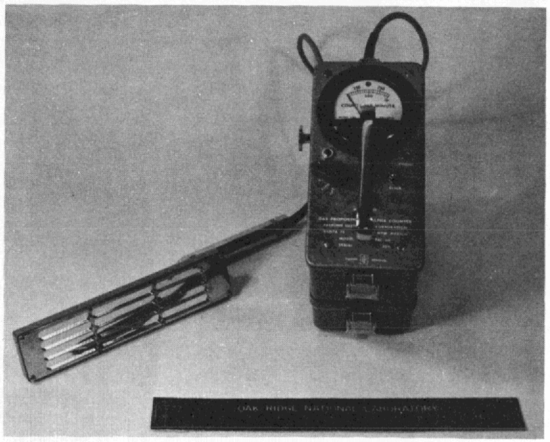
Cutie Pie



Geiger Mueller Survey Meters

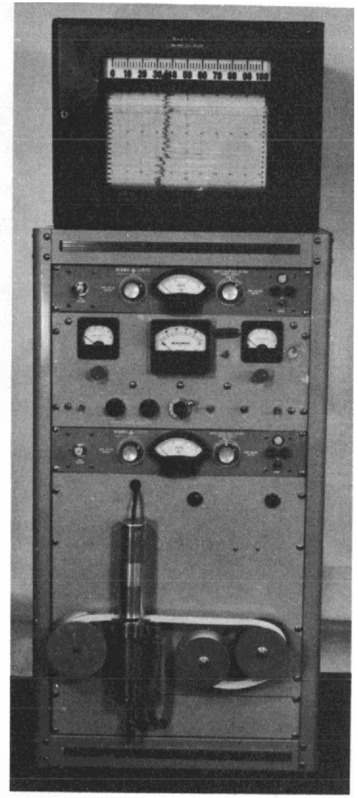


Thermal Neutron Proportional Counter

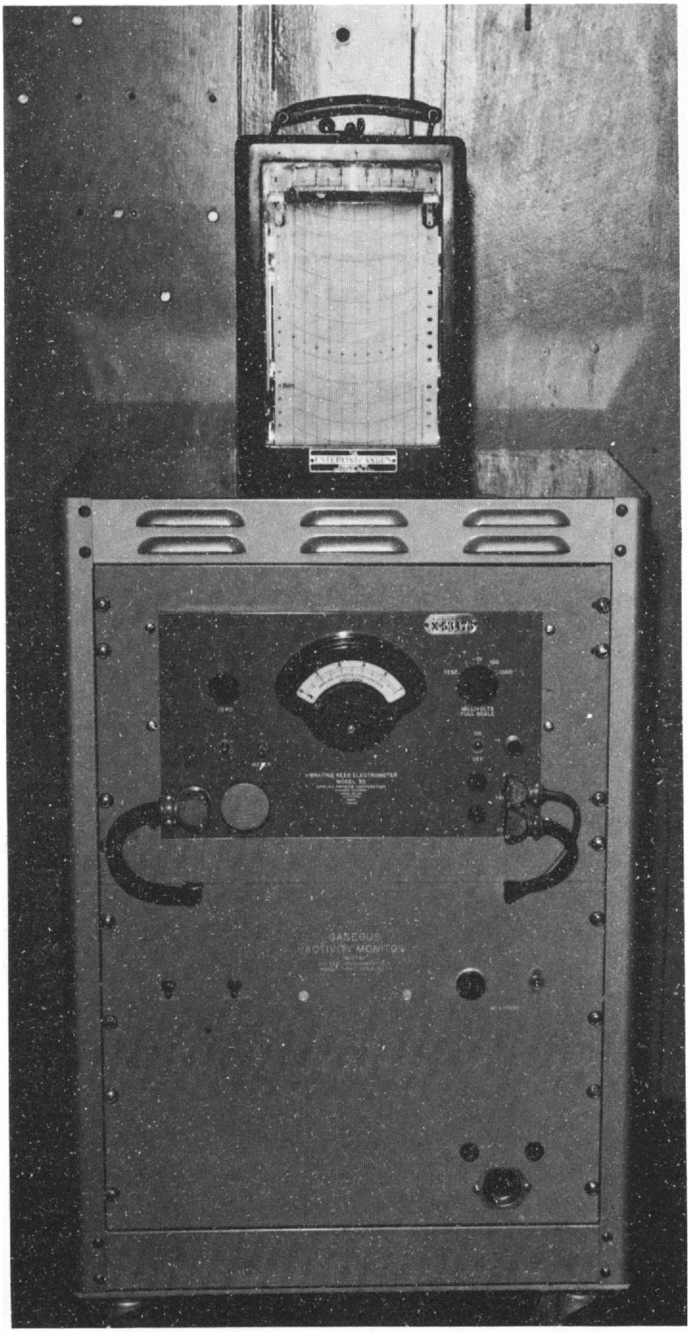


Alpha Proportional Counter

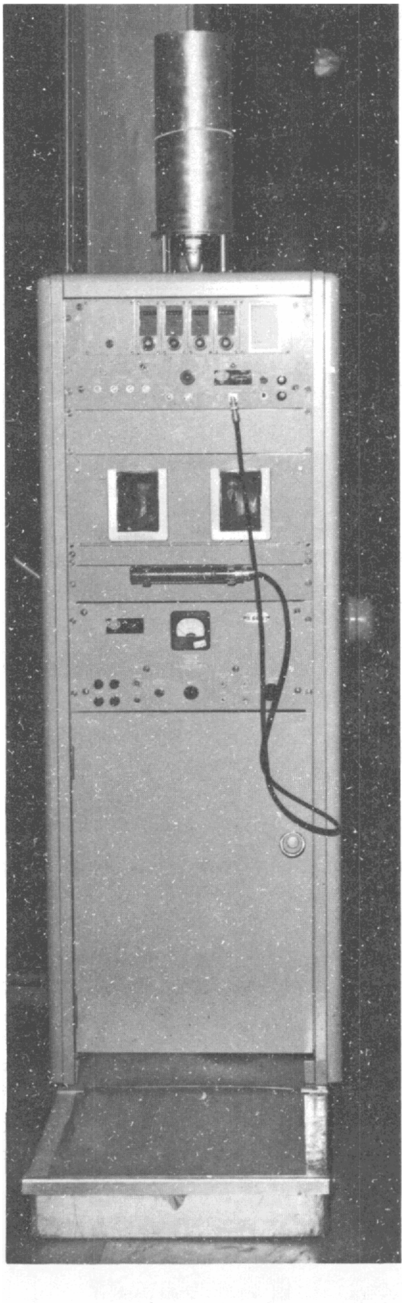
Gamma Scintillation Counter



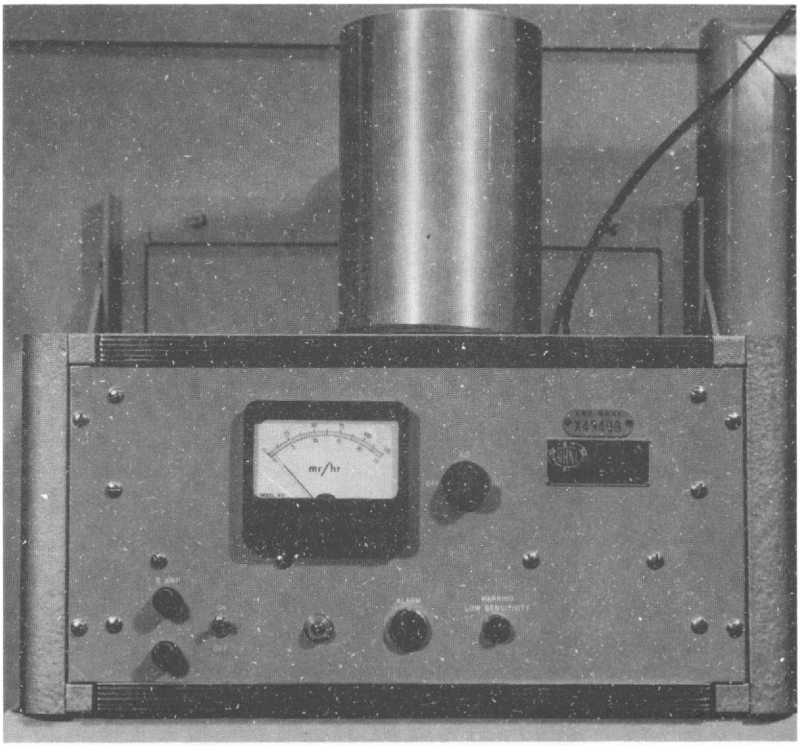
Continuous Alpha-Particulate Air Monitor



Continuous Gaseous Air Monitor



Hand and Foot Monitor



Monitron

Use of Radiation-Detection Instruments and Methods

Film Badges. – Film badges, worn by all persons in the laboratory, are exchanged routinely every 13 weeks, or on special request, and assayed for personal exposure levels. The films are retained and become part of the individual's permanent record of exposures. The adequacy of an employee's exposure record, which must be considered in planning his work in radiation zones, depends primarily on the obvious requirement that the *film badge be worn at all times in the Laboratory.* It should be worn face out and above the belt-line.

The regular issue of monitoring films is the least expensive method of personnel monitoring and has the advantages of convenience and accuracy over a range from 0.1 to 10,000 rads.

Purposes of films may be summarized:

To aid management in ensuring that the external radiation protection is satisfactory.

To satisfy employees that the dose they receive during their employment is observed and recorded.

To satisfy AEC requirements.

Pocket Dosimeters. – Pocket dosimeters should be carried by all persons in known exposure areas. These instruments are designed to provide (a) immediate warning of dangerous radiation levels by sound and a blinking light or the position of an electrometer fiber or (b) a measurement of day-to-day gamma exposure. When "indirect reading" instruments are used they are collected daily by Health Physics at set pickup points and read on a minometer. The self-reading electroscope is of particular value in an area where the maximum permissible dose may be approached or exceeded. *It is mandatory that a pocket dosimeter be carried by any person likely to be exposed to a significant fraction of the maximum permissible external dose. Additional special instrumentation or surveillance must be used where required by the regulations posted for particular Contamination and Radiation Zones.* It is important that the indirect-reading type of dosimeters be returned to the pickup points daily: a reading from an instrument that has been in use for a week is little help in evaluating a daily dose rate or in tracking down the source of the exposure.

Other Special Monitors. – Health Physics is also responsible for the bioassays such as urinalysis performed as a check on radionuclides taken into the body. Analyses may also be made of sputum, blood, or tissue and may involve arduous chemical separations to remove normal background interference. Health Physics will advise, when aware of the need, of the necessity for such assays and *should therefore always be informed* when ingestion, inhalation, or a wound is suspected of having introduced radioactive materials into the body.

The body burden of radionuclides may also be estimated by use of a whole-body counter which permits discrimination between types and energies of radiation and therefore – particularly when supported by analyses of body fluids – gives evidence of the radionuclides in the body.

Urine Analysis. – Urine analysis may be used in two ways; first, as a routine check to ensure that conditions in an area are satisfactory. The frequency of samples in this case would depend upon the nature of the work in the area. It is essential that urine and air sampling should be regarded as complementary. Generally the frequency of urine sampling should increase in proportion to the air concentration found; that is, in areas showing a higher fraction of a maximum permissible concentration, the frequency of urine sampling should be correspondingly increased. Second, urine samples may be taken in emergency or accident conditions such as high levels of air contamination to ascertain the intake of radioactive material by those exposed. It is *desirable* that a urine sample should be taken if a cut or wound is sustained in an area where contamination might be present, and it is essential that a sample be taken when the most hazardous radioactive materials are present – strontium-90, radium-226, plutonium-239, etc. When contamination of skin or clothing has not been detected immediately a urine investigation should be requested.

Records and Reports. – The instruments and monitoring procedures referred to above merely provide part of the information necessary for adequate control of personnel exposure to harmful radiation. To ensure the proper use of such information in determining allowable risks of future exposure, permanent records are kept and a system of routine reporting of significant exposures has been established. The duty of Health Physics ends with the reporting of these exposures. Acting on the information is the responsibility of the Division Director, who should be alert not only to significant accumulated doses and the need for rescheduling the work of persons having such exposures but also to increases in background radiation that might require additional shielding, decontamination, or changes in operation.

Accumulated exposure must be reported to an employee on request and on termination of employment.

Laboratory Area Monitoring

The fixed and portable surveying and monitoring instruments monitor the radiation background of the Laboratory and its surroundings. They may be permanently installed gaseous and liquid effluent monitors, the survey meters used routinely in checking surface contamination and dose rates in work areas, or parts of the more complex instrumentation involved in reactor safety devices. In any case their purpose is implementation of the Laboratory radiation safety criteria: to help protect personnel from internal and external radiation exposure, to help limit the spread of radioactive contamination, and to help prevent the release of more than the permissible concentrations of radioactive materials to areas outside the Laboratory.

The limitations of portable survey meters should be known by all users, and their dependability for the detection of radiation likely to be encountered in particular areas should be determined from Health Physics.

Despite limitations the area monitoring instruments provide immediate warning of changes in background radiation sufficient to call for immediate protective action and adequate warning of long-term changes requiring attention.

Zoning

The zones are defined as follows.

A ***Regulated Zone*** is an area where operations are restricted to control radioactive contamination. This zone may contain Radiation Zones, Contamination Zones, or both, ranging in size from a small spot to a large area.

A ***Radiation Zone*** is an area where control measures involve external radiation exposure to personnel. Such a zone must be posted where the dose rate is above 3 mrems/hr and the accumulated daily dose to personnel may be 20 mrems.

A ***Contamination Zone*** is established where personnel, equipment, or the environs may be significantly contaminated with radioactive nuclides and where deposition of the nuclides in the body is possible.

Zoning Signs and Procedures. – Zoned areas are indicated by signs which include instructions pertaining to requirements for entry (necessary approval, protective clothing, etc.), occupancy, and departure. It is the responsibility of operations supervision to familiarize personnel with these requirements and to enforce compliance. In addition, these general rules should be followed:

(a) A Regulated Zone – which may be surrounding, adjacent to, passing through, or connecting Contamination Zones – is accessible to all authorized Laboratory personnel, with restrictions only on Contamination Zone personnel and equipment as in (b) below.

(b) Entrance to, and exit from Contamination Zones will be through specified portals. Personnel and equipment may leave the Contamination Zone only when approved monitoring shows them to be free of transferable contamination.

(c) *Only those authorized by supervision are permitted to enter a Radiation Zone.* They will be provided with all required special instrumentation and Health Physics surveillance.

(d) If operating supervision finds entry to a Radiation Zone necessary when required Health Physics surveillance is not available, the office of the Health Physics Division Director will be notified of the action taken.

(e) Contamination Zone clothing or equipment will not be used outside a Contaminated or Regulated Zone.

(f) Contamination Zone vehicles, where the cab is marked as a Regulated Zone and the bed marked as a Contamination Zone, must be used when personnel in Contamination Zone clothing or contaminated equipment are transported through a nonzoned area. Contamination Zone vehicles must follow prescribed routes between zones.

(g) Eating, smoking, and drinking (except from approved fountain) is prohibited in Contamination Zones.

Responsibilities. — Since according to Laboratory policy the primary responsibility for radiation safety rests on the Division supervision, Health Physics functions must be regarded as purely advisory. Though Health Physics personnel will be alert to radiation hazards and will report them, they do not usurp the primary responsibility which is assigned to the Divisions. Only the Division is assumed to be familiar enough with its own operations to evaluate the hazards involved. Health Physics will advised on safe procedures when asked to do so. It is therefore the responsibility of supervision to:

see that all areas are surveyed by Health Physics as required and properly zoned as specified above,

establish appropriate boundaries and portals for zoned areas,

assist Health Physics in the posting of zone signs with up-to-date instructions,

provide suitable change rooms for personnel working in Contamination Zones, with provision for storage of personal effects if needed, *provide a supply of required Contamination Zone clothing and equipment,*

establish eating places as required and in accordance with Health Physics specifications.

It is the obvious responsibility of the individual worker to familiarize himself with these regulations and procedures and to cooperate with them – for his own protection and the protection of others. He should, for example, request a Health Physics survey where he has good reason to suspect that a hazardous radiation level or contaminated area may have been overlooked.

Radiation Work Permit

A Radiation Work Permit, approved by the immediate supervisor and certified by the area health physicist, will be required for entry into any area where one of the following limits is equaled or exceeded:

Single planned exposure	20 mrems
Dose rate	5 rems/hr
Air contamination	$(MPC)_{air}$ (40-hr week)

For *operating personnel,* properly approved posted regulations may replace the RWP where (*a*) total-body exposure will not exceed 100 mrem/wk, (*b*) all usual precautions are taken, and (*c*) the radiation conditions associated with the work are well understood.

Operating personnel are those assigned to an operation or facility for a time sufficient to permit control of the individual's weekly accumulated dose by the immediate operating supervisor. The immediate supervisor may in cases of necessity approve exposures up to 300 mrems/week for such personnel (*provided that every effort is made to keep below the recommended administrative quarterly maximum of 1.3 rems*) and up to 60 mrems/day for nonoperating personnel. Planned exposures above these levels require the approval of the individual's Division Director.

The Radiation Work Permit is an important part of the control and records system intended to ensure that no individual exceeds his quarterly or annual recommended average exposure. Health Physics will report to an individual's Division Director and immediate supervisor whenever his accumulated dose averages 300 mrems/week for four consecutive weeks. This would be a total of 1.2 rems, or about the quarterly *recommended permissible average* dose.

Since 3 rems in a quarter (13 weeks) is the *maximum permissible dose*, the individual is at this point well within the acceptable limit. In view of the controls listed above, particularly the Radiation Work Permit and the clear marking of Radiation and Contamination Zones, a nonaccidental overexposure is very unlikely – *if the rules are understood and obeyed.* The individual worker should, of course, inform his supervisor of any occupational exposure that he suspects might not have been included in his personal exposure record.

Time – Distance – Shielding

Time. – The effect of time spent in a radiation field at a certain dose rate has been touched upon in the definition of accumulated dose and in the discussion of the Radiation Work Permit. In practice, safety is usually attained by a combination of budgeting of time, the use of shielding, and distance. Shielding and distance reduce the exposure *rate,* but whenever they cannot be sufficient to reduce it to a level incapable of producing an overexposure in a 40-hr week, the time spent in the radiation field must be controlled.

Sample Problem

A man has already been exposed to 100 mrems in the week. How long can he be permitted to work in a gamma radiation field of 0.3 r/hr without exceeding a weekly accumulated dose of 300 mrems?

Since, for gamma radiation in soft tissue, r = rad = rem (i.e., the RBE of gamma radiation is 1), and 1 rem = 1000 mrems,

$$0.3 \text{ r/hr} = 0.3 \text{ rem/hr} = 300 \text{ mrems/hr} .$$

The man is allowed 300 – 100, or 200 mrems, which he would receive in 2/3 hr. He could therefore be permitted to work in the 0.3-r/hr field for 40 minutes.

Shielding. – The amount of shielding necessary to reduce radiation fields to acceptable levels has been calculated for various types of radiation and shielding material. Since appropriate shielding will be provided for radiation sources where required (see Appendix for kinds and effectiveness of shields) the important point in this connection is that the individual be aware of the existence of hazards and the need for caution. Areas containing such sources will be posted with warning signs and should be entered only for approved work.

Accidental destruction or removal of shielding, or the escape of radioactive material from a shielded container are possibilities to be considered. Any suspicious opening in a shield, breakage of a container, or leakage of possibly radioactive material should be reported.

Distance. – A radioactive source dangerous to handle in bare or gloved hands may be safe when handled by long tongs. A more intense source might require special manipulators and added shielding. In either case distance provides the factor of safety, but in *no case should radioactive sources be handled except according to a procedure approved by supervision.*

Time-budgeting and shielding are always involved in planned exposures: distance, rapidly placed between person and source, is the best answer to the unplanned exposure. If shielding can be included in the distance, all the better; but unless a release, spill, or suspicious occurrence is definitely known to be harmless the first steps to be taken are away.

VI. CHEMICAL AND OTHER HAZARDS

Chemical and other hazards will be discussed here only as they may be involved with radiation hazards. A chemically or electrically caused explosion or fire can cause the spread of radioactive material or destruction of the shielding of a radioactive source. Where these possibilities exist, a fire that otherwise might be easily handled would require special precautions – or an explosion that might at first seem to have created only slight damage would be sufficient reason to leave the immediate area until it has been surveyed.

Anyone working near radioactive materials should therefore:

Be aware of the exact location of any radioactive materials.

Be aware of the existence of any other hazards, particularly those that might affect the containers, shielding, or form of radioactive materials.

In the event of an accident, be prepared to inform fire and emergency crews of the location, and if possible the condition, of radioactive materials.

Be aware of exits and evacuation routes from the work area.

VII. SAFE PRACTICES

Many recommended safe practices have already been discussed. This chapter will summarize them and present more specific and detailed examples. *The most important single requirement is that the hazards be understood,* so that the intent of each rule is clear.

Attention to Monitors

Until the Laboratory alarm system is completely standardized it will be necessary to be aware of the meaning of the alarms in each work area. *Find out when and how to leave, but also what signals require no action.*

Obey Specific Regulations

Radiation Zones. – A favorite short-cut between two areas may be temporarily barred by a chain bearing a Radiation Zone sign. It is easy to step over or under a chain and pick up an extra radiation dose. *Do not enter a Radiation Zone without supervisory approval.* If entry is approved, examine the posted regulations for special precautions and follow them.

Contamination Zone. – The following rules summarize the basic safe practices for Contamination Zones:

Eating, smoking, and drinking except from an approved fountain is prohibited.

Personnel and equipment may leave only after monitoring shows them to be free from transferable contamination.

Contamination Zone clothing or equipment must not be worn or used outside a Contamination or Regulated Zone.

If masks, respirators, or special clothing are required, they must be worn.

Special posted instructions must be followed.

The intent of these rules is to prevent the inhalation, ingestion, or spread of radioactive contamination.

Anything that might permit more than the maximum permissible concentration to enter the body or spread contamination outside the zoned area should be avoided. A cut on the hand that might be insignificant in other circumstances, for example, is reason to stop handling possibly contaminated materials and to request a urine analysis.

Combinations of Hazards

Chapter VI, on chemical and other hazards, showed how accidents may have side effects not immediately obvious. Hazards may be combined or multiplied on any complex job, or even on a simple one involving more than one man.

For example, a man might be heating a section of a long pipe suspected to be heavily contaminated on the inside. He might be wearing a mask and other protective equipment. Another man at a distant open end of the pipe, working at a "safe" job, would be unknowingly exposed to a high concentration of whatever radioactive fumes were driven off. A situation of this kind could not occur unless someone had overlooked the possibility of such an accident – *but the likelihood of an oversight should always be considered.* If such an accident does occur, it should *never be concealed.* Even if the results are minor, they might not be the next time. Something can be learned from every blunder.

Criticality Controls

All operations or situations involving a possibility of criticality are reviewed by the Criticality Review Committee, which recommends the approval or disapproval of suggested procedures. The best procedure, however, is always at the mercy of a single mistake.

The undesired assembly of a critical mass is generally prevented by one or a combination of three basic types of control:

the concentration of fissionable material in solution *the total mass of fissionable material*

the shape and dimensions of metal or of solution containers

The safe maximum for mass is less than half the minimum critical value; this is to guard against the accidental production of a critical mass by the double-batching of process solutions or metals.

A near-critical mass may be made critical in ways other than the obvious one of adding more fissionable material. The presence of a moderator (which slows fission neutrons to an energy more likely to cause new fissions) such as carbon, beryllium, or water increases the possibility of a critical reaction. The same is true of a reflector, which returns to the fissioning volume neutrons which would otherwise escape. Each of these methods increases the number of effective neutrons.

A change of shape of a container can have the same effect. A solution that is safe (subcritical) in a long, narrow pipe – because of the larger surface per volume through which neutrons may escape – could become critical if placed in a large drum. The assembly of subcritical masses shown in the figure in Chapter I is in effect simply just such a change of shape. It may be viewed as the material, once extended through a long pipe, being brought together in another container.

The same is true of the placing of two subcritical containers too close to one another – with the additional hazard that reflection may be added. The proper racks (birdcages) should always be used.

Remember that the human body is composed largely of excellent neutron-reflector material. Too close an approach to a near-critical mass could make it critical.

"*Poisons*," materials which absorb neutrons and make them thus unavailable for fission, are sometimes added to fissionable materials in shipping containers or process streams. Such situations should be examined for the possibility of loss (e.g., by precipitation from solution) or change of characteristics of the absorber. If the absorber surrounds the fissionable material, its shielding effect on the detectors of any alarm systems should be considered.

Responsibilities of Foreman

The immediate supervisor has one major radiation-safety responsibility:

TO PREVENT THE OVER-EXPOSURE OF HIS WORKERS

He is also responsible for seeing that they do not cause the spread of radioactive contamination or any other hazard to other persons or operations. To fulfill these duties he should:

Inform his men of all rules and special precautions for a work area and see that they are followed; see that required masks and protective clothing are worn.

Inform himself and keep a record of the accumulated exposure history of each of his men for the work week and be sure that **the 300-mrems/week limit is not exceeded** *without approval of his Division Director.* He should be aware that the recommended average weekly dose is 100 mrems/week and that the 300-mrems/week dose should not be received by any individual for more than four consecutive weeks. Where possible, men should be rotated on jobs to minimize exposures.

Inform his men of the meaning of the radiation alarm systems and evacuation routes in each work area.

See that radiation zone barriers and signs are not removed or altered in the progress of work.

Remember, particularly, that most accidents are the result of violations of well-known regulations. The foreman should not permit familiarity with certain operations to be an excuse for a casual attitude:

short-cutting procedures leads to accidents. If a required item of safety equipment is missing, it is safer to wait to replace it than to try and get along without it.

Report all near-accidents.

Handling and Storage of Radioactive Materials (General Rules)

Zoning requirements must be followed for all areas in which radioactive materials are handled, and secondary containment must be provided for all amounts of radioactive material above 1 g of plutonium-239 or its equivalent hazard. The following general rules also apply to areas where radioactive materials are regularly handled:

(a) areas should be at a negative pressure in respect to surrounding offices and other laboratories;

(b) ventilation systems should be filtered into appropriate waste streams;

(c) room air should not be recirculated unless it is passed through high-efficiency filters;

(d) average face velocity of air through hood openings should be 100 linear ft/min for low- to moderate-level materials and 125–200 linear ft/min for high-level materials;

(e) routine spot checks for leaks and contamination of equipment should be made;

(f) wash basins and drains used for decontamination should be plainly marked.

Some standard methods for the control of small amounts of radioactive contamination include the use of absorbent paper as covering for hood lips, lab benches, and trays, and of easily replaceable tile or linoleum for floors. Walls should be given a hard gloss finish. Work requiring changes in familiar handling methods should be approved by supervision and tried with nonradioactive materials or small amounts of short-half-life materials; in either case the hazard of chemical toxicity should be considered.

Radioactive materials should be kept from contact with the skin and particularly from wounds or cuts. Standard precautions against such contact – and against ingestion and inhalation – include:

(a) use of gloves even with forceps or tongs,

(b) a method of removing rubber gloves without contaminating the inside of the gloves,

(c) avoidance of sharp-edged containers and glassware,

(d) avoidance of pipetting radioactive solutions by mouth,

(e) requiring Medical Division approval for work with radioactive materials by persons with open wounds below the wrist,

(f) forbidding welding, soldering, or brazing of contaminated equipment except in specially ventilated areas where proper respiratory equipment is used,

(g) use of disposable paper handkerchiefs rather than personal linen,

(h) monitoring after any suspected contamination of self, clothing, or area.

Storage Place

The place of storage should be selected with the following requirements in mind:

(a) Storage sites, especially for large amounts of radioactive materials, should be as remote from occupied areas as is practicable.

(b) The storage place should be chosen so as to minimize risk from fire. If feasible, floor areas should be equipped with hot drains to facilitate clean-up.

(c) There should be a method of ventilating the storage area, preferably through filters, and a method of supplying sufficient heat to the area in cold weather.

(d) The place of storage should be provided with suitable means of exit.

(e) The entrances to storage areas should be well marked and entrance requirements posted. Emergency crews should be kept posted on the storage of materials presenting unusual hazards (i.e., critical amounts of fissionable materials, highly inflammable materials, explosive materials, unusually high intensity sources, etc.).

(f) The storage area for radioactive materials should be used only for the storage of such materials and should not be cluttered with nonradioactive materials.

(g) Preferably only one person and possibly an alternate should have the responsibility for maintaining the storage area. Only authorized personnel, as recognized by the responsible person noted above, should be allowed to introduce or remove materials from storage.

(h) To avoid cluttering and confusion of responsibility the storage area should be for the use of only one department or at most one division if at all possible.

(i) Storage areas containing multicurie sources of activity should be provided with alarm devices such as monitrons and constant air monitors.

Handling Stored Radioactive Materials

(a) Containers should be labeled to indicate kind and quantity of material and name of person responsible for material.

(b) Adequate records should be kept on all stored radioactive materials with a check-out and check-in system established for sealed sources that are used frequently. Periodic inventories should be performed.

(c) Each container of radioactive materials should be provided with a secondary container adequate to retain safely the full amount of material involved.

(d) Thermally unstable solutions of radioactive material containing oxidizing agents and containing organic material should be stored in vented vessels. Other sealed or unsealed radioactive materials, where there is a likelihood of the release of radioactive gases, should be stored in exhaust hoods.

(e) The opening of containers and transferring of radioactive liquid material from one vessel to another should not be performed in a storage area unless that area has the appropriate laboratory facilities available for such handling.

(f) In storing radioactive materials in glass vessels, it should be realized that the vessel may break without apparent cause and a secondary container must be utilized.

(g) Radioactive materials must not be stored in the same refrigerator with foodstuff. All refrigerators used for storage of radioactive materials should be well marked and located in an area where there is no likelihood of their being used for food storage.

(h) All storage containers, including the sealed sources, should be periodically surveyed and inspected for leakage.

VIII. RADIATION EMERGENCY PROCEDURES

Definitions

Assembly Points. – Predetermined locations where evacuees will assemble. Should a location prove unsafe the wardens will select another. The Laboratory-wide assembly points are the major east and west parking lots.

Divisional Emergency Call List. – A list of six names supplied by each Division Director to the Laboratory Shift Supervisors' office. In the event of a serious divisional emergency, one of the listed individuals will be called and he will call the others on the list. This group will then take necessary action.

Emergency Control Center. – The location selected by the Laboratory Emergency Director for operational control of an emergency. The Guard Department will furnish radio communications at this location.

Emergency Zones. – Numbered subdivisions of the Laboratory Area.

General Alert Emergency. – An emergency wherein the Laboratory Emergency Director determines that the General Alert signal must be sounded to summon additional equipment and manpower to the scene. This signal is also sounded for a second-alarm fire.

Laboratory Emergency Director. – The Laboratory Shift Supervisor on duty.

Local Emergency. – An instance wherein only local personnel and normal emergency service units are required to bring the emergency under control.

Local Emergency Supervisor. – The individual appointed by his division head to organize and train the local emergency squad and direct it during a local emergency.

Local Emergency Squads. – Groups organized and trained by the local emergency supervisor to cope with local emergencies. Local emergency supervisors, wardens, and searchers are members of these squads.

Laboratory Communication Center. – Telephone 6358; located at Guard Headquarters.

Laboratory Emergency Truck. – Operated by the Fire Department; carries protective and other equipment for use during an emergency.

Emergency Service Units. – Groups organized and trained within certain divisions for specialized emergency service as required by the Laboratory.

ORNL General Staff. – The Laboratory Director, the Deputy Director, and the staff, consisting of assistant directors and division heads.

Searchers. – Local emergency squad members who must completely check assigned areas during an evacuation to make sure all employees have evacuated.

Wardens. – Local emergency squad members who are responsible for the safety of employees in assigned areas during an emergency.

Responsibility

Division supervision should foresee possible accidents and makes all necessary plans for handling such when they occur. These responsibilities involve:

appointment of local emergency supervisors and squads for all areas,

assisting local emergency supervisors in training their squads,

posting, in a conspicuous location, lists of local emergency supervisors and squad members,

continual evaluation of hazards and determination of corrective actions,

ensuring that each employee is familiar with the local and Laboratory-wide emergency procedures, the method of reporting an emergency, and his course of action for each type of foreseeable emergency that he may discover in his area, *organizing, training, and maintaining those Laboratory-wide emergency service units for which they are responsible,*

formulation of procedures for the shutting down of process and building equipment in the event of an evacuation,

reporting, in the event of a General Alert emergency, to the Emergency Control Center and advising the Laboratory Emergency Director of readiness to assist.

Person Discovering Emergency

The person discovering an emergency should immediately act to protect personnel and property and bring the situation under control by:

1. handling the emergency alone if safe and possible;
2. if not, summoning help from
   (a) Laboratory Communication Center (telephone 6358),
   (b) local emergency squad members,
   (c) anyone nearby;
3. sounding the building evacuation alarm if necessary;
4. directing emergency service units to the scene.

He should be aware that prompt action may make the difference between a minor and a major accident.

The first "act to protect personnel" may well be to depart from the scene of the accident as rapidly as possible. If it is not completely evident that the situation is safe, that the radiation level and/or air contamination are within permissible emergency limits, and that the accident does not have a possible second phase (further explosion or fire, for example), the matter is better considered at a distance while the appropriate persons (listed above) are informed. The immediate area, or the entire building, should be evacuated as soon as possible. If it is clear that the area is at least temporarily safe, action should be taken to prevent the spread of damage; a small fire may be put out, valves closed, material (if it can be handled safely) placed in a hood, etc., and the local emergency supervisor informed.

When the emergency cannot be handled by the person discovering it and the Laboratory Communication Center has been informed, emergency personnel will probably arrive in the order of the following headings. They should get as complete and accurate information as possible from the person discovering the accident.

Emergency Personnel

Local Emergency Personnel. – The local emergency supervisor should ensure that:

all personnel have been evacuated from the area,

the Laboratory Communication Center has been notified,

emergency service units are met, briefed, and directed to the scene,

equipment and processes are shut down for safety,

the Laboratory Emergency Director is kept informed of the status and extent of the emergency and of any needed assistance,

for an emergency affecting more than his own area, follow the directions of the Laboratory Emergency Director,

provide for personnel and area monitoring and prevent re-entry to unsafe areas.

Emergency Service Units. – These groups, whose duties are outlined in the ORNL Emergency Manual, include:

the Health Division unit,

Fire and Emergency unit,

Guard unit,

Radiation Safety and Control unit,

Health Physics unit,

Engineering and Mechanical Division units,

others when necessary.

They will be dispatched to the scene of the emergency by the Laboratory Communication Center as required. (A Health Physics representative answers all emergency alarms directly.)

Health Physics Unit. – The Health Physics unit should:

1. Aid Laboratory Shift Supervisor and other responsible parties in evacuating all personnel from area of concern, with consideration for medical aid and checks for gross personnel contamination.
2. Appraise need for auxiliary help and request aid in notifying this help. When sufficient help is available, prepare a copy of form entitled "Personnel Record Sheet" on each person that was in area of concern.
3. Close off possible entrances to the immediate source of the accident. Place warning signs in position. If ventilation system is indicated as a possible carrier for the contamination, it should be shut off if possible.
4. Where liquid waste may be involved, qualified aid should be obtained in closing off and/or diverting materials from White Oak Creek.
5. Determine the outer boundaries of radioactive contamination. Request aid in roping off this area and affixing warning signs.
6. Begin a more detailed radiation survey. During early part of the survey obtain samples of air, liquid, and surface contamination for immediate analysis of materials involved. Request aid in having radiochemical analysis performed in order to identify and determine concentration of beta-emitting materials. Also, gamma spectrometry should be requested to evaluate and determine gamma emitting materials.

If alpha emitters are suspected, a range analysis should be made to identify the isotopes present.

(a) The results of the more detailed survey should be recorded on a map or sketch of the area.

(b) Consideration should be given at this time to the feasibility of using (1) gum paper fall-out trays, (2) additional air sampling equipment, (3) paper towel smears, etc.

7. Before starting full scale decontamination proceedings, a meeting between responsible supervision and other participating parties should be held in order to determine the following:

   (a) Method to be used in decontamination work (i.e., vacuum cleaning, soap and water, use of acids, removal and disposal, or combinations of the above methods).

   (b) Entrances and exits from Contamination Zone.

   (c) Availability of constant supply of contamination clothing and protective devices such as masks.

   (d) Availability of personnel for clean-up duty.

   (e) Which areas should be cleaned up first in relationship to the over-all Laboratory program.

8. A copy of all data and information pertaining to the accident (i.e., smear results, air sample results, film badges, urinalysis results, etc., should be kept in the radiation survey area field office handling the emergency). This procedure will aid in quickly obtaining information concerning progress of work relating to the accident.

General Principles

The handling of a spill of a small amount of radioactive material can illustrate some of the general principles (italics below) involved in the handling of any radiation accident. The person responsible for the spill usually takes the first steps in bringing the situation under control.

The most important principle in radiation safety is that each step must be *planned in advance* and detailed procedures for each area prepared before an accident occurs. Proper design of ventilation, vacuum, alarm, and other systems can ensure that sealing off an area is automatic; but even where this is possible, matters of personal judgment will always be involved. For example, it is obvious that one should *protect people before equipment*, but situations are conceivable where an emergency exposure might be risked to ensure the functioning of a piece of equipment whose failure would or could cause a greater exposure to a large number of people.

The person discovering the accident should first try to *estimate the hazard* caused by the accident and *evacuate* to a check station any persons likely to be contaminated. Special attention should be paid to the possibility of contaminated wounds. All those remaining in the area should wear appropriate *masks* if air-borne radioactivity is suspected.

He should *prevent the spread of contamination* by cutting off room ventilation fans, sealing windows, applying absorbers such as paper or sand to the contaminated area, and roping off or barricading the area. Radiation or contamination warning signs should be set up as soon as possible.

Help should be summoned; however, because of the importance of immediate action, as many of the precautions mentioned above should be taken by those on the spot. No one should be admitted to the contaminated area except authorized emergency personnel, and they should be protected by clothing and masks where needed. No persons should be permitted to leave the area except by the check station where (a) they are monitored for contamination that might be spread to other areas and (b) their personal monitoring instruments are taken up and replaced.

By this time the first phase of the emergency has been dealt with. Similar controls are necessary for the further cleanup. It may be advisable, if the spilled material is short-lived, to seal off the area and wait for the activity to decay through several half-lives (the activity of a radioisotope is reduced to less than 1% after 7 half-lives). Where this is not practical, working time of the cleanup crew should be limited and shielding used where necessary to limit exposure. After each operation or *before* an exposure of 3 rems to the total body or 25 rems to the hands, forearms, and feet (the limits for 13 weeks), persons engaged in the cleanup should be relieved and decontaminated if necessary.

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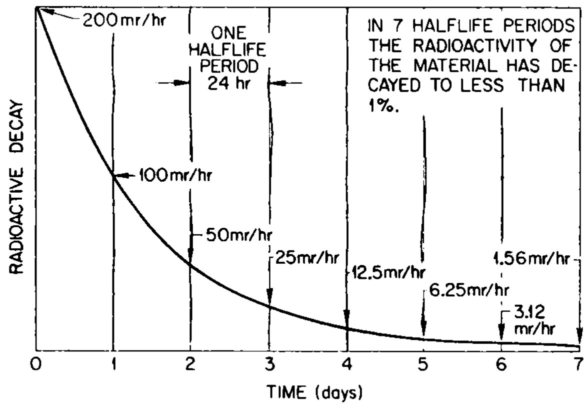

Radioactive Decay (Nuclear Safety Principles and Practices — (UCNC)

Some Points To Be Considered in a Major Emergency or Accident Involving Radioactive Materials

Evacuate

Evacuate exposed or contaminated personnel from accident area and isolate immediately any contaminated equipment, buildings, or spaces.

Delineate

Close off the radiation and/or contamination zones. Where contamination is the primary consideration, seal off the affected area where possible.

Contain

If air contamination is present, shut off air conditioning and ventilation insofar as processes will permit. Where liquid wastes may be involved, prevent their release to White Oak Creek if possible.

Sample

Obtain sample of air, liquid, and surface contamination for immediate analysis. Radiochemical analysis is necessary to identify and determine the concentration of fission products which are beta emitters only; for example, strontium-90. Gamma spectrometry should be used to evaluate most fission product hazards. Alpha range analysis should be made to determine the presence of such isotopes as Pu, Am, Cm, etc.

Decontaminate

Start immediate decontamination efforts to return as much of the laboratory normal operation as possible.

RULES OF THUMB

Specific Activity

$$\text{curies/gram} = \frac{1.308 \times 10^8}{AT_r};$$

$$\text{grams/curie} = 7.645 \times 10^{-9} AT_r,$$

where

A = atomic weight,

T_r = radioactive half-life, days.

Dose Rate from Fission Products

At time t,

$$\text{r/unit time} = It^{-1.2},$$

where I is the measured or calculated dose rate, and t is in the same time units.

Alpha Particles

Must be 7.5 Mev to penetrate the 0.07-mm protective layer of skin.

Beta Particles

Range in air, ~ 12 ft/Mev.

The *range* of beta particles in g/cm^2:

$$R, \sim \frac{E}{2},$$

where E is the maximum energy in Mev.

Dose rate in rads/hr at 1 ft from a point source, ~ 200 c, where c is curies.

Skin penetration (0.07 mm) requires 70 kev.

Bremsstrahlung from a 1-c P^{32} aqueous solution is about 3 mrhM.

Half-Value Layers (see also Appendix A)

HVL for 1-Mev neutrons, ~ 1.26 in. paraffin.

HVL for 5-Mev neutrons, $\sim$2.72 in. paraffin.

Dose Rates from X and γ Point Sources

The exposure dose rates at 1 cm and 1 ft are:

$$R_1\ (\text{cm}) = 1.50 \times 10^8 \sigma cE \text{ r/hr},$$

$$R_1\ (\text{ft}) = 1.61 \times 10^5 \sigma cE \text{ r/hr},$$

where c is curies and E is energy in Mev.

If σ in air is taken as 3.7×10^{-5} cm^{-1} for the energy range 0.07 to 2 Mev, then the exposure dose rates are (within $\pm$20%):

$$R_1\ (\text{ft}) \cong 6\, cE,$$

$$R_1\ (\text{cm}) \cong 5.6 \times 10^3\, cE.$$

The two above formulas are approximate only and *definitely cannot be used* for x-ray and gamma energies outside the range 0.07 to 2 Mev.

Instrument Time-Lag

Maximum allowable lag time for an air-monitoring warning instrument (to limit maximum dose to building occupants to 250 mrems before warning):

$$t = \frac{2.5 \times 10^5 \times (\text{MPC})_{\text{air, 40-hr}}}{C},$$

where

t = maximum permissible instrument lag-time, sec,

C = actual air contamination to be detected, μc/cc.

Compton Scattering of γ and X Rays

$$\lambda_\theta = \lambda_0 + 0.0242\,(1 - \cos\theta).$$

Range of Protons

In air, R, $\sim(E/9.3)^{1.8}$, where E is energy in Mev (few Mev to 200 Mev).

APPENDIX

Broad-Beam Gamma-Ray Attenuation (with Buildup)*

Isotope	Shield Material	Inches of Shield Material					
La^{140}	Water	26	46	62	83	106	
	Aluminum**	10.5	19	28	35	43	50
	Iron	3.6	6.6	9.6	12.2	15.2	
	Lead	1.8	3.7	5.5	7.4	9.4	
	Uranium	1.1	2.1	3.2	4.2	5.3	6.3
Co^{60}	Water	26	44	62	77	98	
	Aluminum**	10.6	18	26	32	39	46
	Iron	3.6	6.2	8.8	11.1	13.7	
	Lead	1.8	3.4	4.8	6.5	8.3	
	Uranium	1.0	1.9	2.7	3.5	4.4	5.2
$Ba^{140} + La^{140}$	Water	25	45	65	82	105	
	Aluminum**	9.7	19	27	35	43	50
Attenuation factor		10	10^2	10^3	10^4	10^5	10^6

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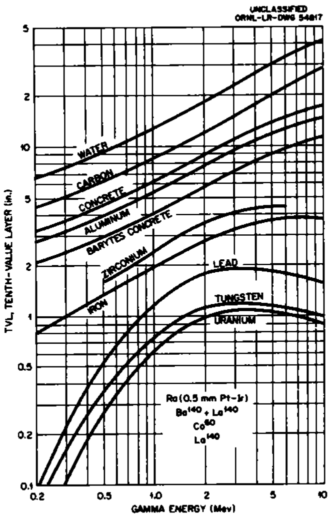
Broad-Beam Gamma-Ray Attenuation (with Buildup)* (continued)

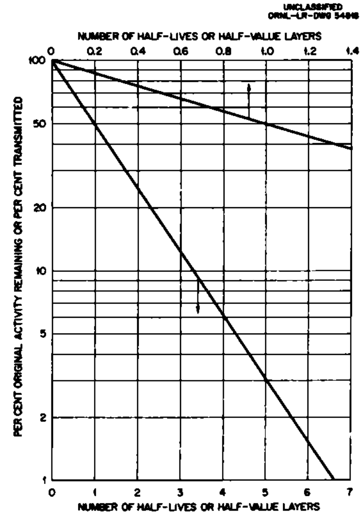
Isotope	Shield Material	Inches of Shield Material					
$Ba^{140} + La^{140}$	Iron	3.4	6.4	9.2	12.0	14.9	
	Lead	1.6	3.6	5.3	7.2	9.2	
	Uranium	0.96	2.1	3.1	4.1	5.2	6.2
Ra^{226} (in equilibrium with drs, encased in 0.5 mm Pt-Ir)	Water	25	44	64	81	104	
	Aluminum**	9.8	18	27	35	44	51
	Iron	3.4	6.4	9.2	11.8	14.8	
	Lead	1.6	3.4	5.2	7.1	9.0	
	Uranium	0.87	2.0	3.0	4.1	5.2	6.3
Attenuation factor		10	10^2	10^3	10^4	10^5	10^6

*Calculated from data of Fano (as plotted in AERE HP/L23) and recent values for spectra energies, relative intensities, and attenuation coefficients. Figures are probably conservative, as buildup values were calculated for inside an infinite shield.

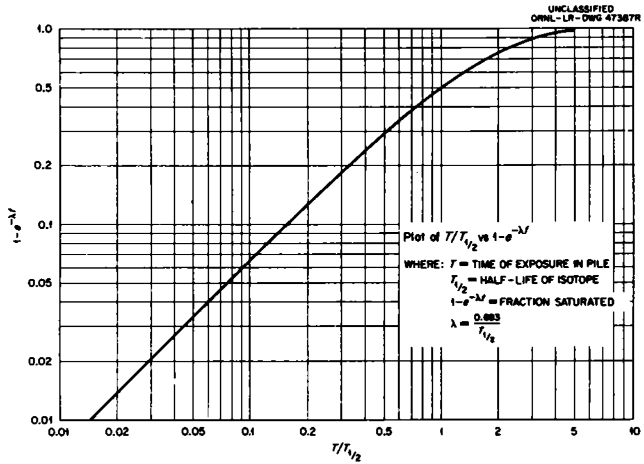
**Reasonable approximation for ordinary concrete.



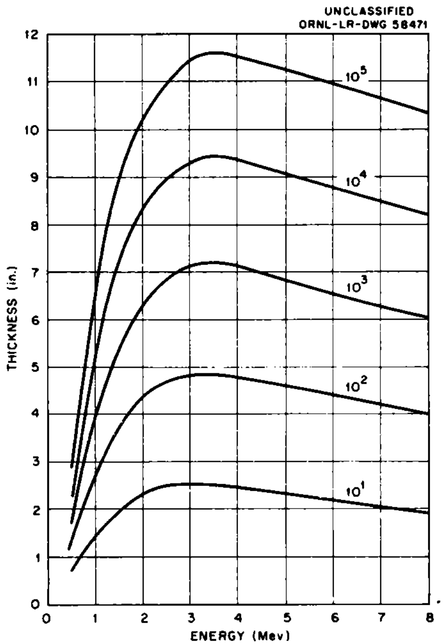
Narrow-Beam Gamma Attenuation (From APEX 176)



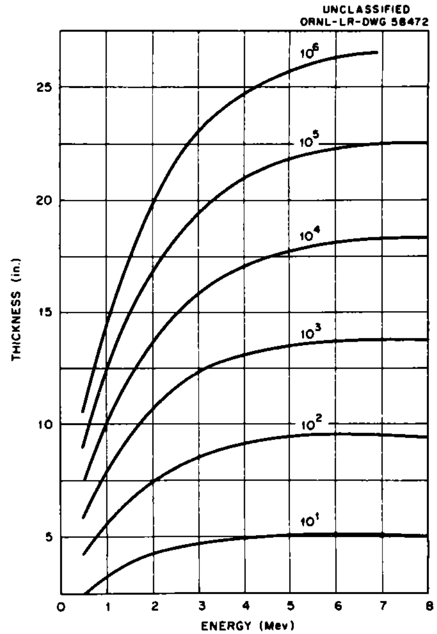
Semilog Plot for Radioactive Decay and Neutron Attenuation



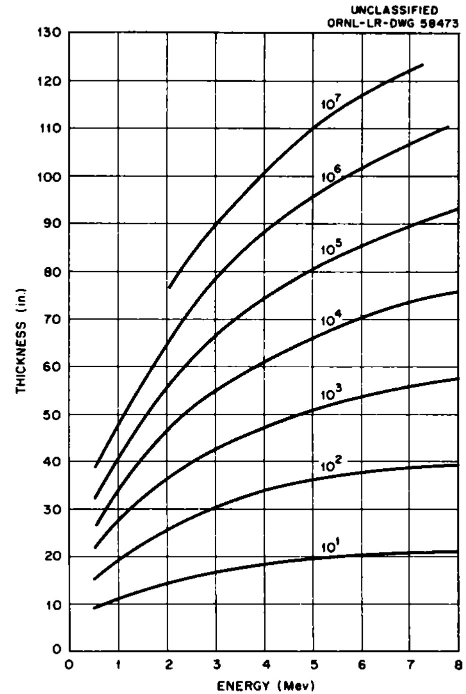
Plot of $T/T_{1/2}$ vs $1 - e^{-\lambda t}$



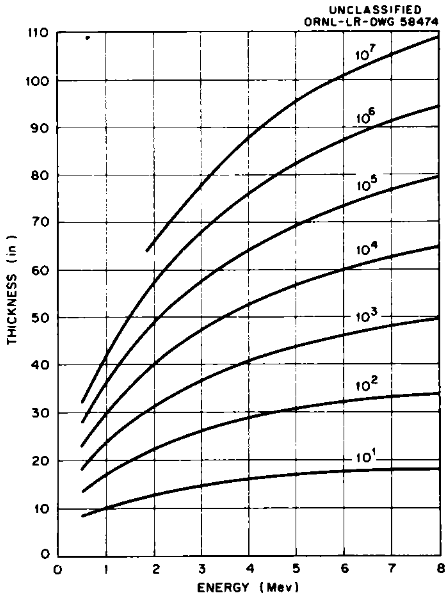
Thickness of Lead to Attenuate Broad Beam of Rays by Factors of 10, 10^2, 10^3, 10^4, and 10^5 (Fano, Nucleonics, Aug.–Sept., 1953)



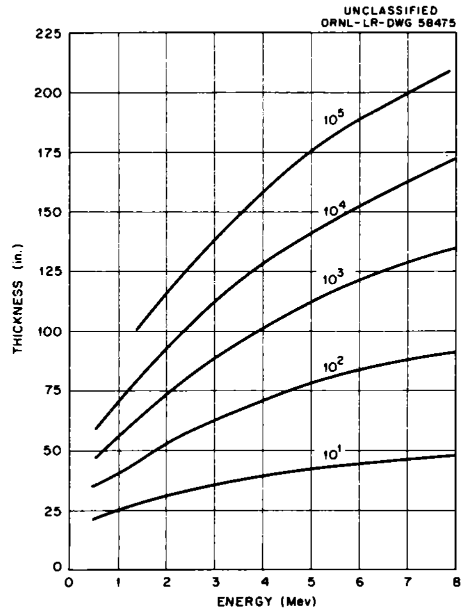
Thickness of Iron to Attenuate Broad Beam of Rays by Factors of 10, 10^2, 10^3, 10^4, 10^5, and 10^6 (Fano, Nucleonics Aug.–Sept., 1953)



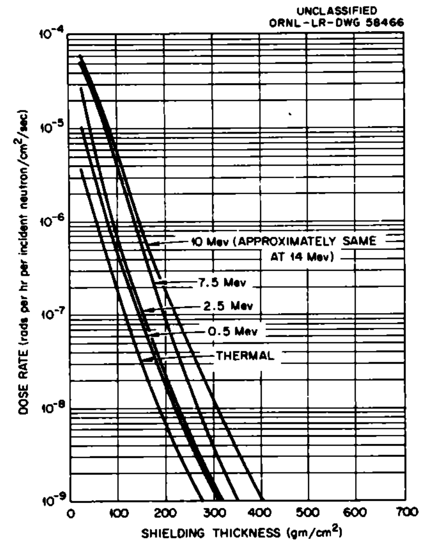
Thickness of Concrete to Attenuate Broad Beam of Gamma Rays by Factors of 10, 10^2, 10^3, 10^4, 10^5, 10^6, and 10^7 (Fano, Nucleonics, Aug.–Sept., 1953)



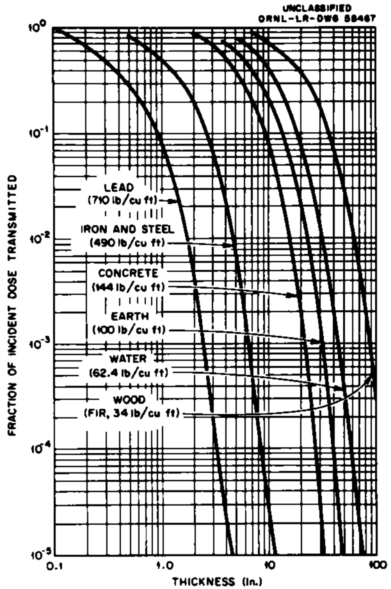
Thickness of Aluminum to Attenuate Broad Beam of γ Rays by Factors of 10, 10^2, 10^3, 10^4, 10^5, 10^6, and 10^7 (Fano, Nucleonics, Aug.–Sept., 1953)



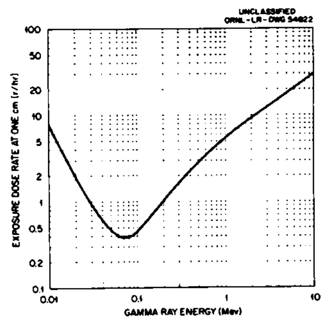
Thickness of Water to Attenuate Broad Beam of γ Rays by Factors of 10, 10^2, 10^3, 10^4, and 10^5 (Fano, Nucleonics, Aug.–Sept., 1953)



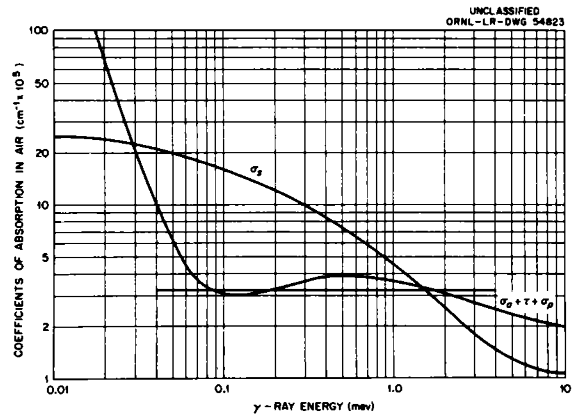
Transmission of Prompt Gamma Radiation in Ordinary Portland Concrete or Norfold Sandy Loam with 10% Water Added



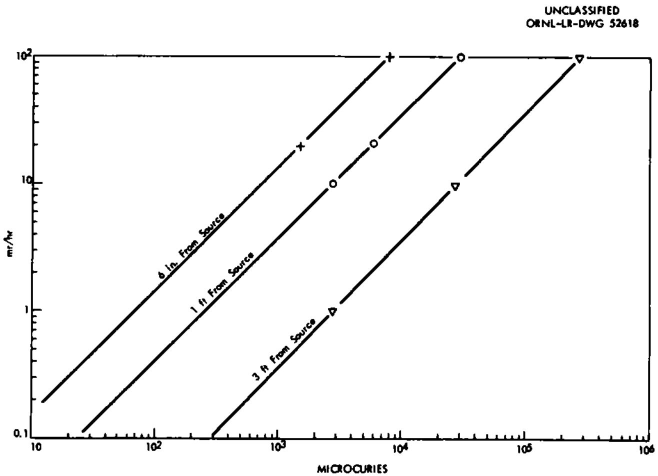
Transmission of Fission Product Gamma Radiation in Several Shield Materials (TID-8206)



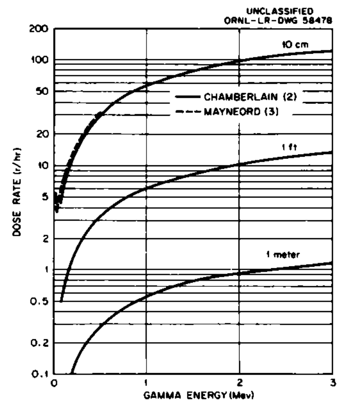
Exposure Dose Rate from a 1-mc Point Source



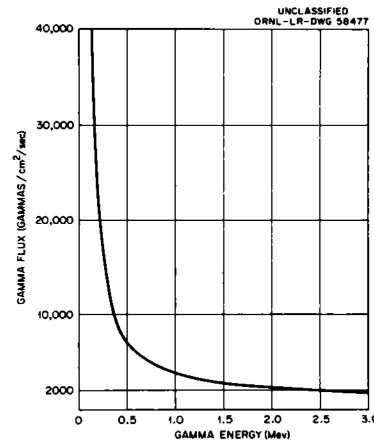
Coefficients of Absorption, in Air, for Gamma Rays



Activity Level from Point Source (0.5 Mev γ) vs Distance and Source Strength

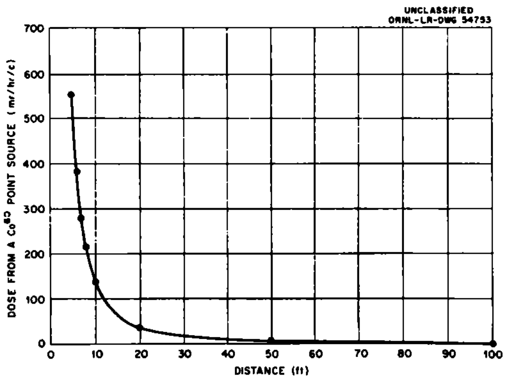


Dose Rate from a Point Gamma Source of Strength 1 Gamma Curie [R&DB (W) TN-58-AERE]

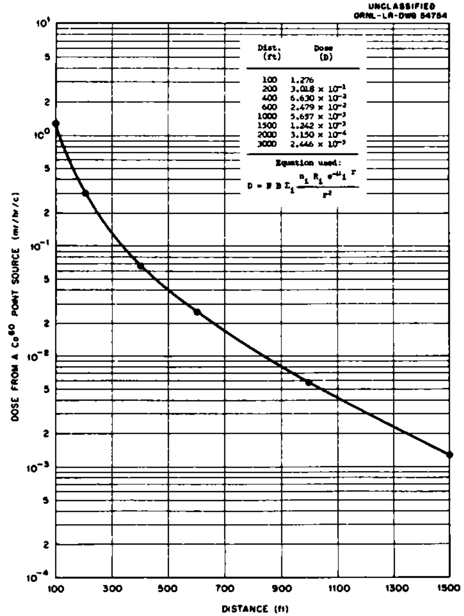


Gamma Flux to Give 0.3 Roentgens/40-hr Week [R&DB (W) TN-58-AERE]

Revised 9-11-61



Dose from a Co^{60} Point Source

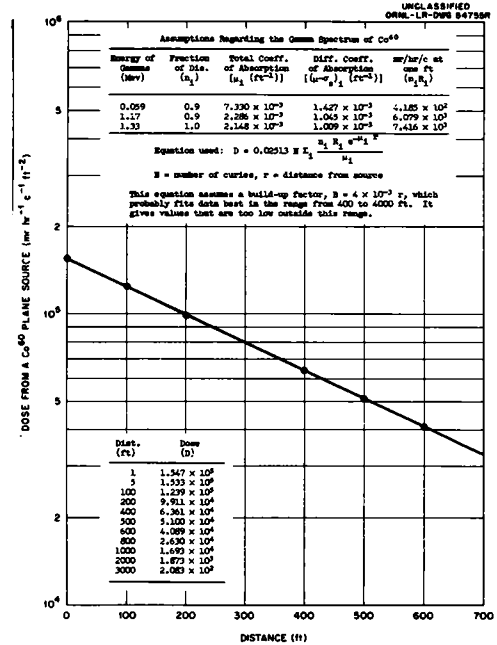


Dist. (ft)	Dose (D)
100	1.276
200	3.018×10^{-1}
400	6.630×10^{-2}
600	2.479×10^{-2}
1000	5.657×10^{-3}
1500	1.242×10^{-3}
2000	3.150×10^{-4}
3000	2.446×10^{-5}

Equation used:

$$D = N\,B\,\Sigma_i \frac{n_i\,R_i\,e^{-\mu_i r}}{r^2}$$

Dose from a Co^{60} Point Source



Assumptions Regarding the Gamma Spectrum of Co^{60}

Energy of Gamma (Mev)	Fraction of Dis. (n_i)	Total Coeff. of Absorption [μ_i (ft^{-1})]	Diff. Coeff. of Absorption [$(\mu-\sigma_s)_i$ (ft^{-1})]	mr/hr/c at one ft ($n_i R_i$)
0.059	0.9	7.330×10^{-3}	1.427×10^{-3}	4.185×10^{2}
1.17	0.9	2.286×10^{-3}	1.045×10^{-3}	6.079×10^{3}
1.33	1.0	2.148×10^{-3}	1.009×10^{-3}	7.416×10^{3}

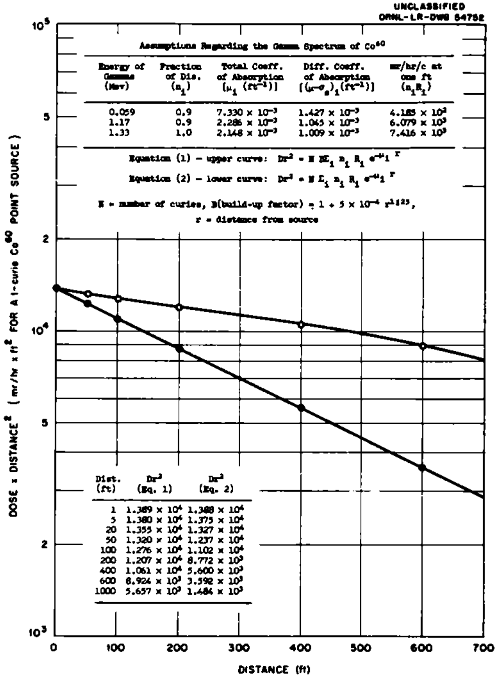
Equation used: $D = 0.02513\,N\,\Sigma_i \frac{n_i\,R_i\,e^{-\mu_i r}}{\mu_i}$

N = number of curies, r = distance from source

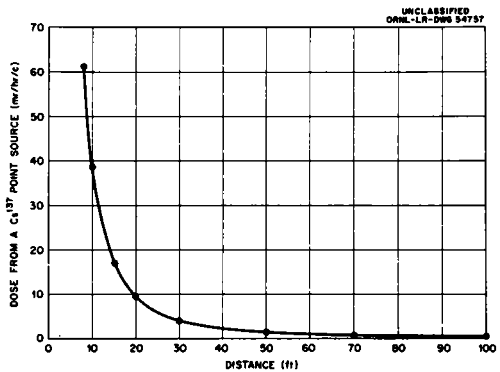
This equation assumes a build-up factor, $B = 4 \times 10^{-3}\,r$, which probably fits data best in the range from 400 to 4000 ft. It gives values that are too low outside this range.

Dist. (ft)	Dose (D)
1	1.547×10^{5}
5	1.533×10^{5}
100	1.239×10^{5}
200	9.911×10^{4}
400	6.361×10^{4}
500	5.100×10^{4}
600	4.089×10^{4}
800	2.630×10^{4}
1000	1.693×10^{4}
2000	1.873×10^{3}
3000	2.083×10^{2}

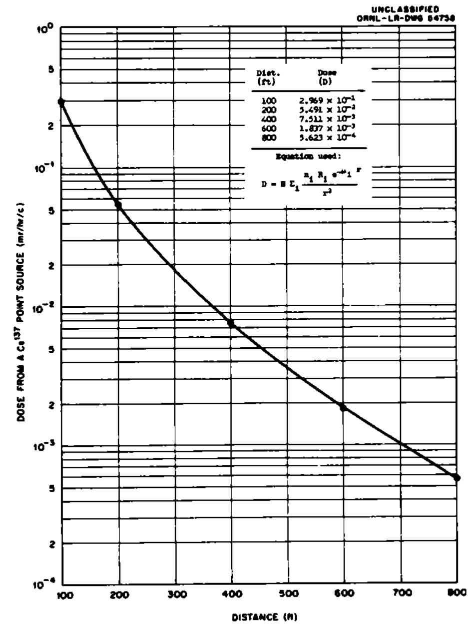
Dose from a Co^{60} Plane Source



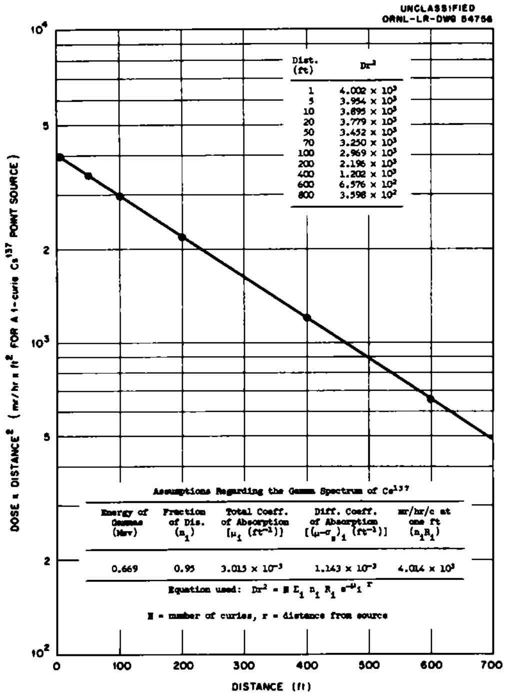
Dose × Distance Squared for a 1-Curie Co^{60} Point Source



Dose from a Cs^{137} Point Source



Dose from a Cs^{137} Point Source



Dist. (ft)	Dr^2
1	4.002×10^3
5	3.954×10^3
10	3.895×10^3
20	3.779×10^3
50	3.452×10^3
70	3.250×10^3
100	2.969×10^3
200	2.196×10^3
400	1.202×10^3
600	6.576×10^2
800	3.598×10^2

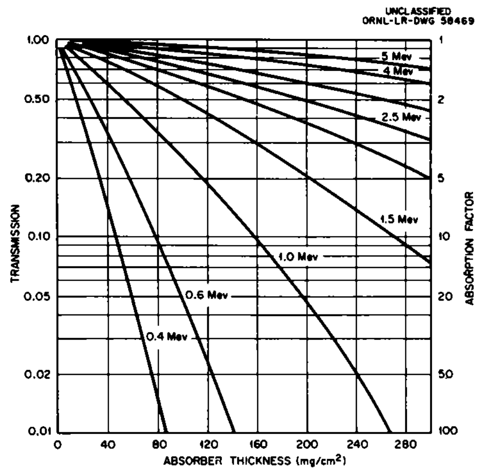
Assumptions Regarding the Gamma Spectrum of Cs^{137}

Energy of Gammas (Mev)	Fraction of Dis. (n_i)	Total Coeff. of Absorption [μ_i (ft^{-1})]	Diff. Coeff. of Absorption [$(\mu-\sigma_s)_i$ (ft^{-1})]	mr/hr/c at one ft ($n_i R_i$)
0.669	0.95	3.015×10^{-3}	1.143×10^{-3}	4.014×10^3

Equation used: $Dr^2 = N \Sigma_i n_i R_i e^{-\mu_i r}$

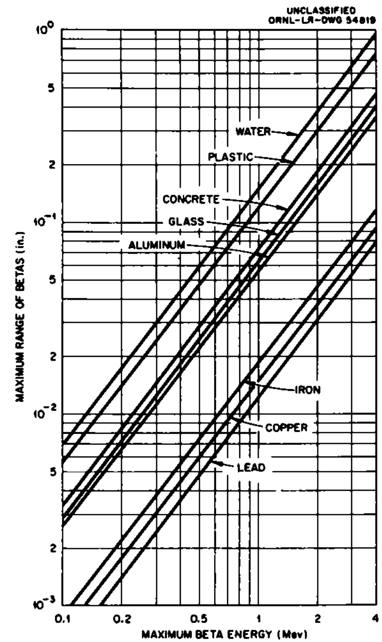
N = number of curies, r = distance from source

Dose × Distance Squared for a 1-Curie Cs^{137} Point Source

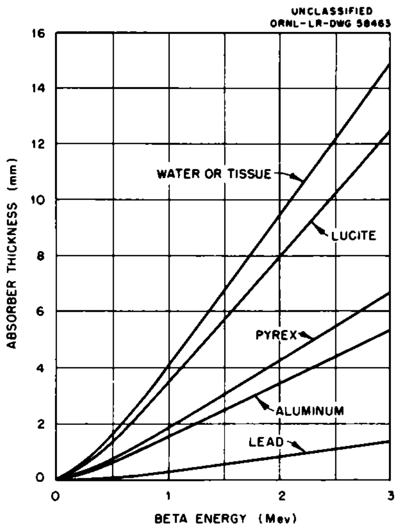


BETWEEN 0 AND 37.8 mg/cm² THE CURVES ARE EXTRAPOLATED.
THE ABSORBER IS ASSUMED TO BE NEAR THE COUNTER.

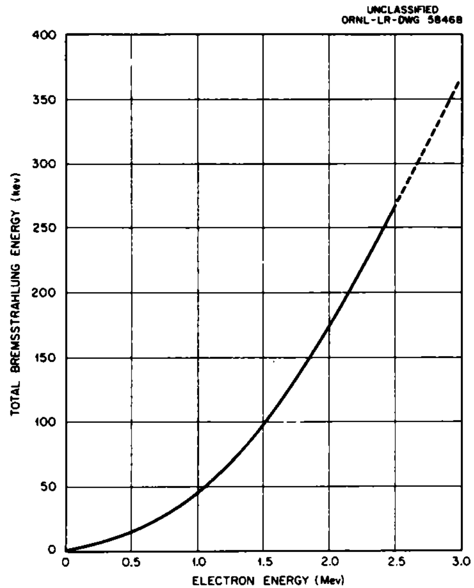
Transmission of Beta Spectra Through Aluminum [R&DB (W) TN-58-AERE]



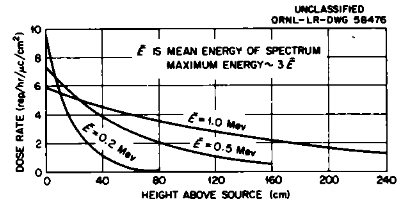
Beta-Ray Shielding



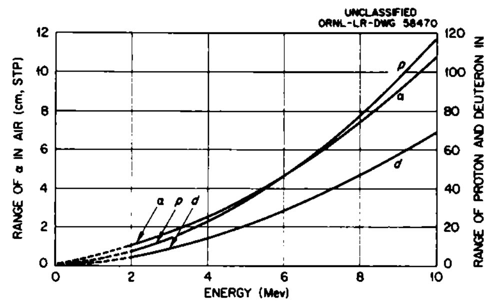
Relation Between Beta Radiation Energy Level and Range in Aluminum and Various Other Materials (Atomic Radiation – RCA Service Co.)



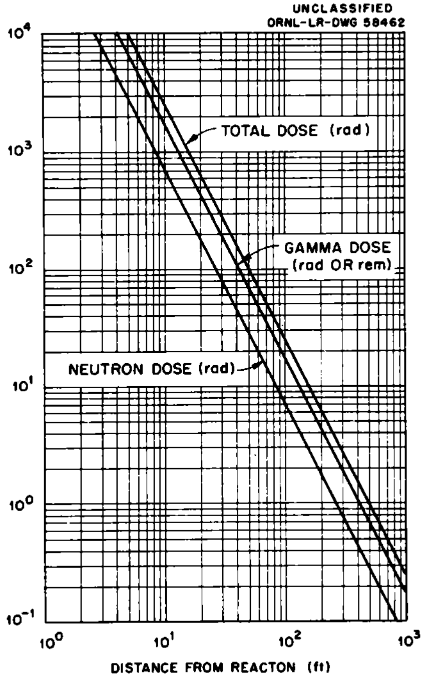
Total Bremsstrahlung Energy from Monokinetic Electron Stopped in Lead [R&DB (W) TN-58-AERE]



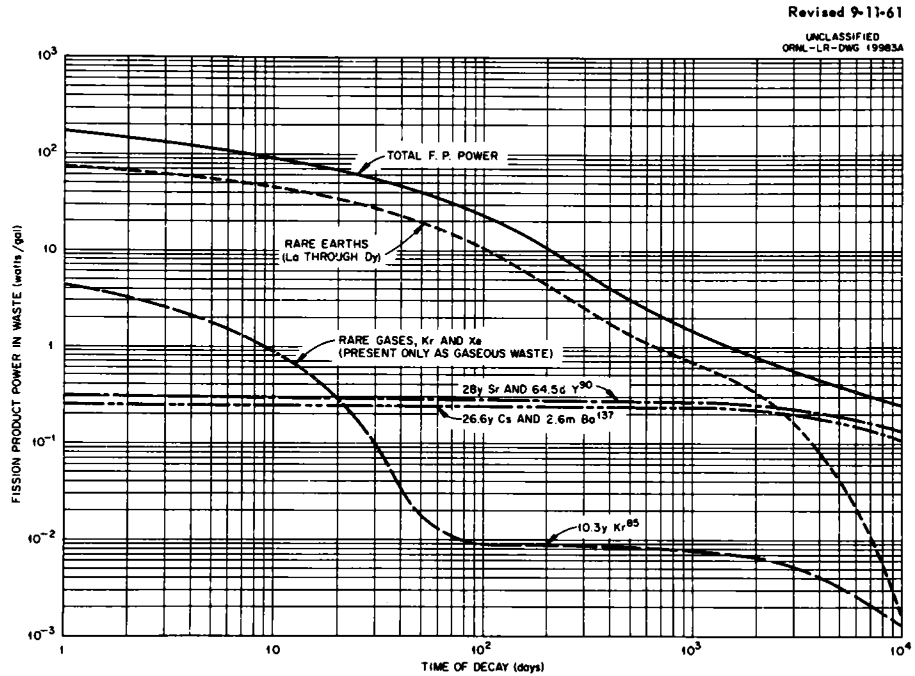
Dose Rate from Beta Emitter on Infinite Plane Area in Air [R&DB (W) TN-58-AERE]



Range – Energy Relationships for α-Particles, Protons and Deuterons [R&DB (W) TN-58-AERE]



Estimated Prompt Neutron and Gamma Doses from a Critical Burst of 10^{18} Fissions in a Uranium Solution (Nuclear Safety Principles and Practices – UCNC)



Fission Product Power in Waste as a Function of Decay Time. Basis: 800 gal waste per metric ton of uranium irradiated 10,000 Mwd/ton at 33 Mw/ton specific power.

Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure*

Radionuclide	Maximum Permissible Burden in Total Body q (μc)	Maximum Permissible Concentrations for 40-hr week (μc/cc)	
		$(MPC)_w$	$(MPC)_a$
H^3 (HTO) or (H_2^3O)	10^3	0.1	5×10^{-6}
C^{14} (CO_2)	300	0.02	4×10^{-6}
P^{32}	6	5×10^{-4}	7×10^{-8}
Ca^{45}	30	3×10^{-4}	3×10^{-8}
Cr^{51}	800	0.05	2×10^{-6}
Co^{60}	10	10^{-3}	9×10^{-9}
Zn^{65}	60	3×10^{-3}	6×10^{-8}

Revised 9-11-61

Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (continued)

Radionuclide	Maximum Permissible Burden in Total Body q (μc)	Maximum Permissible Concentrations for 40-hr week ($\mu c/cc$)	
		$(MPC)_w$	$(MPC)_a$
As^{76}	20	6×10^{-4}	10^{-7}
Sr^{89}	4	3×10^{-4}	3×10^{-8}
Sr^{90}	2	4×10^{-6}	3×10^{-10}
Zr^{95}	20	2×10^{-3}	3×10^{-8}
Nb^{95}	40	3×10^{-3}	10^{-7}
Ru^{106}	3	3×10^{-4}	6×10^{-9}
I^{131}	0.7	6×10^{-5}	9×10^{-9}

Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (continued)

Radionuclide	Maximum Permissible Burden in Total Body q (μc)	Maximum Permissible Concentrations for 40-hr week ($\mu c/cc$)	
		$(MPC)_w$	$(MPC)_a$
Cs^{137}	30	4×10^{-4}	10^{-8}
Ce^{144}	5	3×10^{-4}	6×10^{-9}
Pm^{147}	60	6×10^{-3}	6×10^{-8}
Ta^{182}	7	10^{-3}	2×10^{-8}
Ir^{192}	6	10^{-3}	3×10^{-8}
Au^{198}	20	10^{-3}	2×10^{-7}
Rn^{222}			3×10^{-8}

Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (continued)

Radionuclide	Maximum Permissible Burden in Total Body q (μc)	Maximum Permissible Concentrations for 40-hr week (μc/cc)	
		$(MPC)_w$	$(MPC)_a$
Ra^{226}	0.1	4×10^{-7}	3×10^{-11}
U^{235}	0.03	8×10^{-4}	10^{-10}
U^{238}	5×10^{-3}	10^{-3}	7×10^{-11}
Np^{237}	0.06	9×10^{-5}	4×10^{-12}
Pu^{239}	0.04	10^{-4}	2×10^{-12}
Am^{241}	0.05	10^{-4}	6×10^{-12}
Cm^{242}	0.05	7×10^{-4}	10^{-10}

*Lowest value (soluble or insoluble form) is given for MPC and q.

Maximum Permissible Concentration of Unidentified Radionuclides (MPCU Values) in Air

Values that are applicable for occupational exposure (168 hr/wk) to any radionuclide or mixture of radionuclides

Limitations	$(MPC)_a$ (168 hr/wk) (μc/cc of air)**
If there are no α emitters and if β emitters Sr^{90}, I^{129}, Pb^{210}, Ac^{227}, Ra^{228}, Pa^{230}, Pu^{241}, and Bk^{249} are not present,* the continuous exposure level, $(MPC)_a$, is not less than	10^{-9}
If there are no α emitters and if β emitters Pb^{210}, Ac^{227}, Ra^{228}, and Pu^{241} are not present,* the continuous exposure level, $(MPC)_a$, is not less than	10^{-10}
If there are no α emitters and if β emitter Ac^{227} is not present,* the continuous exposure level, $(MPC)_a$, is not less than	10^{-11}
If Ac^{227}, Th^{230}, Pa^{231}, Th^{232}, Th-nat, Pu^{238}, Pu^{239}, Pu^{240}, Pu^{242}, and Cf^{249} are not present,* the continuous exposure level, $(MPC)_a$, is not less than	10^{-12}
If Pa^{231}, Th-nat, Pu^{239}, Pu^{240}, Pu^{242}, and Cf^{249} are not present,* the continuous exposure level, $(MPC)_a$, is not less than	7×10^{-13}
In all cases the continuous occupational level, $(MPC)_a$, is not less than	4×10^{-13}

*In this case "not present" implies the concentration of the radionuclide in air is small compared with the MPC value for occupational exposure.

**Use $\frac{1}{10}$ of these values for interim application in the neighborhood of an atomic energy plant.

Maximum Permissible Concentration of Unidentified Radionuclides (MPCU Values) in Water

Values that are applicable for occupational exposure (168 hr/wk) to any radionuclide or mixture of radionuclides

Limitations	$(MPC)_w$ (168 hr/wk) (μc/cc of water)**
If Sr^{90}, I^{126}, I^{129}, I^{131}, Pb^{210}, Po^{210}, At^{211}, Ra^{223}, Ra^{224}, Ra^{226}, Ra^{228}, Ac^{227}, Pa^{231}, Th^{230}, Th^{232}, and Th-nat are not present,* the continuous exposure level, $(MPC)_w$, is not less than	3×10^{-5}
If Sr^{90}, I^{129}, Pb^{210}, Po^{210}, Ra^{223}, Ra^{226}, Ra^{228}, Pa^{231}, and Th-nat are not present,* the continuous exposure level, $(MPC)_w$, is not less than	2×10^{-5}
If Sr^{90}, I^{129}, Pb^{210}, Ra^{226}, and Ra^{228} are not present,* the continuous exposure level, $(MPC)_w$, is not less than	7×10^{-6}
If Ra^{226} and Ra^{228} are not present,* the continuous exposure level, $(MPC)_w$, is not less than	10^{-6}
In all cases the continuous occupational level, $(MPC)_w$, is not less than	10^{-7}

*In this case "not present" implies the concentration of the radionuclide in water is small compared with the MPC value for occupational exposure.

**Use $\frac{1}{10}$ of these values for interim application in the neighborhood of an atomic energy plant.

Procedure for Posting and Establishing Radiation Zones

Dose Rate Range	Immediate Action	Follow-Up Action
3 mrem/hr to 6 mrem/hr	Post low-level tags if the accumulated daily dose to personnel may be 20 mrem.	Periodic review
6 mrem/hr to 1 rem/hr	Post warning signs or tags.	Rope off the area if the accumulated weekly dose may be 1 rem.
1 to 3 rem/hr	Post warning signs or tags. Rope off.	Erect a barricade which provides absolute exclusion of personnel if the accumulated weekly dose in the area may be 12 rem. Lock or block entrance.
Over 3 rem/hr	Post warning signs, tag, and erect a temporary barricade. Lock and/or block all entries.	

Administrative Approvals Required for Planned Personnel Exposures

Minimum Supervisory Approval (each also requires those listed above it)	Dose Rate (rems/hr)	Accumulated Dose
Immediate Supervisor	To 5	To 0.3 rem in one week*
Division Director	>5	>0.3 rem in one week
Radiation Safety and Control Director	>20	
Laboratory Deputy Director	>50	Single exposure > 1/3 of the quarterly MPD

*This may be given in one day if the supervisor can ensure that the weekly total is below 300 mrems.

Contamination Levels To Be Used as a Guide in the Establishment of Contamination Zones

Type of Radiation	Air-Borne Contamination (μc/cc air)	Direct Reading Surface Contamination	Transferable Surface Contamination (d/m/ 100 cm^2)
α	2×10^{-12}	300 d/m/ 100 cm^2	30
β,γ	3×10^{-10}	0.25 mrad/hr	1000

Maximum Permissible Contamination Guide for Skin Surfaces

Surface	Direct Survey		Transferable (Smear)
	α (d/m/ 100 cm^2)	β,γ (mrads/hr)	α,β,γ
General body	150	<0.06	None detectable
Hands	150	<0.3	

Maximum Permissible Contamination on Clothing

Item	Direct Survey		Transferable (Smear)	
	α (d/m/100 cm^2)	β,γ (mrads/hr)	α	β,γ (d/m/100 cm^2)
Shoes, contamination zone				
Inside	300	1.0	30	1000
Outside	300	2.5	30	1000
Shoes, personal				
Inside	300	0.3	30	1000
Outside	300	0.6	30	1000
Clothing, contamination zone	150	0.75*		
Clothing, other company issued, and personal	150	0.25		

*No 100 $in.^2$ area to average greater than this value.

Permissible Contamination on Items Given Radiation or Contamination Clearance

Direct Survey		Transferable (Smear)	
α (d/m/100 cm^2)	β,γ (mrads/hr)	α (d/m/100 cm^2)	β,γ (d/m/100 cm^2)
<300	<0.05	<30	<200

Guide for Respiratory Protection from Air-Borne Contamination

Air-Borne Contamination Levels		Respiratory Equipment Required
α (μc/cc)	β,γ (μc/cc)	
$<2 \times 10^{-11}$	$<3 \times 10^{-9}$	None
2×10^{-11} to 2×10^{-9}	3×10^{-9} to 10^{-7}	Filter and/or canister-type full face mask
$>2 \times 10^{-9}$	$>10^{-7}$*	Positive-pressure clean air supply with mask or hood

*Consider external exposure in these cases.

Flux of Various Types of Ionizing Radiation to Give Dose of 100 mrems/40 hr

Type of Radiation	RBE	Average Exposure Rate (mrads/week)	Approximate Maximum Flux for 100 mrems/40 hr
X and gamma rays	1	100	$\frac{1400}{E}$ photons cm^{-2} sec^{-1} (error $< 13\%$ for E = 0.07 to 2 Mev)
Beta rays and electrons	1	100	15 betas cm^{-2} sec^{-1} of 1 Mev energy incident on tissue
Thermal neutrons	2.5	40	700 thermal neutrons cm^{-2} sec^{-1} incident on tissue
Fast neutrons	10	10	19 neutrons cm^{-2} sec^{-1} of 2 Mev energy incident on tissue
Alpha particles	10	10	$\cong$0.005 alpha cm^{-2} sec^{-1} of 5 Mev energy incident on tissue
Protons	10	10	$\cong$0.06 proton cm^{-2} sec^{-1} of 5 Mev energy incident on tissue
Heavy ions	20	5	$\cong$0.0002 oxygen ion cm^{-2} sec^{-1} of 5 Mev energy incident on tissue

Maximum Permissible Contamination on Noncontamination-Zone Laboratory Surfaces

Type of Contamination	Direct Survey	Transferable ($d/m/100\ cm^2$)
1. α Where cleanup to listed values is feasible, and contaminant is not fixed to surface by an approved bonding material	300* $d/m/100\ cm^2$	30*
2. α Where cleanup to values listed opposite 1 above is not feasible, and contamination will be permanently fixed to surface by an approved bonding material**	3000* $d/m/100\ cm^2$ (before bonding)	300* (before bonding)
3. β, γ	0.25 mrad/hr	1000

*When the contamination involves an extensive area (e.g., larger than a single room or cell) and consists of radionuclides such as Pu^{239} or other long-lived α emitters of comparable toxicity, the listed maximum values continue to apply with the added limitation that the *average* contamination level will not be greater than $\frac{1}{10}$ of the specified maximum values. The average level will be determined from a minimum of 10 measurements consisting of at least one sample or reading from each square meter of projected area.

**Surveillance of area and maintenance of bonding cover will be required as long as the contaminant remains in excess of values specified opposite 1 in this table.

Recommended Maximum Permissible Yearly Nonoccupational Doses

Nonoccupational Group	Total Body, Lenses of Eyes, Gonads	MPC
Adults who work in vicinity of the controlled area or who enter controlled area occasionally	1.5 rems/yr	30% of 40-hr occupational
Persons living in neighborhood of controlled area	0.5 rem/yr	10% of 168-hr occupational
Population at large	0.5 rem/yr or 5 rems to age 30	1% of 168-hr occupational

Relation of Symptoms and Signs to Gamma Radiation Dose Received

Dose (rads)	Symptoms	Peripheral Blood Changes	Outcome
0–50	None	Not detectable	No illness
51–100	Usually none; at 100 rads 15% experience nausea; weakness during first 2–3 days	Early depression of lymphocytes	Trivial, if any, illness; complete recovery
101–150	15–50% nausea and weakness	About $\frac{1}{3}$ show depression of total white blood cell (WBC) count	Complete recovery
151–200	50–70% nausea and weakness early; fatigue after 3d week lasts 3–6 weeks	Depression definite but hemorrhage uncommon	Complete recovery

Relation of Symptoms and Signs to Gamma Radiation Dose Received (continued)

Dose (rads)	Symptoms	Peripheral Blood Changes	Outcome
201–400	Typical acute radiation syndrome; all exposed persons require hospitalization	Severe depression; hemorrhage and infection may be severe	Except at upper limits, recovery usual
401–600	Above 500 rads gastrointestinal damage critical	Fever; infection and hemorrhage severe; death 3–7 weeks	50% will die at 500 rads
2000	Convulsions, dizziness, staggering, and unconsciousness	Not important	Death within 24–48 hr

CONTAINMENT CRITERIA

The following criteria are to be considered in the design and modification of chemical plants, hot cells, and the buildings containing them.

For the Cell

(a) Vacuum should be equal to, or greater than, 1 in. of water and a minimum flow through all openings of 100 ft/min maintained. A minimum cell vacuum is established to ensure a positive flow of air from the building into the cell.

(b) Cell exhaust capacity should be equal to, or greater than, 0.1 cell volume per minute. This value precludes an explosion hazard in cells handling flammable solvents; and it gives assurance that, in the event of an explosion that brings the cell pressure positive with respect to the building pressure, it will be returned to the negative 1 in. of water in an acceptable time.

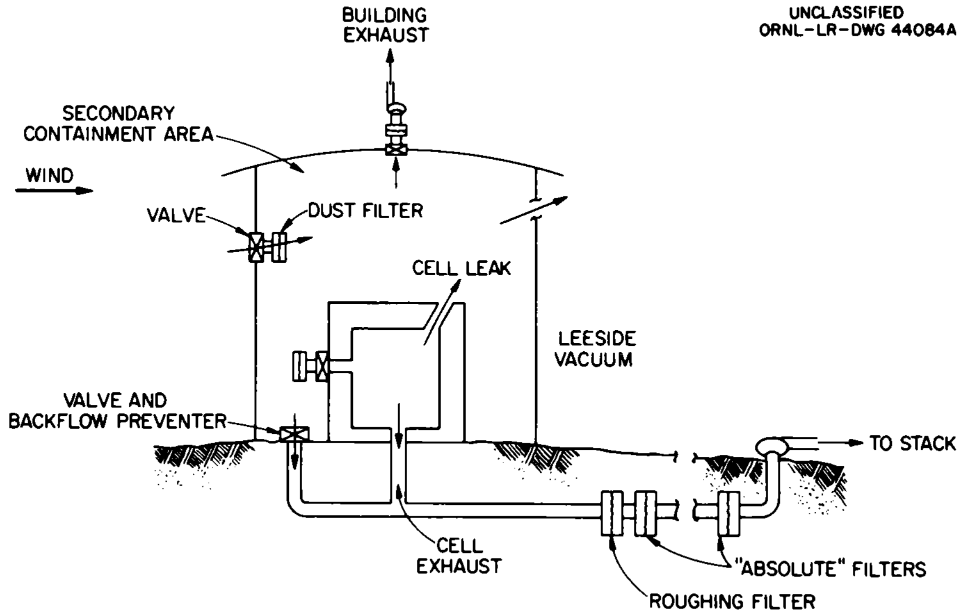
(c) Leak rate should be equal to, or less than, 0.01 cell volume per minute at 2 in. of water pressure difference. This specification ensures that contamination escaping the cell is minimized in the event that an accident causes the pressure to go positive with respect to the building pressure.

(d) Seals are to withstand a pressure difference equal to, or greater than, 10 in. of water. In the event of an explosion the integrity of cell-block cover seals, etc., must not be destroyed.

(e) The shielding must be designed to withstand the pressure produced by the maximum credible accident.

(f) An alarm should be provided to indicate loss of cell negative pressure.

(g) Exhaust from hot cells must pass through at least one roughing filter and an absolute filter and be continuously monitored with a suitable alarm to indicate the presence of radioactivity before being discharged to the environment.



Example of Hot Cell and Containment

(h) Operations capable of producing large quantities of air-borne contamination should be carried out within a secondary enclosure within the cell. This enclosure is to be provided with an exhaust which is filtered before discharge into the cell ventilation system.

(i) Chemical contaminants capable of damaging the filters must be removed from the cell ventilation air.

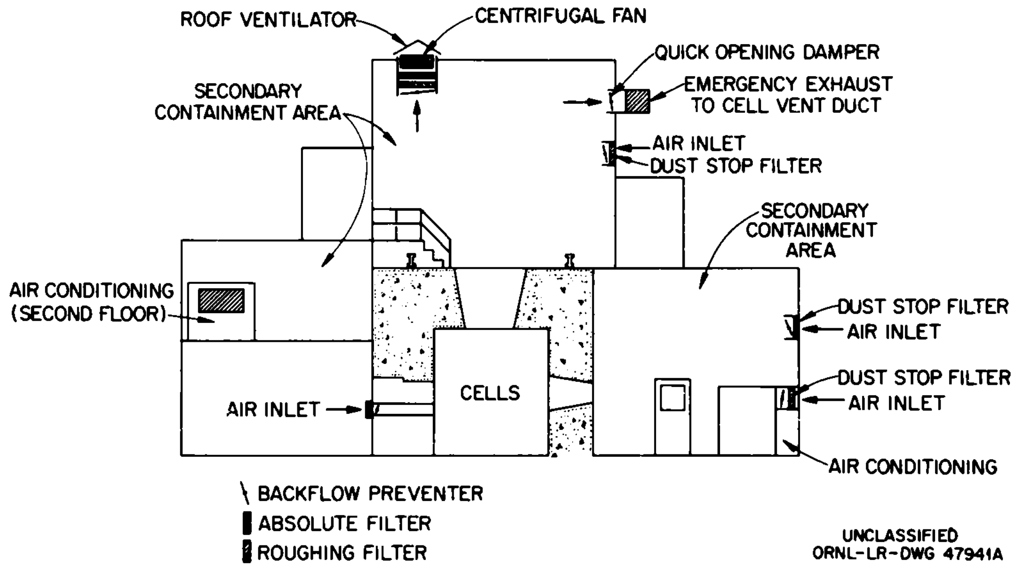
For the Containment Building

(a) Under the emergency condition, the building vacuum should be equal to, or greater than, 0.3 in. of water.

(b) Under the emergency condition, the containment building air is evacuated through the cell ventilation system which is provided with roughing and absolute filters.

(c) Building leak rate should be equal to, or less than, 6×10^{-3} building volumes per minute to ensure that accidental radioactive releases from the building will be acceptable.

(d) Time required to bring the building to 0.3 in. negative pressure should be equal to, or less than, 20 seconds. In this time radioactivity escaping the building because of a leeside negative pressure difference will be acceptable.



Example of Hot Cell and Containment

Values of Basic Nuclear Safety Parameters

This table gives the current best estimates of several minimal critical dimensions of the three most readily fissionable isotopes and the corresponding maximum value recommended for the design of process equipment and procedures. The recommended values singly provide safety and are independent of one another.

	U^{235}		U^{233}		Pu^{239}	
	Recommended Safe Maximum	Minimum Critical Value	Recommended Safe Maximum	Minimum Critical Value	Recommended Safe Maximum	Minimum Critical Value
Mass, kg						
Solution	0.35	0.82	0.25	0.59	0.22	0.51
Metal	10.0	22.8	3.2	7.5	2.6	5.6 (α phase)
					3.5	7.6 (δ phase)
Diameter of infinite cylinder, in.						
Solution	5.0	5.4	3.7	4.4	4.2	4.9
Metal	2.7	3.1	1.7	1.9	1.4	1.7 (α phase)
					1.8	2.1 (δ phase)
Thickness of infinite slab, in.						
Solution	1.5	1.7	0.8	1.2	0.9	1.3
Metal	0.5	0.60	0.2	0.3	0.18	0.22 (α phase)
					0.24	0.28 (δ phase)

Values of Basic Nuclear Safety Parameters (continued)

	U^{235}		U^{233}		Pu^{239}	
	Recommended Safe Maximum	Minimum Critical Value	Recommended Safe Maximum	Minimum Critical Value	Recommended Safe Maximum	Minimum Critical Value
Solution volume, liters	4.8	6.3	2.3	3.3	3.4	4.5
Chemical concentration of aqueous solution, g (of isotope)/liter	10.8	12.1	10.0	11.2	6.9	7.8
U^{235} enrichment of homogeneous hydrogen-moderated uranium, wt %	0.95	1.0				

Notes: (a) H_2O moderator and thick reflector are assumed for solutions.
(b) H_2O reflector and no moderator assumed for metal.
(c) No D_2O, Be, or other material having reflector or moderator properties better than H_2O are allowed.
(d) Values do not apply to high-density pellets, bundles of rods, etc., without special consideration.
(e) The recommended values of chemical concentration and U^{235} enrichment do not contain safety factors covering uncertainties in sampling and analytical errors.

OAK RIDGE NATIONAL LABORATORY RADIATION SAFETY POLICY

It is the radiation safety policy of the Oak Ridge National Laboratory to:

1. Carry out all operations with the lowest reasonable personnel exposure to radiation and contamination; in no case should internal and external exposures exceed the recommendations of the FRC and the NCRP.
2. Perform all work in such a manner that losses resulting from contamination are minimized. Such losses may include research, development, and production time; facility and/or equipment abandonment; and the cost of cleaning up contamination.
3. Maintain environmental contamination at as low a level as possible consistent with sound operating practice; in no case should the atmospheric and water contamination outside the controlled area exceed the maximum permissible concentration values for the neighborhood of an atomic energy installation.

In order to carry out this policy, specific responsibilities and authorities are delegated by the Laboratory Director. The general nature of the delegated responsibilities are as follows.

A. Divisions

The Laboratory Divisions are responsible for conducting all activities safely.

B. Applied Health Physics

Applied Health Physics is responsible for the audit radiation monitoring of Laboratory operations, the Laboratory environs, and for advising the Divisions on the safe conduct of their operations.

C. Radiation Safety and Control

Radiation Safety and Control represents the Laboratory management in all matters of radiation safety.

D. Instrumentation and Controls

Instrumentation and Controls is responsible for the development of health physics instruments, recommending specific makes for purchase, and for performing maintenance on health physics instruments.

E. Laboratory Shift Supervisor

The Laboratory Shift Supervisor represents Laboratory management in radiation safety matters on shift. He assumes full responsibility for the handling of emergencies affecting more than one facility.

F. Radiation Control Officer

The Radiation Control Officer represents the Division Director in matters of radiation safety, discharging at the divisional level the responsibilities which are designated by the Division Director.

G. Radiation Safety and Control Advisory Groups

The Radiation Safety and Control Advisory Groups are established to advise and assist the Director of Radiation Safety and Control in the handling of special problems of radiation safety.

H. Laboratory Director's Review Committees

The Laboratory Director's Review Committees are responsible for the independent evaluation of the radiation safety of Laboratory operations and for reporting their conclusions and recommendations to the Laboratory Director.

The specific responsibilities for radiation safety which are delegated by the Laboratory Director fall into two categories: those shared jointly by more than one group; and those which are, in the main, the responsibility of a single group. These responsibilities are shown on the following tables.

JOINT RESPONSIBILITIES FOR RADIATION SAFETY

A. Divisions

A-1 Assume primary responsibility for attainment of policy objectives with regard to personnel exposure, minimizing losses due to contamination, and environmental contamination.

A-2 Inform Health Physics of radiation safety problems present in current or proposed operations.

A-3 Consult with Health Physics and use personnel exposure data provided by Health Physics in planning all operations where significant exposure might occur.

A-4 Inform Health Physics whenever work requiring the presence of a health physicist is to be performed.

B. Applied Health Physics

B-1 Serves in an advisory capacity in matters involving radiation safety and health physics.

B-2 The area health physicist maintains intimate knowledge of the radiation-safety aspects of work being carried out in his area, currently assesses the hazards of each operation, advises on the radiation-safety aspects of operating procedures, and staffs each job requiring health physics surveillance with a surveyor of sufficient competence to handle the assignment.

B-3 In order to keep and control personnel exposures below the maximum permissible, the Health Physics Division compiles, and maintains current, exposure data for all craft and operating people who may be required for assignments necessitating significant exposure. The data will be readily and currently available, and supervision will be promptly informed whenever an individual's exposure for the quarter reaches 1 rem.

B-4 Determines accurately the radiation field existing in a proposed work area, calculates allowable working time, and either times or arranges to have the work timed. In case of radiation fields which are difficult to assess, the highest radiation level (general field, not localized reading) measured in the area where personnel will be working shall be assumed and working times calculated on this basis until such time as a lower radiation field is indicated by measurement. Advises the supervisor of other protective measures required for the job.

C. Radiation Safety and Control

C-1 Establishes, on behalf of the Laboratory Director, policy with respect to radiation protection and ascertains that Laboratory policy with regard to radiation safety and control is met.

D. Instrumentation and Controls

E. Laboratory Shift Supervisor

E-1 Represents Laboratory management in all matters of radiation safety and control on shifts.

F. Radiation Control Officers

F-1 Actively and aggressively keeps under continuous surveillance all operations of the Division which could lead to radiation incidents. Should, under Division Director, assume full responsibility for radiological safety in the Division.

JOINT RESPONSIBILITIES FOR RADIATION SAFETY (continued)

A. Divisions	B. Applied Health Physics	C. Radiation Safety and Control	D. Instrumentation and Controls	E. Laboratory Shift Supervisor	H. Laboratory Director's Review Committees
A-5 All work likely to result in (a) unnecessary personnel exposure, (b) unnecessary contamination of the facility or equipment, or (c) unnecessary environmental contamination, will be stopped unless it is judged, for good and specific reasons, that the advantages of continuing the operation outweigh the disadvantages.	*B-5* The attending health physicist immediately informs the supervisor of the operation if any of the following appear likely: (a) unnecessary personnel exposure, (b) unnecessary contamination of the facility or equipment, or (c) unnecessary environmental contamination.				
A-6 Work of the character described in *B-6* will be *promptly* halted on the recommendation of Health Physics unless (a) cessation of the operation will create a greater hazard than its continuance or (b) there are definite reasons for believing that no hazard is involved in continuing the operation.	*B-6* Whenever, in the opinion of the attending health physicist, work may result in (a) personnel exposure in excess of the maximum permissible, (b) cleanup costs or property loss in excess of $5,000, (c) an incident of public-relations significance, or (d) exposure of the population off site to radiation in excess of the maximum permissible, it is his responsibility to recommend to the operating supervision that the work be stopped.				
A-7 Cooperate with Health Physics in assessing radiation safety through notification of unusual occurrences or incidents that have occurred when Health Physics surveyors were not present and by providing access to, and making readily available, all relevant information.	*B-7* Has responsibility of making an early and thorough assessment of any unusual occurrences or incidents that may have occurred in the course of an operation.				
A-8 Define radiation safety problems expected in new facilities or facilities to be significantly modified.	*B-8* Gives advice on health physics requirements for new facilities or facilities to be significantly modified and, with Radiation Safety and Control, issues formal approval.	*C-8* Approves, jointly with Applied Health Physics, the design of planned new facilities or facilities to be significantly modified.			
A-9 Schedule and carry out regular tests of all facilities for adherence to radiation safety and control criteria.		*C-9* Approves and audits tests of radiation safety features of facilities.			*H-9-11* Conduct reviews of experiments or operations at the discretion of the Committee Chairmen, Executive Secretary, or on request. Make recommendations to improve operating safety.
A-10 Prepare written procedures for safe execution of research, development, and operations; such procedures to be approved by the Division Director.	*B-10* Reviews and comments on the health physics aspects of procedures, informs supervision of unusual health physics problems anticipated, and gives advice on their handling.	*C-10* Audits, from the radiation safety viewpoint, the research, development, and operating procedures which are employed by the Divisions.			

A. Divisions	B. Applied Health Physics	C. Radiation Safety and Control	D. Instrumentation and Controls	E. Laboratory Shift Supervisor	F. Radiation Control Officer
A-11. Prepare hazards evaluations of all operations handling significant quantities of radioactive materials or other sources of ionizing radiation.		*C-11* Reviews and approves hazards evaluations.			
A-12 Execute Radiation Work Permits as required for operations involving radioactive materials or other sources of ionizing radiation.	*B-12* Certifies Radiation Work Permits for operations involving radioactive materials or other sources of ionizing radiation.				
A-13 Procure health physics instruments for each area.	*B-13* Recommends numbers and types of health physics instruments to be employed.		*D-13* Specifies makes of health physics instruments to be employed, with the advice of Applied Health Physics, and maintains health physics instruments.		
A-14 Assume responsibility for the adequacy of employee training in radiation safety.	*B-14* Conducts health physics part of employee training program.	*C-14* Coordinates and organizes radiation safety training programs.			
A-15 Assume primary responsibility for action in the case of a local emergency, acting on the advice of the Radiation Incident Advisory Group and Applied Health Physics.	*B-15* Advises the Laboratory Shift Supervisor or operating supervision on health physics aspects of emergencies.	*C-15* Activates, and serves as chairman of, the Radiation Incident Advisory Group to give advice on action following an incident.		*E-15* Immediately and automatically assumes responsibility for emergency following an incident until relieved.	
A-16 Inform promptly the line supervision, the Laboratory Shift Supervisor, and the Director of Radiation Safety and Control of all personnel overexposures, unusual contamination incidents, or excessive releases of radioactivity to the environment.	*B-16* Informs promptly the Division Director concerned and the Director of Radiation Safety and Control of all personnel overexposures, unusual contamination incidents, excessive releases of radioactivity to the environment, or other unusual occurrence.	*C-16* Assumes responsibility for release of radiation incident information outside the Laboratory. All such information is to be approved by the Laboratory Director.		*E-16* Informs promptly the Division Director concerned, Applied Health Physics, and the Director of Radiation Safety and Control of all personnel overexposures, contamination incidents, excessive releases of radioactivity to the environment, or other unusual occurrence.	
A-17 Appoint a Radiation Control Officer and designates his responsibilities for radiation safety at the divisional level.		*C-17* Holds regular meetings with the Radiation Control Officers, informing them of the status of radiation safety and control matters at the Laboratory.			
A-18 Plan for local radiation emergencies and conduct regular drills.				*E-18* Plans for emergencies involving more than one facility and conducts regular drills.	
	B-19 Gives advice and approval for Laboratory waste disposal operations and for new waste disposal facilities.				

RESPONSIBILITIES TO BE DISCHARGED BY GROUP INDICATED

(The assistance of other groups may be requested.)

Divisions

1. Conduct investigations of all unusual occurrences and prepare a report making recommendations for preventing recurrence.
2. Hold regularly scheduled radiation safety meetings.
3. Implement the advice of Applied Health Physics and the Laboratory Director's Review Committees on matters of radiation safety.

Applied Health Physics

1. Establishes and maintains a Laboratory zoning program.
2. Specifies protective clothing and equipment requirements for work in contaminated areas.
3. Specifies radiation surveys needed in each area and recommends the frequency.
4. Performs radiation surveys of all areas on a recommended frequency.
5. Reports, biweekly, the results of radiation surveys and the status of the radiation protection program in each area to the Division Director and the Director of Radiation Safety and Control.
6. Conducts the personnel monitoring program, interprets results, maintains records, and reports results to the Division Director and the Director of Radiation Safety and Control.
7. Performs analyses required for bioassays and reports results to the Division Director and the Director of Radiation Safety and Control.
8. Conducts environmental monitoring program, interprets results, and reports biweekly to the Operations Division Superintendent and the Director of Radiation Safety and Control.
9. Prepares and keeps up to date a manual of radiation protection procedures.
10. Calibrates health physics instruments.

Radiation Safety and Control

1. Approves all requests, prior to Policy Committee consideration, involving radiation protection and health physics instruments.
2. Conveys recommendations of Director's Committees to responsible Division and ensures conformance.
3. Prepares publicity material for furthering the radiation protection program.

Radiation Safety and Control Advisory Groups

1. ADVISORY GROUP FOR FIXED RADIATION-CONTROL INSTRUMENTS – Specifies numbers and makes of fixed instruments required for new and existing facilities and advises on the necessary replacement schedule.
2. ADVISORY GROUP FOR PORTABLE RADIATION-CONTROL INSTRUMENTS – Specifies numbers and makes of portable instruments required for new and existing facilities and advises on the necessary replacement schedule.
3. RADIATION INCIDENT ADVISORY GROUP – Gives advice on action to be taken following an incident, including: health physics procedures, cleanup techniques, standards for cleanup, staffing the cleanup effort, funding, and work restrictions to be imposed on exposed personnel.
4. DESIGN CRITERIA REVIEW GROUP – Approves (for conformance with radiation safety and control policy) all design criteria for facility changes under the containment program.
5. RADIOACTIVE MATERIALS TRANSPORT ADVISORY GROUP – Establishes criteria for shipping containers for radioactive materials and recommends procedures to be employed for shipments – in the Laboratory and to other Oak Ridge plants.

LABORATORY DIRECTOR'S REVIEW COMMITTEES

Executive Secretary – F. Kertesz

Committee	Chairman
Criticality	A. D. Callihan
Radiochemical Plants	S. E. Beall
Hot Cells and Sources	H. F. McDuffie
Reactor Operations	M. E. Ramsey
Reactor Experiments	E. P. Epler
Waste Effluents	W. H. Jordan

Radiation Control Officers

Name	Phone	Building	Division
L. G. Farrar	6560	3019	Analytical Chemistry
M. L. Randolph	7046	9207, Y-12	Biology
C. E. Guthrie	6838	4500	Chemical Technology
J. W. Boyle	6-1629	4501	Chemistry
C. G. Bell, Jr.	6-1111	2068	Education
C. B. Fulmer	7398	9201-2, Y-12	Electronuclear Research Oak Ridge Relativistic Isochronous Cyclotron
W. M. Stanley	6-1301	1000	Engineering and Mechanical
E. D. Gupton	6912	4500	Health Physics
K. K. Klindt	7558	9204-1, Y-12	Inspection Engineering
G. S. Sadowski	6-1276	3500	Instrumentation and Controls
E. H. Acree	6661	3037	Isotopes
J. J. Pinajian	7133	9201-2, Y-12	Isotopes 86-Inch Cyclotron
A. R. Olsen	6347, ofc. 6588 6537	4501	Metallurgy
Dixon Callihan*	7-8237	9213, Y-12	Neutron Physics
T. M. Sims	6-1108	3001	Operations
J. H. Neiler	6372	4500	Physics
A. J. Miller	7723	9704-1, Y-12	Reactor
G. W. Keilholtz	6-1101	4500	Reactor Chemistry
J. T. Howe	6281	3025	Solid State
Craig Harris	7-8612	9201-2, Y-12	Thermonuclear Experimental

*In Callihan's absence – Joe Thomas.

Data on Containers Used in Shipping Radioisotopes

Type of Material Shipped	Maximum Activity		Thickness of Lead Shield (in.)	Outside Dimensions of Box, If Used (in.)	Volume of Bottle, If Used (ml)	Total Weight of Assembled Container (lb)
	Typical Radioisotope	Amount				
Liquid, beta emitters, and small amounts of gamma emitters	P^{32}	500 mc	None	$4\frac{1}{2} \times 4\frac{1}{2} \times 8$	15, 25, 50, 100, 200, 500	1–2
	P^{32}	>500 mc		$8 \times 8 \times 8$	Same	2–3
	I^{131}	9 mc				
	P^{32}	>700 mc		$12 \times 12 \times 12$	Same	4–5
	I^{131}	25 mc				
Liquid, gamma emitters	I^{131}	50 mc	$\frac{1}{8}$	$8 \times 8 \times 8$	15, 25	3
		100 mc	$\frac{1}{4}$			4
		145 mc	$\frac{3}{8}$			5–7
		300 mc	$\frac{1}{2}$			6–8
		400 mc	$\frac{5}{8}$			8–10
		650 mc	$\frac{3}{4}$			10–12
		1,500 mc	$\frac{3}{4}$	$12 \times 12 \times 12$	Same	11–13
Solids (service irradiations)	Fe^{55}, Fe^{59}	13 mc of Fe^{55}	$\frac{1}{4}$	$8 \times 8 \times 8$	Aluminum irradiation can	4
		5 mc of Fe^{59}				
		26 mc of Fe^{55}	$\frac{1}{2}$		Same	6
		10 mc of Fe^{59}				
Toxic liquids	Sr^{89}	1 curie	None	$8 \times 8 \times 8$	15, 25, 50, 100, 200	6–10
	Sr^{90}	2 curies				
		$2\frac{1}{2}$ curies		$12 \times 12 \times 12$	Same	7–11
Liquid, gamma emitters	Co^{60}	10 mc	1	$9\frac{1}{2} \times 9\frac{1}{2} \times 12$	15, 25, 50, 100	36–53
		25 mc	$1\frac{1}{2}$			56–57
		10 mc	$\frac{1}{2}$	$20 \times 20 \times 17$	200, 500	100
		25 mc	1			117–133
		50 mc	2		15, 25, 100, 200	142–222
		500 mc	3		15, 25	231–253
Solids	Co^{60}	10 mc	1	Container mounted in wooden block	Aluminum irradiation can	25
		25 mc	$1\frac{1}{2}$			53
		60 mc	2			107
Solids	Co^{60}	125 mc	$2\frac{1}{2}$	Container mounted on pallet	Aluminum irradiation can	136
		300 mc	3			162
		600 mc	$3\frac{1}{2}$			275
Solids	Co^{60}	1 curie	4	None	Aluminum irradiation can	277–298
		5 curies	5			525
		25 curies	6			850
		180 curies	$7\frac{1}{2}$			1320
Solids	Co^{60}	>1,000 curies	$8\frac{1}{2}$			2620
Solids	Co^{60}	10,000 curies	$9\frac{3}{4}$	None	None	5600
Gases	A^{37}	15 mc	None	$5 \times 5 \times 16$	1-, 5-, 10-, and 25-ml glass ampoules	4
	H^3	Up to 5 curies				
Gases	H^3	5–1,000 curies	None	4 in. dia × 12 in. long to 4 in. dia × 33 in. long	10–1,000-ml metal cylinders	6–25
	Kr^{85}	10 mc–90 curies				8–86
Toxic liquids	Sr^{90}	7 curies	1 in. of steel	None	200, 500	45–53