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GENERAL HANDBOOK
FOR
RADIATION MONITORING

Compiled and Edited

by

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Second Edition

HEALTH AND BIOLOGY

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PREFACE

This handbook was prepared specifically for use at the Los Alamos Scientific Laboratory. The philosophy and procedures set forth apply to the situations and needs found here. Definitions included in the glossary are specific applications of the terms in the realm of radiation monitoring and do not necessarily include the complete definitions as applied to general nuclear energy fields. Names of commercial products mentioned are those which are in satisfactory use at this Laboratory; use of such names in this handbook does not constitute an endorsement of the products.

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MONITOR'S CHECK LIST

This is a reminder list of some equipment and operations which may be required to carry out properly a monitoring job. Be sure you have what you need.

Equipment

1. Protective clothing (proper type of respiratory protection)
2. Film badges (body and/or wrist)
 - a. Beta-gamma
 - b. Neutron
3. Pocket dosimeters and charger
4. Survey meters (type and directions for using)
5. Tolerance tables, tolerance times, neutron survey data sheets
6. Signs (radiation), rope, source tongs
7. Air samplers and filters
8. Miscellaneous: paper, pencil, cardboard boxes, masking tape, chalk, grease pencil
9. Vehicle (gas, trip ticket, post pass)

Operations

1. Check for contamination on surfaces, equipment, and personnel
2. Decontaminate (agents and facilities)
3. Dispose of contaminated waste
4. Take nose swipes
5. Collect urine specimens (containers - tag completely filled out)
6. Summarize in written report

RADIO CODE

10-0 Operations normal at this location
10-1 Receiving poorly
10-2 Receiving well
10-3 Stop transmitting
10-4 O.K. Roger. Message received and understood
10-5 Relay
10-6 Busy
10-7 Out of service
10-8 In service (Give name of operator with first 10-8 call, e.g., Station Hickory 3 to Station 7, 10-8, Doakes)
10-9 Repeat
10-19 Return to your station; come to this location
10-20 What is your location?
10-21 Call this station or location by telephone
10-36 Correct time
10-95 Radio check (Answer with 10-1 or 10-2)
10-97 Arrived at scene
10-98 Finished with last assignment
10-99 Emergency within section or area
5-7 Fire at _____

The word Broadcast repeated three times means a general or extreme emergency.

EMERGENCY MONITORING

Emergency Equipment

A. Emergency Vehicle (key always in vehicle) Radio call:
Station Hickory 1

<u>Monitoring Equipment</u>	<u>Use</u>
2 2111 PeeWee Proportional Counters	Alpha
1 100A Ion Chamber	High Range Beta-Gamma
1 D-1 Cutie Pie Ion Chamber	Intermediate Range Beta-Gamma
2 263B G-M Tube Instruments	Low Range Beta-Gamma
1 2111N Converted PeeWee	Neutrons
1 101 Portable Sniffer	Tritium (and Gamma)

Equipment for Personnel Protection and Exposure Evaluation

1 Gast Pump Air Sampler, 6 Volt
3 Sets of Protective Clothing (Coveralls, Booties, Gloves, Caps)
2 Chemox Breathing Apparatus
8 Ultra-Filter Comfo Respirators
15 Pocket Dosimeters (1 and 5 r)
1 Dosimeter Charger
(Pick up film badges from H-1 Monitoring Office, if needed)

Miscellaneous Equipment

First Aid Kit	Cardboard Boxes
Blanket	Masking Tape
Fire Extinguisher	Emergency Procedures
Axe, Shovel, and Hand Tools	Check List
Rope and Radiation Signs	Emergency Monitoring Hand-
Paper, Pencil, Chalk,	book
Grease Pencils	

- B. Alpha, Beta-Gamma, Neutron Survey Instruments
(Room A-113)

Philosophy and Procedures

First! Obtain all readily available information before proceeding on any emergency. Be sure it is an emergency, then proceed, using mature judgment, common sense, knowledge of the hazards, and all available equipment to limit the personnel, and their exposures, to a working minimum.

Emergencies will probably be of the following types:

- (a) Explosion (chemical or nuclear)
- (b) Fire
- (c) Dispersal of radioactive materials by fire or explosion

Of the above, in general, (a) will be local but (b) or (c) may affect the community. In cases reaching disaster proportions, the Santa Fe Operations Office will be responsible and the LASL position will be only that of a technical assistant.

The monitor should be a self-sufficient unit, able and equipped to step into any situation and take over the necessary monitoring duties. He must have a knowledge of the materials being used, their usual location, and an active imagination in guessing just what sort of accidents may occur in the use of these materials.

Some things to keep in mind:

- (a) Gamma radiation will be the first and easiest to detect
- (b) Explosives and/or chemicals may be a problem
- (c) Air-borne contamination (sample with Gast pump air sampler - survey filter with PeeWee and/or beta-gamma meter)
- (d) Personnel involved - protect, monitor, decontaminate, list names

PERSONNEL DECONTAMINATION

The procedures listed below are in order of increasing severity, and the monitor's judgment, as well as the level of contamination, should dictate whether or not to use the next step. For each step, rub with the decontaminating agent in a circular motion for a minimum of 5 min, then rinse, dry, and monitor the area.

Alpha

1. Apply sodium hypochlorite-Igepal solution freely. Use no brush. (1 pint NaClO, 1 quart Igepal-C.A.Extra, 18 liters of water)
2. Use Ivory soap and water with a brush.
3. Apply ammonium citrate or citric acid. No brush.
Alternate method: soak in a basin of warm water containing 1 gm of a 1-to-1 mixture by weight of tartaric and citric acid.

Beta-Gamma

1. Use Dreft and water with a brush.
2. Apply ammonium citrate or citric acid. No brush.
3. Use Sugar Beet Soap (SBS 11) and water with a brush.

Both Alpha and Beta-Gamma (with doctor's consent)

4. Rub only the contaminated area with a swab soaked with potassium permanganate (saturated solution) and then remove the stain with sodium bisulfite.
5. Use a mixture of lanolin (Lanum) and cornmeal. No brush. Cornmeal has an abrasive action and the grease picks up the contamination. Remove all grease with soap and water.
6. If still above tolerance levels, release worker, but suggest he not handle or prepare food for the rest of the family and exercise care in handling his own food. If it is an alpha count in excess of 20,000 c/m* and distributed over the entire surface of the hand, suggest he wear rubber gloves while eating. The continuous wearing of rubber gloves causes sloughing off of the outer layer of skin and hence removal of the contamination. Any person who is released with above-tolerance levels should report for daily rechecks until the count drops to tolerance.

*Counts per minute.

GENERAL DECONTAMINATION

Only general methods are suggested because each situation usually requires special considerations. These are nominally listed in order of increasing severity.

1. D-R method (cleaning with a damp rag).
2. Vacuum cleaning (exhaust of cleaner must be filtered to prevent escape of contamination).
3. Detergent and water (for alpha) or soap and water scrubbing.
4. Paint over low level contamination.
5. Dilute Versene solution scrubbing (use rubber gloves to prevent absorption through the skin).
6. Scrubbing with citric acid solution.
7. Pumice soap scrubbing.
8. Other acids (HCl, HNO₃, etc.) in varying solution strengths or mixtures.
9. Removal of surfaces (sanding, paint removers, concrete chipping, etc.)
10. Removal of buildings or portions thereof.

Note: Vigorous action with stiff-bristled brushes or wire brushes will often aid in decontamination.

PROTECTIVE MEASURES

The "atomic era" had its beginning in the wooden horse tubs and pails used by the Curies in their laborious purification of radium. Its progress has only been retarded by the very application for which it is so desirable, viz., that of being able to produce large amounts of energy from small amounts of material. Herein lies the greatest hazard to all industrial users, as well as to research and development personnel. It requires the greater part of the time spent in personnel training to instill the healthy respect for radiation essential in maintaining the well-being of those same trainees while handling - in a sometimes awkward but safe manner - radioactive materials.

The exposure to the worker may come from two directions. There may be radiation external to the body - directly from a source, contamination outside the source container, or contamination on the person or clothing of the worker. The other direction from which exposure may come is from inside the worker's body - material collected through inhalation, ingestion, or absorption through the skin.

Any unnecessary exposure to radiation is too much.

To limit the external exposure, any one or all of the following measures may be taken:

1. Remove the source of contamination. If the source is not being used, take it to a segregated storage place. Removal of contamination is much easier if proper precautions, such as covering the area with Kraft paper or painting the surface with strippable plastic paint (Monsanto D-1000), have been taken before the material becomes dispersed. Decontaminating an unprotected surface is primarily an abrasive process (see Decontamination Methods), scrubbing with a detergent and water, "hosing down" with high pressure water or steam, using a complexing agent such as citric acid, or removing the surface with acid or by sandblasting.

Each worker should be given protective clothing which provides enough coverage to protect the worker as well as his personal clothing, and which can be washed in a "contaminated" laundry equipped to handle contaminated clothing and dispose of the contaminated wash water.

2. Limit the amount of time spent in a radiation area. Determine the rate of exposure and limit the amount of time the worker spends in that area to that which will give him only his permissible exposure. (See Permissible Exposure Times). Each worker should be given personnel monitoring equipment to record the exposure which he will receive.

3. Reduce the rate of exposure. Interposing shielding between the source and the worker or moving the worker farther from the source will reduce the rate of exposure to the

worker. Lucite or glass can be used for beta shielding. Gamma shielding may be estimated by use of the Point Source Nomogram. A graph of fast neutron attenuation in paraffin and water is included in the discussion of Neutron Monitoring.

The internal exposure can be controlled only by preventing the entry of radioactive materials into the body. Respiratory protection for short periods in low concentrations of air-borne contamination may be provided by respirators which filter the air to the mouth and nose, such as the Willson 750D, Mine Safety Appliance "Dustfoc," or the MSA "Comfo" with an ultrafilter. For higher concentrations (50 times the MPC) and longer periods, supplied air masks are recommended, such as the Scott Air-Pak with a compressed air bottle, Chemox with an oxygen generating cannister, or a hood to which air is supplied through a hose from a compressor outside the area. The way any mask fits the face is extremely important because only that air which is filtered or is supplied is not contaminated. Any leakage, usually around the nose or chin, is unfiltered, and perhaps contaminated air. Nose swipes (see Contamination Tolerances) taken at the end of a working period may be used as indicators of inhaled contamination. Eating and smoking should not be permitted in contaminated areas. Training to teach cleanliness and care in all activities will do much to reduce the amount of material ingested by the worker. Workers should be properly indoctrinated to use hand counters, request surveys often when handling radioactive materials, and report immediately all injuries where the skin is broken in order that any contamination may be removed with a minimum amount being absorbed.

The amount of material which has reached the interior of the body (excluding lung and gut) can be estimated by the quantity found in the body fluids. The urine is the most available body fluid. Whenever an internal exposure is suspected, a urine specimen should be requested and analyzed as soon as possible. Radium, for example, quickly becomes fixed in the bone and can then only be detected by taking breath samples and counting them in a Radon Breath Counter.

Materials which are contaminated with short-lived isotopes can be stored until normal decay makes possible their disposal through usual channels. A segregated burying pit, plainly marked and surrounded by a high, strong fence, is used for disposal of waste contaminated with long-lived radioactive isotopes. All contaminated waste should be packaged in sealed containers and labeled at the laboratory (with the date and origin) for hauling to the dump. The truck used for hauling the waste is of such construction that it can be decontaminated easily. Records of the approximate location of the labeled boxes in the burying pit are kept in the event that recovery should become necessary.

Natural radiation sources should be leak-tested whenever dropped, or when deterioration of the container is suspected, or at least once every six months. Polonium sources are especially dangerous because of the great tendency of Po to escape and spread; contamination tolerances have been established in this connection. The testing of Ra sources is accomplished by placing the source in a small sealed jar with a 2- or 3- in. diameter filter paper (not in contact with the source) for 12 to 24 hr. A count of the filter paper in excess of 50 c/m for beta and gamma (less than 10 per cent efficient, horizontal, G-M counter) may be considered to indicate a dirty or leaking source. A high count on a recheck after scrubbing the source with trichloroethylene would indicate the source is leaking and should be returned to the supplier for resealing. A more sensitive method of counting gas evolved from the source with the Radon Breath Analyzer also is used to test Ra sources. Swipe tests (a piece of Kleenex rubbed over the surface and counted) can be made on most other sources.

LOS ALAMOS SCIENTIFIC LABORATORY
RADIATION SAFETY POLICIES

Summary of Responsibilities

Each individual at the Los Alamos Scientific Laboratory who has any contact with radioactive materials or radiation is responsible for:

1. Keeping his own exposure to radiation as well as that of others as low as possible and specifically below the maximum permissible levels of 300 mr of gamma or 500 mrep of beta plus gamma radiation per week, except in cases of extreme emergency or exposures incurred during medical examinations and treatments. Health Division approval should be sought in advance for other urgent situations requiring exposures in excess of the above figures.
2. Wearing the prescribed monitoring equipment (pocket dosimeters, film badges) in gamma, beta, and neutron radiation areas. Requesting neutron film badges where significant neutron exposures are anticipated. Surveying hands, shoes and body for radioactivity and removing loose contamination to the tolerance levels before leaving the Laboratory, in accordance with the recommended decontamination procedures.
3. Wearing appropriate protective clothing whenever clothing contamination is possible, and not wearing such clothing outside of the Laboratory area. Using gloves, hoods, and respiratory protection (respirators or supplied air masks, as recommended by the Health Division) where necessary. Using proper techniques and facilities in operations involving radioactive or toxic materials.

4. Observing the recommended procedures in regard to eating and smoking.

5. Reporting injuries and ingestion or inhalation accidents promptly to the Health Division and carrying out the recommended corrective measures. Cooperating in any and all attempts to evaluate the exposures, particularly by promptly returning requested urine specimens.

6. Carrying out recommendations of the Health Division in roping off hazardous areas, posting warning signs, and otherwise controlling special hazards for which he is responsible. Contacting the Health Division (H-1 Group) for recommended procedures in high level radiation areas.

7. Cleaning up contamination for which he is responsible. Arranging for a survey by Group H-1 and carrying out the decontamination recommended for the area when changing locations or ending an operation.

8. Proper storage and labeling of radioactive materials for which he is responsible.

9. Packaging in a closed (sealed, whenever possible) container, and labeling the container as to origin and date, contaminated articles for the contaminated waste disposal.

Supervisors are responsible for ensuring that the above individual responsibilities are discharged by those under their control, and are further responsible for:

1. Instructing those employees for whom they are responsible in the use of safe techniques and in the application of approved radiation safety practices.

2. Providing such staff as is required for packaging contaminated waste and for decontaminating anything for which he is responsible.

3. Furnishing information to the Health Division concerning individuals and activities in their areas, particularly additions to or deletions from their personnel rosters, as well as vacations, etc.

4. Contacting the Health Division whenever major changes in operational procedures, new techniques, alterations in physical plant or new operations which might lead to personnel exposures are anticipated.

The Monitoring Group, H-1, is responsible for:

1. Furnishing consulting services on all aspects of radiation protection.

2. General surveillance of all health physics activities,

including the assisting of individuals and supervisors in discharging their responsibilities.

3. Distribution and processing of personnel monitoring equipment, including the keeping of personnel exposure records, and notifying individuals and their supervisors of exposures greater than the allowable tolerance for their situation and recommending appropriate restrictions.

4. Supervision and coordination of the waste disposal program, including the keeping of waste storage records.

5. A continuous program of environmental hazard evaluation and hazard elimination.

6. Storage, leak testing (and sealing of natural sources), issue, disposal, recording and supervising of the shipping of all natural radioactive sources and most artificially produced sources. Further, the inspection of all requests for natural sources to assure standardization of capsules for general utility.

7. Scheduling urinalysis measurements when required.

8. Decontaminating large pieces of equipment (e.g., motor vehicles) and supervising personnel decontamination in cases of contaminated wounds or persistent personal contamination.

CONTAMINATION TOLERANCES

The values quoted below apply in the general case. However, good judgment, with consideration for the health and safety of any personnel involved, as well as the economic and legal aspects of the situation, may necessitate revisions in some cases.

Note: Beta-gamma tolerances - contact with shield open on G-M tube. Alpha tolerances - measured with a PeeWee probe of 55 cm² area.

Wounds

0.15 mrep/hr beta-gamma except Sr-90 which is 0.05 mrep/hr
10 c/m alpha

Nose Swipes*

50 c/m alpha on each swipe

Skin

1 mrep/hr beta-gamma except Sr-90 which is 0.05 mrep/hr
For alpha emitters: Po 1000 c/m
Tuballoy or Oralloys 500 c/m
Pu 250 c/m

Note: If, after two attempts to decontaminate the skin surface, greater than 3 mrep/hr remains, send subject to Decontamination Room (128) at the Medical Center; if 3 mrep/hr or below, release subject. For alpha, recheck subject the following day if decontamination efforts fail. Notify the H-1 Group Office in all cases.

Bench Tops and Floors

1 mrep/hr beta-gamma except Sr-90 which is 0.05 mrep/hr
500 c/m alpha except Po which is 5000 c/m. All swipes** must show no detectable activity, either beta-gamma or alpha.

Vehicles

6 mrep/hr beta-gamma except Sr-90 which is 0.05 mrep/hr
500 c/m alpha

For Public Sale - No detectable activity of any kind.
For policy reasons, no active material may be sold to the general public.

Clothing

1 mrep/hr beta-gamma, Sr-90 contaminated - to the dump
For alpha emitters: Po 1000 c/m
Tuballoy or Oralloys 500 c/m
Pu 250 c/m

Note: Shoes 5 mrep/hr beta-gamma on exterior
1 mrep/hr beta-gamma on interior
Booties 5 mrep/hr beta-gamma
Respirators 50 c/m alpha

Clothing returned from CMR contaminated clothes
laundry for use in contaminated areas:

Underclothes - No detectable activity
Coveralls Po 1500 c/m alpha
Tuballoy, Oralloy
& Pu 500 c/m alpha
Booties (spot checked)
Po 6000 c/m alpha
Tuballoy, Oralloy
& Pu 1500 c/m alpha

Swipes on Uranium Transport Containers***
250 c/m alpha

Equipment (for use in an already contaminated area)
3 mrep/hr beta-gamma except Sr-90 which is 0.05 mrep/hr
Alpha tolerances vary with the situation, type, and
cost of equipment, the consumer, etc. Nominally
1000 c/m, providing a swipe** shows less than 250 c/m.

Equipment (for use in a non-contaminated area)
All swipes** must show no detectable activity, either
beta-gamma or alpha.
1 mrep/hr beta-gamma except Sr-90 which is 0.05 mrep/hr
500 c/m alpha

Equipment (to be used outside the Project but in areas
already contaminated)
The intended recipient must be given a written state-
ment of the conditions of the contaminated equipment
and must be able to handle it as such. The transfer
of such equipment must be approved by the Monitoring
Group Office.
Arbitrary limits - no health hazard

Equipment (to be used outside the Project realm, e.g., gas
cylinders, salvage materials)
No detectable activity of any kind

Equipment (to be used for monitoring or counting purposes
or in photographic processes)
No detectable activity of any kind or of such a value
as not to significantly interfere with the operation
of the instrument.

Equipment (going to the machine shop, to stock, or to other
"clean" areas)
No detectable activity of any kind

*For the nose swipe a commercial applicator, paper-tipped
(paper 3 in. x $\frac{1}{2}$ in. glued to a 3 x $\frac{3}{32}$ in. stick with

waterproof adhesive), is dipped into distilled water and the paper wrapped tightly around the stick with a pair of tweezers. An applicator is given the subject to swab each nostril. Both swipes are placed in an envelope with name, date, and location on the outside. After drying, the outer 1 in. of paper is counted on a gas flow proportional counter.

**A handful of Kleenex tissue or cheesecloth is rubbed over an area to constitute a swipe. The entire area found to be contaminated by direct count during a survey must be thus swiped. For beta-gamma areas, moisten the Kleenex or cheesecloth. Swipes are more or less qualitative and used only to determine whether or not a contaminant is likely to rub off a surface.

***A dry piece of Hollingsworth and Vose #70 (H-70) filter paper about $2\frac{1}{2}$ x $2\frac{1}{2}$ in. is rubbed over the handle, lid, sides, and bottom (outside only) of the material containers (cans) and counted on the PeeWee probe.

MAXIMUM PERMISSIBLE EXPOSURES
FOR EXTERNAL RADIATION

Total Body Exposures

X-rays and Gamma	300 mr/wk
Beta	500 mrep/wk
Beta and Gamma (sum)	500 mrep/wk
X-ray (below 15-kv average)	500 mr/wk

For beta exposures of a peak energy below 2 Mev and x- or gamma rays below 15-kv average energy, a single week's exposure should not exceed 1000 mrep and the total over a three-month period should not exceed 6500 mrep (13 weeks at 500 mrep/wk = 6500 mrep).

The maximum permissible exposure for neutrons, as adopted at the Tripartite Conference in Harriman, New York, April 1953, (N.B.S. Handbook 55), varies with energy as follows:

<u>Neutron Energy (Mev)</u>	<u>Permissible Flux for 40-hr Week (n/cm²/sec)</u>	<u>MPE per Week (n/cm² x 10⁶)</u>
Thermal (0.03 x 10 ⁻⁶)	2000	288
Epithermal (10 ⁻⁶)	1500*	216
10 ⁻⁵	1000	144
Slow (10 ⁻³)	1000*	144
10 ⁻²	1000	144
Intermediate (10 ⁻¹)	200	28.8
5 x 10 ⁻¹	80	11.5
1	60	8.64
2	40	5.76
3	30	4.32
5	30	4.32
10	30	4.32
14	30*	4.32
28	30*	4.32

*Values interpolated or extrapolated from the original values given. The MPE values for the higher energies are subject to revision as additional information becomes available. It may be noted that LRL-146, June 1954, quotes 20 n/cm²/sec for 200-Mev neutrons.

Note: Exposures to combined types of radiation must be limited to that which will give only the maximum permissible amount for the total flux (e.g., in 1 week, 150 mr gamma + 2.16 x 10⁶ fast n/cm² = 50% gamma MPE + 50% neutron MPE for a total of 100% MPE)

Extremities

X-rays and Gamma	1000 mr/wk
Beta	1500 mrep/wk
Beta and Gamma (sum)	1500 mrep/wk

Only the hands and forearms are considered extremities (see Glossary). The head (if shielding of 3 mm of glass, or equivalent, is provided for the eyes) and the feet can be considered extremities in areas of radiation stemming from radioactive Ba-La or other beta or low energy (less than 15 kv) gamma radiation.

PERMISSIBLE EXPOSURE TIMES FOR 0.3 r/wk

Note: Since the extremities may receive 1.0 r/wk, multiply any applicable permissible exposure time by 3-1/3 to obtain the allowable time for the extremities only.

(h hours; ' minutes; " seconds)

Rate r/hr	Daily Permissible Exposure Times		Total Permissible
	5-day Week	6-day Week	Exposure Time per Week
0.0075	8 h	6 h 40'	40 h
0.01	6 h	5 h	30 h
0.05	1 h 12'	1 h	6 h
0.100	36'	30'	3 h
0.50	7' 12"	6'	36'
1.00	3' 36"	3'	18'
5.0	43"	36"	3' 36"
10.0	22"	18"	1' 48"

Calculation: $\frac{\text{Tolerance Rate}}{\text{Exposure Rate}} = \frac{0.3 \text{ r/wk}}{0.1 \text{ r/hr}} = 3 \text{ hr/wk or } 36 \text{ min/day for 5-day week}$

For Neutrons: $\frac{n/cm^2/week \text{ (for given energy)}}{n/cm^2/sec \text{ detected} \times 3600 \text{ sec}} = \frac{\text{Tolerance time}}{\text{in hrs per week}}$

RULE OF THUMB OPERATION

Rough, practical methods of procedure

1. The Kelekot pocket dosimeter records about 1/10 the dose received from beta exposures above 1-Mev energies.
2. When working with Au-198, experience has shown that under some conditions the beta will be 5 times the gamma value. Therefore, the dosimeter will record only 1/6 of the total exposure and should be limited to readings of 83 mr for the body and 250 mr for the hands per week.
3. The effective energy of an x-ray machine may be assumed (for survey meter energy dependence correction) to be 1/3 the peak kilovolt energy on the tube. This will be high in the lower energies.
4. Barometric Correction Factor (for use with all unsealed chambers except Victoreen Thimble Chambers)

$$f = 2.78 \frac{t + 273}{p} \quad \begin{array}{l} t \text{ is the temp in } ^\circ\text{C} \\ p \text{ is the pressure in mm Hg} \end{array}$$

For the Victoreen Thimble Chambers, the temperature correction is to 22°C and the factor:

$$f = 2.576 \frac{t + 273}{p}$$

5. The activity of any radioisotope is reduced to less than 1 per cent after 7 half-lives.

$$(2^{-7} = 0.8\%)$$

6. The activity-mass relation may be found as follows:

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

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

where A = atomic weight and
T = radioactive half life in days

7. It requires an alpha particle of at least 7.5 Mev or a beta of at least 70 kev to penetrate the protective layer of skin, 0.07 mm thick.
8. The range of beta rays in grams per square centimeter (thickness in cm x density in gm/cm³) is approximately equal to the maximum energy in Mev divided by 2.

$$R = E/2$$

9. Radioactive Material	Contact Dose Rate (mrep/hr)	Permissible Exposure Times for Hand Contact (hr/wk)
Th	43 (4 to 5 years after separation) 115 (at equilibrium)	30 - bare hands
Tuballoy	about 250	6 - bare hands 12 - 1-mm leather gloves
Pu	900 (IA-1574)	1-1/2

Note 1: Tuballoy may show a much higher beta-gamma activity during the initial 50 to 100 days after casting, because of an increase in the concentration of UX₁ and UX₂ on the top of the melt.

Note 2: A correction factor of 2 should be applied to measurements of U beta radiation made with G-M tube instruments (shield open), calibrated with gamma radiation (Ra-Det, July-Oct, 1953).

10. Beta-ray Surface Dose Rates (AECD-2753, 1949) with 7 mg/cm² filter

Source	mrep/hr
U slug	239
UO ₂ (brown oxide)	212
UF ₄ (green salt)	183
UO ₂ (NO ₃) ₂ ·6H ₂ O (yellow uranyl nitrate hexahydrate)	114
UO ₃ (orange oxide)	208
U ₂ O ₃ (black oxide)	207
UO ₂ F ₂ (cliptite or uranyl fluoride)	181
Na ₂ U ₂ O ₇ (soda salt or sodium diuranate)	171

11. With 2 π geometry, the surface of a thick source of tuballoy will give about 2400 alpha c/m per cm²; Pu about 70,000 alpha c/m/ μ g. 16.2 gm of Pu has an activity of 1 curie.

12. When machining Pu, the dust formed has an average particle size of about 2 or 3 μ ; vaporized Pu produces a median particle size of 0.1 μ .

13. A 1-curie source of Po has a gamma output equivalent to 7 μ g of Ra or about 65 mr/hr at 1 cm when unshielded. It is normally requested that the impurities (oxygen in particular) in separated Po be reduced so that the neutron activity is not greater than 100 n/sec/curie; however, the activity may be as great as 200 n/sec/curie.

If Po is exposed to air, the activity may become as great as 2800 n/sec/curie. Also, 1 curie of Po when in an intimate mixture with Be has a gamma output equivalent to 0.12 mg of Ra or about 1.1 r/hr at 1 cm when unshielded.

14. Passage through 3 in. of paraffin will reduce the flux of 4-Mev neutrons to about 37 per cent of the original value.
15. The intensity of Bremsstrahlung increases approximately with the square of the maximum energy of the beta-ray spectrum and about as the square of the atomic number of the absorbing material.
16. The gamma output (roentgens per hour at 1 meter) of 1 curie of some radioisotopes has been determined as follows: (Evans, NSS-PreR-11; Kinsman, Radiological Health Handbook)

Isotope	rhm	Isotope	rhm
Astatine 76	0.391	Iodine 131	0.292
Bromine 82	1.50	Iron 59	0.645
Cesium 137	0.324	Lanthanum 140	1.2
Cobalt 58	0.556	Manganese 52	1.93
Cobalt 60	1.33	Manganese 54	0.485
Copper 64	0.115	Sodium 22	1.29
Gold 198	0.236	Sodium 24	1.93
Iodine 128	0.018	Zinc 65	0.284
Iodine 130	1.24		

	Filter	rhm
Radium-226 (in equilibrium with its decay products)	Thuringian Glass	0.93
	0.5 mm Pt-Ir	0.84
	1.0 mm Pt-Ir	0.78
	0.5 mm Pt-Ir & 5 mm Brass	0.7
	Each millimeter of lucite reduces the gamma output by 0.35%	

17. When sampling with filter paper air contaminated by noble gases, the efficiency of the collection may be very inconsistent due to variations in adsorption of the decay products on dust and on the filter, zones of gas concentrations, equilibrium state, etc. For example, certain conditions around a homogenous reactor result in a collecting efficiency of 5 per cent for Cs-138 (multiply the count on H-70 paper by 20).

TABLE OF ISOTOPES

The table which follows lists alphabetically isotopes of general interest. First is given the element, then the isotope with the atomic number (Z), which identifies the chemical properties, and the atomic mass number (A), which is the weight of the isotope in mass units.

The maximum permissible concentration (MPC) for continuous exposure in air is given in disintegrations per minute per cubic meter (d/m/m³). The MPC for water is given in disintegrations per minute per liter (d/m/l). Figures* given in parentheses are the MPC values for exposures of only 48 hr per week which are being used at Los Alamos. All other values are taken from N.B.S. Handbook 52 prepared by the Sub-Committee on Internal Dose of the National Committee on Radiation Protection. The total body burden given in microcuries (uc) is the calculated amount of internally deposited material thought permissible without detectable damage to the carrier. The critical organ is that organ which, either by being more sensitive to radiation or by retaining a larger per cent of the isotope than other organs, determines the total body burden.

The half-life values given in days are for the normal radioactive decay and an effective decay which is a combination of biological elimination (T_b) and radioactive decay (T_r).

$$T_{1/2 \text{ eff}} = \frac{T_r \times T_b}{T_r + T_b}$$

General levels of MPC considered safe for any radioactive isotope except Sr-90, Pu-239, or Ra-226 are:

<u>Media</u>	<u>Beta-Gamma Emitter</u>	<u>Alpha Emitter</u>
Air	2.22 x 10 ³ d/m/m ³	11.1 d/m/m ³
Water	222 d/m/l	222 d/m/l

*These values are based on a memorandum from Shields Warren of the AEC Division of Biology and Medicine, December 8, 1950. A local board corrected the MPC values in air for an exposure period of 48 hr/wk and a 25 per cent increased breathing rate. Other of these values were calculated by Wright Langham and George Angleton of this Laboratory.

Some values which were assumed in the calculations of the MPC levels are:

Breathing rate	20 m ³ of air per 24-hr day
	10 m ³ of air per 8-hr work day
Water consumption	2.2 liters per 24-hr day
Exposure period	10 ⁴ days or 33 years

Reasons for limiting exposure even more than figures which are given:

1. Uncertainty of biological factors, half-life, absorption, etc.
2. Variations in radio sensitivity among individuals.
3. Possibility of nonuniform distribution within critical organs which was assumed for the calculations.
4. Lack of biological data on man and only short-term experiments with animals.
5. Possibility of combined effects on organs from simultaneous exposures to several isotopes.
6. Certain biological changes, such as shortening of the life span.
7. The concentrations found by taking air samples are not necessarily indications of the material breathed.

ELEMENT	ISOTOPE			MAXIMUM PERMISSIBLE CONCENTRATIONS		TOTAL BODY BURDEN		HALF-LIVES	
	Z		A	Air(d/m/m ³)	Water(d/m/l)	Micro- curies	Critical Organ	Radioactive (days)	Effective (days)
Americium	95	Am	241	66.6 (8.8)	222 x 10 ³	0.056	Bone	1.79 x 10 ⁵	890
(based on 241)	95	Am	242	66.6 (8.8)	222 x 10 ³	0.056	Bone	1.46 x 10 ⁵ 0.67	890 0.67
Argon	18	A	41	1.11 x 10 ⁶	1.11 x 10 ⁶	30	Total Body	0.074	
Arsenic	33	As	76	4.44 x 10 ⁶	444 x 10 ⁶	10	Kidneys	1.12	1.09
Astatine	85	At	211	666	4.44 x 10 ³	6 x 10 ⁻⁴	Thyroid	0.31	0.31
Barium- Lanthanum	56 57	Ba- La	140 140	133 x 10 ³ (244)	4.44 x 10 ⁶ (1.4 x 10 ³)	5	Bone	12.8	12
Beryllium	4	Be	7	8.88 x 10 ⁶	2.22 x 10 ⁹	670	Bone	54.5	48
Cadmium- Silver	48 47	Cd- Ag	109 109m	155 x 10 ³	155 x 10 ⁶	40	Liver	330	77
Calcium	20	Ca	45	66.6 x 10 ³	1.11 x 10 ⁶	65	Bone	152	151
Carbon	6	C	14	1.11 x 10 ⁶	6.66 x 10 ⁶	250	Fat-Bone	2.09 x 10 ⁶	35-180
Cesium	55	Cs	134					0.13 840	0.13 16.6
Cesium- Barium	55 56	Cs- Ba	137 137m	444 x 10 ³	3.33 x 10 ⁶	90	Muscle	1.2 x 10 ⁴	17
Cesium	55	Cs	138	(2.2 x 10 ⁶)				0.023	0.023
Cerium- Praseodymium	58 59	Ce- Pr	144 144	15.5 x 10 ³	88.8 x 10 ⁶	5	Bone	275	180

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ELEMENT	ISOTOPE		MAXIMUM PERMISSIBLE CONCENTRATIONS		TOTAL BODY BURDEN Micro-curies	Critical Organ	HALF-LIVES		
	Z	A	Air(d/m/m ³)	Water(d/m/l)			Radioactive (days)	Effective (days)	
Chlorine	17	Cl	36	888 x 10 ³	4.44 x 10 ⁶	200	Total Body	1.6 x 10 ⁸	29
Chromium	24	Cr	51	17.7 x 10 ⁶	1.11 x 10 ⁹	390	Kidneys	26.5	22
Cobalt	27	Co	60	2.22 x 10 ⁶	44.4 x 10 ⁶	3	Liver	1.9 x 10 ³	8.4
Copper	29	Cu	64	13.3 x 10 ⁶	177 x 10 ⁶	150	Liver	0.54	0.53
Curium	96	Cm	241	(8.8)	(3.33 x 10 ³)	0.04	Bone	55	50.4
	96	Cm	242	444	1.99 x 10 ⁶	0.05	Bone	150	120
	96	Cm	243	(8.8)	(3.33 x 10 ³)	0.04	Bone	3.65 x 10 ⁴	590
	96	Cm	244	(8.8)	(3.33 x 10 ³)	0.04	Bone	3.65 x 10 ³	515
Europium	63	Eu	154	13.3 x 10 ³	66.6 x 10 ⁶	22	Bone	1.97 x 10 ³	820
Fission Products			(2.22 x 10 ³)			Bone	I = I ₀ t ^{-1.2}		
(Sr-89, Y-91, Ce-144, Zr-95, Tc-99, Pm-147, Pu-239)									
Fluorine	9	F	18	222 x 10 ⁶	1.99 x 10 ⁹	24	Bone	0.078	0.078
Gallium	31	Ga	72	6.66 x 10 ⁶	19.9 x 10 ⁹	8	Bone	0.59	0.59
Germanium	32	Ge	71	88.8 x 10 ⁶	19.9 x 10 ⁹	67	Kidneys	11.4	3.9
Gold	79	Au	198	222 x 10 ³	6.66 x 10 ⁶	10	Kidneys	2.69	2.6
	79	Au	199	555 x 10 ³	15.5 x 10 ⁶	28	Kidneys	3.3	3.1
Holmium	67	Ho	166	6.66 x 10 ⁶	51 x 10 ⁹	17	Bone	1.14	1.1
Hydrogen (tritium)	1	H	3	44.4 x 10 ⁶ (HTO-111 x 10 ⁶ or 50 µc/m ³) (HT-222 x 10 ⁹)	444 x 10 ⁶ (888 x 10 ⁶)	10 ⁴	Total Body	4.6 x 10 ³	19

ELEMENT	ISOTOPE			MAXIMUM PERMISSIBLE CONCENTRATIONS		TOTAL BODY BURDEN		HALF-LIVES	
	Z		A	Air(d/m/m ³)	Water(d/m/l)	Micro- curies	Critical Organ	Radioactive (days)	Effective (days)
Iodine	53	I	131	6.66 x 10 ³	66.6 x 10 ³	0.3	Thyroid	8	7.7
Iridium	77	Ir	190	1.55 x 10 ⁶	22.2 x 10 ⁶	21	Kidneys	10.7	7.3
	77	Ir	192	111 x 10 ³	1.99 x 10 ⁶	3.4	Kidneys	70	17
Iron	26	Fe	55	1.33 x 10 ⁶	8.88 x 10 ⁶	10 ³	Blood	1.06 x 10 ³	61
	26	Fe	59	33.3 x 10 ³	222 x 10 ³	11	Blood	46.3	27
Lanthanum	57	La	140	2.22 x 10 ⁶ (22.2 x 10 ³)	2.22 x 10 ⁹ (6.66 x 10 ⁶)	24	Bone	1.67	1.6
Lead	82	Pb	203	14.4 x 10 ⁶	222 x 10 ⁶	57	Bone	2.17	2.16
Lutetium	71	Lu	177	11.1 x 10 ⁶	53 x 10 ⁹	78	Bone	6.7	3.2
Manganese	25	Mn	56	6.66 x 10 ⁶	333 x 10 ⁶	2	Kidneys	0.108	0.106
Molybdenum	42	Mo	99	4.44 x 10 ⁹	31 x 10 ⁹	50	Bone	2.85	2.8
Neptunium	93	Np	237	(8.8)	(3.33 x 10 ³)	Sol 0.04	Bone	8 x 10 ⁸	4.3 x 10 ⁴
	93	Np	239	(8.8)	(3.33 x 10 ³)	Insol 0.008 0.04	Lungs Bone	360 2.33	
Niobium (Columbium)	41	Nb (Cb)	95	888 x 10 ³	8.88 x 10 ⁶	90	Bone	35	21
Nickel	28	Ni	59	44.4 x 10 ⁶	555 x 10 ⁶	39	Liver	9.1 x 10 ⁷	8
Palladium- Rhodium	46 45	Pd- Rh	103 103	1.55 x 10 ⁶	22.2 x 10 ⁶	6	Kidneys	17	4.4
Phosphorus	15	P	32	222 x 10 ³	444 x 10 ³	10	Bone	14.3	14

ELEMENT	ISOTOPE		MAXIMUM PERMISSIBLE CONCENTRATIONS		TOTAL BODY BURDEN		HALF-LIVES	
	Z	A	Air(d/m/m ³)	Water(d/m/l)	Micro-curies	Critical Organ	Radioactive (days)	Effective (days)
Plutonium	94	Pu	239	4.44 (8.8)	3.33 x 10 ³	Sol 0.04 Insol 0.008	Bone Lungs	8.8 x 10 ⁶ 4.3 x 10 ⁴ 360
Polonium	84	Po	210	Sol 444 Insol 155 (1.4 x 10 ³)	66.6 x 10 ³	0.02 0.007	Spleen Lungs	138.3 40 31
Potassium	19	K	42	4.44 x 10 ⁶	22.2 x 10 ⁶	20	Muscle	0.52 0.51
Praseodymium	59	Pr	143	1.66 x 10 ⁶	888 x 10 ⁶	29	Bone	13.8 11
Promethium	61	Pm	147	444 x 10 ³	2.22 x 10 ⁹	120	Bone	1.46 x 10 ³ 140
Radium	88	Ra	226	17.7 (33)	88.8	0.1	Bone	5.9 x 10 ⁵ 1.6 x 10 ⁴
Radon	86	Rn	222	(22.2) 22.2 x 10 ³	4.44 x 10 ³		Lungs	6.3 x 10 ⁻⁴ 3.83
Rhenium	75	Re	183	17.7 x 10 ⁶	177 x 10 ⁶	35	Thyroid	240 0.5
Rhodium	45	Rh	105	2.22 x 10 ⁶	33.3 x 10 ⁶	9	Kidneys	1.52 1.4
Ruthenium- Rhodium	44 45	Ru- Rh	106 106	66.6 x 10 ³	222 x 10 ⁶	4	Kidneys	365 19
Rubidium	37	Rb	86	888 x 10 ³	6.66 x 10 ⁶	60	Muscle	19.5 7.8
Samarium	62	Sm	151	22.2 x 10 ³	444 x 10 ⁶	420	Bone	3.6 x 10 ⁵ 3.9 x 10 ⁴
Scandium	21	Sc	46	155 x 10 ³	888 x 10 ⁶	6	Spleen	85 13
Silver	47 47	Ag Ag	105 111	22.2 x 10 ⁶ 66.6 x 10 ⁶	4.44 x 10 ⁹ 8.88 x 10 ⁹	18 36	Liver Liver	45 7.5 2.8 2.1

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ELEMENT	ISOTOPE		MAXIMUM PERMISSIBLE CONCENTRATIONS		TOTAL BODY BURDEN	HALF-LIVES			
	Z	A	Air(d/m/m ³)	Water(d/m/l)	Micro-curies	Critical Organ	Radioactive (days)	Effective (days)	
Sodium	11	Na	24	4.44 x 10 ⁶	17.7 x 10 ⁶	15	Total Body	0.62	0.61
Strontium	38	Sr	89	44.4 x 10 ³ (888)	155 x 10 ³ (2.66 x 10 ³)	2	Bone	53	52
Strontium-Yttrium	38 39	Sr- Y	90 90	444 (444)	1.77 x 10 ³ (1.33 x 10 ³)	1	Bone	7.3 x 10 ³	2.5 x 10 ³
Sulfur	16	S	35	2.22 x 10 ⁶	1.11 x 10 ⁶	100	Skin	87.1	18
Technetium	43	Tc	96	6.66 x 10 ⁶	66.6 x 10 ⁶	5	Kidneys	4.3	2.1
Tellurium	52	Te	127	222 x 10 ³	66.6 x 10 ⁶	4	Kidneys	90.4	13
	52	Te	129	88.8 x 10 ³	22.2 x 10 ⁶	1.3	Kidneys	32	10
Thorium (Thoron-see Radon)	90	Th	234	1.33 x 10 ⁶	6.66 x 10 ⁹	120	Bone	24.1	24.1
Thulium	69	Tm	170	111 x 10 ³	55.5 x 10 ⁶	19	Bone	129	59
Tin	50	Sn	113	1.33 x 10 ⁶	444 x 10 ⁶	80	Bone	112	44
Uranium (tuballoy)	92	U	238	37.7 (66 or 44 μgm/m ³)	155 x 10 ³	Sol 0.2 Insol 0.009	Kidneys Lungs	1.64 x 10 ¹²	30 120
	92	U	233	Sol 222 Insol 35.5 (Sol 3.33x10 ³ Insol 66)	333 x 10 ³ (355 x 10 ³)	0.04 0.008	Bone Lungs	5.9 x 10 ⁷	300 120
	92	U	234	(Sol 3.33x10 ³ Insol 66)	(355 x 10 ³)	0.05 0.008	Bone Lungs	9.75 x 10 ⁷	300 120
(oralloy)	92	U	235	(Sol 3.33x10 ³ Insol 66)	(355 x 10 ³)	0.05 0.008	Bone Lungs	3.21 x 10 ¹¹	

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ELEMENT	ISOTOPE		MAXIMUM PERMISSIBLE CONCENTRATIONS		TOTAL BODY BURDEN Micro-curies	Critical Organ	HALF-LIVES	
	Z	A	Air (d/m/m ³)	Water(d/m/l)			Radioactive (days)	Effective (days)
Vanadium	23	V	48	2.22×10^6	1.11×10^9	20	Bone	16
Xenon	54	Xe	133	8.88×10^6 (37.7×10^6)	8.88×10^6	300	Total body	5.27
	54	Xe	135	4.44×10^6	2.22×10^6	100	Total body	0.38
Yttrium	39	Y	90	(6.44×10^3)	(2.11×10^6)	0.3	Bone	2.58
	39	Y	91	88.8×10^3	444×10^6	15	Bone	57
Zinc	30	Zn	65	4.44×10^6	133×10^6	430	Bone	250

SHIPPING RADIOACTIVE MATERIALS

1. Interstate Commerce Commission Regulations. In general, these apply to Rail, Motor, Water, and Air Transportation.

(a) No significant* surface contamination on any part of shipping container.

(b) Gamma radiation at any surface of container not to exceed 200 mr/hr or equivalent and 11.5 mr/24 hr (0.5 mr/hr) at 15 ft, at any time during transportation.

(c) For Group I materials, the gamma radiation should not exceed 10 mr/hr at 1 meter from any point on the radioactive source at any time during transportation. The shielding must not open or break during transportation and must be sufficient to prevent the escape of any primary corpuscular radiation to the exterior of the shipping container.

Group II should be packed so that at any time during transportation radiation measured at right angles to any point on the long axis of the shipping container will not exceed: (1) gamma radiation of 10 mrhm*; (2) electrically charged corpuscular radiation which is the physical equivalent of 10 mrhm of gamma radiation; (3) neutron radiation which is the equivalent of 2 mrhm of gamma, i.e., 80 n/cm²/sec for Ra-Be, Pu-Be and Po-Be neutrons with average energies of 4 to 5 Mev and 160 n/cm²/sec for Mock Fission neutrons of 1 Mev. (4) If more than one of the types of radiation named is present, the amount of each must be reduced so that the total does not exceed the above equivalents. For Ra-Be, Pu-Be, and Po-Be sources, the following equations may be helpful: Let x = gamma in mrhm (number of radiation units*); y = neutron flux at 1 meter in n/cm²/sec. Then

the permissible gamma rate	or	the permissible neutron
when the neutron flux is		flux when the gamma rate
known: $x = 10 - \frac{y}{8}$		is known: $y = 80 - 8x$

Note: In such instances with multiple types of radiation present, the label should be marked: "Equal to or less than equivalent of (actual number) units."

As a rough rule, 3 in. of paraffin will reduce the flux of 4-Mev neutrons to about 37 per cent of the original flux. Other energies will require different amounts of absorber.

Group III materials must be packed to prevent the escape of primary corpuscular radiation to the exterior of the container and the secondary radiation at the surface must not exceed 10 mr/24 hr (0.42 mr/hr).

(d) Approval from the Bureau of Explosives must be obtained for shipments which exceed 2000 mc content of Ra, Po, or other members of the U-238-Ra-226 family, and 2700 mc of any other radioactive substance.

*See Notes and Definitions at end of this section which give specific interpretation of terms as set up by the Interstate Commerce Commission.

(e) Ra, Pu, Sr-90 or any other material which is a special biological hazard must be enclosed in a Spec. 2R inner container in addition to the packing hereinafter described. (Spec. 2R tube, made of stainless steel, malleable iron, or brass. Outside diameter, 3 in. maximum. Length, 8 in. maximum. Minimum wall thickness, 3/32 in. for O.D. up to 2 in.; 1/8 in. for O.D. above 2 in. Screw type ends, 1 may be brazed or welded. Minimum threads per inch equal to U. S. Standard pipe thread. Certain circumstances may make a neoprene gasket advisable.)

(f) Liquid radioactive materials Groups I, II or III must be packed in tight glass, earthenware, or other suitable inside containers surrounded by absorbent material sufficient to absorb the entire liquid contents and of such a nature that its efficiency will not be impaired by chemical reaction with the contents. If a 2R container is used, absorbent cushioning is not required.

(g) Finished package must have no dimension smaller than 4 in. Outside container must be strong and tight and made of wood (Spec 15A or 15B), fiberboard (Spec 12B or 21A) or other types of material which have been approved and must be able to withstand the shocks encountered in ordinary transportation without allowing any leakage of radioactive material. (See ICC Tariff No. 9 for Specifications)

(h) Each package must be labeled with standard radioactive labels. For Groups I and II, ICC label with red lettering which requires, for example:

Principal radioactive content	<u>RADIUM</u>
Activity of contents	<u>200 millicuries</u>
Radiation units from package No.	<u>3</u>
Shipper's Name	<u>LASL</u>

For Group III, the ICC label has blue lettering and requires, for example:

Name of contents	<u>STRONTIUM-90</u>
Shipper's Name	<u>LASL</u>

In addition, any flammable gas or flammable liquid must be labeled with a red flammable label and any flammable solid or oxidizing material must be labeled with a yellow flammable label. If special containers have been used in packaging, the outer container should be marked with that information.

(i) No more than 40 units* may be shipped in any one car, truck or plane. Furthermore, no Class D Poisons are to be loaded in the same vehicle with explosives.

(j) Large machines (e.g., bulldozers) which cannot be completely decontaminated by practical means or readily packaged may be shipped as long as there is no hazard to personnel or materials. They must be decontaminated to the point that no significant* amount of activity rubs off and the radiation level is no greater than 10 mr/hr gamma (17 mr/hr beta plus gamma) at 1 meter from any accessible surface. Similarly, freight car or truck load lots of high

activity materials (e.g., fuel elements, wastes) may be shipped in strong, tight containers with no loose material in the car or truck. In the latter case, the car or truck is considered as the container and the radiation levels must not exceed 200 mr/hr at contact, 10 mr/hr at 1 meter and 0.5 mr/hr at 15 ft from any surface of the car or truck. In any of the above cases, warning signs (see placard under Exempt Articles) and ICC labels should be posted on exterior surfaces in prominent locations. It is the responsibility of the consignor and/or consignee to supervise all loading and unloading operations and to monitor all personnel involved. (Note: This is an unofficial interpretation which has been proposed as a regulation.)

2. Air Shipments. Restrictions in addition to those given above; also, certain airlines will not accept radioactive or flammable materials for shipment.

(a) No more than 50 lb net weight of any article which is subject to the above regulations may be carried in any one cargo pit or bin on passenger carrying aircraft, or in any inaccessible cargo pit or bin on any aircraft with the following exceptions: (1) no quantity limit for Group III materials; (2) not more than 40 units* of Group I or II on any aircraft; (3) no quantity limit on cargo aircraft.

(b) The package must provide shielding for full protection of undeveloped films at 30 ft and full protection of all airline personnel and passengers. The following table gives the minimum distance between the edge of shipping container and crew or passengers during flight for varying numbers of units* in the shipment.

Units	Distance (ft)	Units	Distance (ft)
0 - 2	1	11 - 20	4
3 - 5	2	21 - 30	5
6 - 10	3	31 - 40	6

(c) Labeling - in addition to the regular ICC label, a special label must be prominently displayed. "Do not place in same compartment with undeveloped films or mail." Also, if the package is acceptable for shipment on a passenger carrying aircraft, a statement to that effect must be plainly visible on the exterior of the package.

3. Courier Service is free of all ICC regulations. Escort personnel assume responsibility of preventing injury to films and personnel. Monitor must advise escort (preferably in writing) of health considerations such as: a. possibility of gas escaping; b. contamination; c. tolerance times; d. not allowing stowage in inaccessible cargo space aboard aircraft.

4. Parcel Post Regulations and Articles Exempt from ICC Packaging and Labeling Requirements (providing they fulfill all of the following conditions).

(a) Package must be such that there can be no leakage of material under normal shipping conditions.

(b) Contents must not be greater than 0.1 mc of Ra or Po; 0.135 mc of Sr-90, Sr-89, or Ba-140; or 1.35 mc of any other radioactive substance.

(c) No significant* alpha, beta or neutron radiation emitted from the exterior of the package and gamma radiation must be less than 10 mr/24 hr (0.42 mr/hr).

(d) Package must have no significant* surface contamination.

(e) All liquids must be packed in tight glass, earthenware, or other suitable inside containers surrounded by absorbent material sufficient to absorb the entire contents and of such nature that its efficiency will not be impaired by chemical reaction with the contents.

(f) Parcel Post Only. Package must be marked on outside: "RADIOACTIVE MATERIAL - GAMMA RADIATION AT SURFACE OF PARCEL LESS THAN 10 MILLIROENTGENS FOR 24 HOURS - NO SIGNIFICANT ALPHA, BETA, OR NEUTRON RADIATION."

(g) Rail, Motor, or Air Freight Only. Car, truck, or plane-load lots of low-activity materials (e.g., ores, residue) may be shipped as exempt materials provided:

(1) they are packed in strong, tight containers with no loose material in the vehicle; (2) gamma radiation or equivalent does not exceed:

10 mr/hr - 12 ft from any car or truck surface

10 mr/hr - 5 ft from any end surface of car or truck

10 mr/hr - 1 meter from any outside surface of aircraft;

(3) car or truck must be labeled with a placard by shipper. Placard to have a diamond shape, 10-3/4 in. on each side, to read - "DO NOT REMAIN IN OR NEAR THIS CAR UNNECESSARILY - Notify Shipper or Bureau of Explosives if necessary to transfer lading enroute - DANGEROUS CLASS D POISON - This car must not be next to a car containing explosives. Avoid contact with leaking contents. When lading is removed this placard must be removed." (4) loading and unloading operations must be monitored by consignor and/or consignee. Any railroad car, motor vehicle, or aircraft which has become contaminated must be thoroughly cleaned by consignee to reduce the radiation in any part to not more than 10 mr/24 hr (0.42 mr/hr at contact with a G-M tube instrument with the shield open) and/or an alpha count of not more than 1500 dis/min/100 cm² (500 c/m with PeeWee probe) and a certificate to that effect given the local agent or driver. (10 mr/24 hr is the only official value. All other figures in this 4th paragraph are unofficial values adopted at LASL.)

5. Empty containers and accessories which have been used for radioactive shipments must meet exempt specifications and have no label other than an EMPTY label for shipment.

Notes and Definitions

Significant amounts of radiation have been defined arbitrarily as being equal to or greater than the following:

alpha 500 dis/min/100 cm² (175 c/m with PeeWee probe)
beta 0.1 mrep/hr
neutron 100 slow neutrons/cm²/sec; 4 fast neutrons/cm²/sec

Radiation Unit - 1 milliroentgen per hour at 1 meter from source (1 mrhm)

Flammable Gas - mixture of 13 per cent or less (by volume) with air forms a flammable mixture (e.g., hydrogen which includes tritium)

Flammable Liquid - gives off flammable vapors at or below 80°F (e.g., acetone, gasoline)

Flammable Solid - likely under conditions incident to transportation to cause fires through friction, absorption of moisture, spontaneous chemical changes, or as a result of retained heat from manufacturing or processing (e.g., powdered thorium metal, powdered uranium - not the oxides)

Oxidizing Material - yields oxygen readily to stimulate the combustion of organic material (e.g., chlorates, nitrates)

Radioactive materials are Class D Poisons and are divided into three groups:

- Group I - emit gamma rays only or both gamma and electrically charged corpuscular rays
- Group II - emit neutrons and either or both of the types mentioned under Group I
- Group III - emit electrically charged corpuscular rays only, i.e., alpha or beta rays, etc., or any other that is so shielded that the gamma radiation at the surface of the package does not exceed 10 mr/24 hr at any time during transportation

For materials with half-lives greater than 6 days, the change in activity after 24 hr will be less than 10 per cent and 10 mr/24 hr may be considered to be equal to 0.42 mr/hr. For materials with shorter half-lives, the activity at the end of 24 hr may be reduced and 10 mr/24 hr will permit a higher initial rate than 0.42 mr/hr.

Most of the permissible levels given in this section include the restriction, "at any time during transportation." If the activity of the contents will be increased as the daughter products of the original isotope build-up, this must be taken into account in the monitoring of the package.

Curie - that amount of a radioactive material which disintegrates at a rate of 3.7×10^{10} atoms/sec.

Physical equivalent - roentgen equivalent physical (rep) or that amount of radiation that would be absorbed in tissue to the extent of 93 ergs/gm.

References: AEC Bulletin GM-87; Tariff No. 8; Tariff No. 9; Civil Air Regulation 49; Evans, R.D., NSS-PreR No. 11; AECU-817

TABLE OF CONVERSIONS FROM RHM TO CURIES

This table may be used to convert from roentgens per hour at 1 meter (rhm) to approximate curie strength, or from curie strength to approximate rhm values, if the quantum energy per disintegration is known in each case. Dosages, not necessarily quantum energies, are additive.

Note: Quantum energies may be found in tables or charts such as the G.E. Chart of Nuclides or Kinsman's Radiological Health Handbook.

When the actual curie strength of a source to be shipped is unknown, the table may be used to obtain a value for printing on the ICC label. First, measure the radiation output of the unshielded source at 1 meter (not through the shipping container). Then from the table, for the proper energy, obtain the number of curies per rhm. Multiply this latter value by the number of rhm as measured. If more than one quantum of energy is released per disintegration, the best value will be given by estimating the dosage for each energy and then averaging these values.

Energy (Mev)	0.2	0.5	0.8	1.0	1.5	2.0	3.0	4.0
rhm per curie	0.05	0.29	0.45	0.56	0.77	0.91	1.2	1.4
curies per rhm	20.0	3.4	2.2	1.8	1.3	1.1	0.85	0.71

Examples: To estimate the curie strength from a 1-curie Co-60 source which emits two gamma rays in cascade each disintegration, one of 1.1 Mev and the other 1.3 Mev energy: From the table above, 1.1 Mev should give about 0.6 rhm per curie and 1.3 Mev should give about 0.7 rhm per curie. Adding these rhm values, 1 curie of Co-60 produces about 1.3 rhm.

Sodium-24 disintegrates with both a 2.8-Mev and a 1.4-Mev gamma being released with each disintegration. A Na-24 source, unshielded, measures 7.6 rhm. Assume one-half of the radiation results from each of the gamma energies. One-half of 7.6 rhm is 3.8 rhm. For 2.8-Mev energy, by interpolation, the number of curies per rhm from the above table is about 0.9. Multiplying the number of curies per rhm by the number of rhm will give the number of curies. $0.9 \times 3.8 = 3.4$ curies. For the other energy of 1.4 Mev, the number of curies is equal to 1.25×3.8 , or 4.7 curies. An average of these two results ($3.4 + 4.7$ divided by 2) is about 4 curies.

INVERSE SQUARE LAW

The Inverse Square Law states that the dose rate from a source is inversely proportional to the square of the distance from the source, provided the dimensions of the source are very small in comparison with the distance involved, and that no appreciable scattering or absorption of the radiation occurs in the medium through which it travels.

For example: 45 mr/hr at 100 cm. The dose rate at 10 cm is

$$45 \times \frac{(100)^2}{(10)^2} = 45 \times \frac{10,000}{100} = 4500 \text{ mr/hr}$$

and 800 mr/hr at 20 cm. The dose rate at 40 cm is

$$800 \times \frac{(20)^2}{(40)^2} = 800 \times \frac{400}{1600} = 200 \text{ mr/hr}$$

For dose rates at very small distances or contact, it is necessary to use an extrapolation chamber (H-6 has such a device) for accurate determinations. As another method which can be used for an estimate, using the extrapolation principle but a survey meter, measurements should be made with the survey meter at varying distances (getting as close as is possible and still having a point source as defined on page 48). Plot these values on a graph (dose rate vs. distance) and extrapolate graphically to zero. This is not possible if scattering or absorption of the radiation becomes a factor: in other words, this will work only for heavily filtered x-radiation above 100 kev or neutron or gamma radiation but not for beta radiation. Only the extrapolation chamber can be used for beta radiation as well.

The following is a table of numbers, their squares, and the reciprocal of their squares. For inverse square law applications, N is the ratio of distances and N^2 or $1/N^2$, the ratio of intensities.

N	N ²	1/N ²	N	N ²	1/N ²
1.0	1.00	1.00	3.5	12.25	0.0816
1.1	1.21	0.826	4.0	16.00	0.0625
1.2	1.44	0.694	4.5	20.25	0.0494
1.3	1.69	0.592	5.0	25.00	0.0400
1.4	1.96	0.510	5.5	30.25	0.0330
1.5	2.25	0.444	6.0	36.00	0.0278
1.6	2.56	0.391	6.5	42.25	0.0237
1.7	2.89	0.346	7.0	49.00	0.0204
1.8	3.24	0.309	7.5	56.25	0.0178
1.9	3.61	0.277	8.0	64.00	0.0156
2.0	4.00	0.250	8.5	72.25	0.0138
2.5	6.25	0.160	9.0	81.00	0.0123
3.0	9.00	0.111	10.0	100.00	0.0100

Figure 1. Semi-Log Plot of Radioactive Decay

To find number of half-lives elapsed, divide elapsed time by half-life in similar units. Read from curve the per cent of original activity remaining. Example: Po-210, $T_{1/2}$ is 138 days. After 40 days, $40/138 = 0.29$ or 82%.

C 8

PORTABLE METERS BEING USED AT LOS ALAMOS SCIENTIFIC LABORATORY

FIGURE NUMBER	MODEL NUMBER	TYPE OF METER	RADIATION DETECTED	WEIGHT (LBS)	NOMINAL RANGE	CHARACTERISTICS AND LIMITATIONS
1	101	Ion Chamber	Beta & Gamma	23	(4 scales, zero set)	Tritium "Sniffer"- air drawn through chamber by small blower. Sensitive to gamma radiation or any ion producing source (lighted match.)
2	2111	Proportional Counter	Alpha	19	0-20,000 c/m	"PeeWee"-probe has steel grid over 0.25 mil Mylar window. Microphonic, easily damaged, requires frequent calibration (Tuballoy source on case), affected by moisture.
3	2111N	Proportional Counter	Neutron	20-1/2	0-10,000 n/cm ² /sec	"Converted PeeWee"- boron-lined tube replaces probe on above meter. One in. thick polyethylene moderator. Twenty mil cadmium absorber. Energy dependent.
4	E-1	Proportional Counter	Fast Neutron	10-1/2	0-500 mrep/hr	"Rudolph"- tissue equivalent chamber for 0.2- to 10-Mev neutrons. 4 ranges.
5	100	Ion Chamber	Beta & Gamma	8-1/2	100 - 50,000 mr/hr	"Converted Model 100"- Mylar-covered probe with 1/4 in. thick lucite beta shield. Requires calibration chart. Beta response assumed reliable.
6	D-1	Ion Chamber	Beta & Gamma	3	0-5000 mr/hr	"Cutie Pie"- end of chamber has thin window, beta shield. Somewhat directional in response.
7	SIC-7A	Ion Chamber	Beta & Gamma	3-1/2	25-10,000 mr/hr	"Cutie Pie"- one-half chamber end has thin window. Requires calibration chart.

FIGURE NUMBER	MODEL NUMBER	TYPE OF METER	RADIATION DETECTED	WEIGHT (LBS)	NOMINAL RANGE	CHARACTERISTICS AND LIMITATIONS
8	SU-10 (T-1-B)	Ion Chamber	Gamma	11	0-50,000 mr/hr	Long warm-up period. Zero adjust requires turning of range switch.
9	AGB-500- SR	Ion Chamber	Gamma	3-1/2	0.5 - 500,000 mr/hr	Jordan "Radector"- 2 ranges, logarithmic response, mr/hr and r/hr. New models have beta window and built-in calibration source. Small energy dependence above 75 kv.
10	SRJ-1	Ion Chamber	Alpha-Beta & Gamma	5	0-5000 mr/hr	"Juno"- Sliding alpha and beta shields. Slow to warm up. Calibration not reliable for 3 types of radiation. Not recommended for general laboratory alpha monitoring.
11	263-B	Geiger- Mueller	Beta & Gamma	11-1/2	0-20 mr/hr	Victoreen - Beta shield slips over 30 mg/cm ² metal G-M tube. Saturates in high fluxes.
12	389-A	Geiger- Mueller	Beta & Gamma	5-1/2	0-20 mr/hr	"Thyac"- see #11. Vibrator high voltage supply. Mechanical difficulties make it somewhat unreliable.
13	SC-2A	Scintillation Detector	Gamma	-	-	Detector head only. May be combined with instrument similar to that shown in #12. Phosphor (usually NaI crystal) and photomultiplier tube.
14	100	Ion Chamber	Beta & Gamma	5	0-1000 mr/hr	"Met-Lab" model shown. Landsverk "Electroscope"- Drift between light flashes measure of radiation. Recommended for ICC shipment measurements.
15	300	Ion Chamber	Gamma	5	0-200 mr	"Proteximeter"- Portable integrating meter. Simple operating instructions on bottom.

Figure 2. Some Radiation Detection Meters Used at Los Alamos.

Figure 3. Personnel Monitoring Equipment (left to right)
 Film packet for Beta-Gamma - DuPont D-1 (502 emulsion) with
 a processed film above. For Neutrons - Ilford (C-2 emulsion)
 with a processed plate, a wrapped plate, and the same emulsion
 in packet form which is under test.
 Special film badge (Al and Cd filters)
 Body, wrist, and ring badges (Brass and Cd filters)
 Pocket chamber (200 mr); dosimeters (200 mr, 1 r, 5 r);
 slow neutron pocket chamber (1.5 to 2 daily tolerances)
 Above - dosimeter charger and chamber charger-reader.

DOSIMETER OPERATION

A dosimeter is essentially a condenser constructed to discharge in a predictable fashion when exposed to ionizing radiation. From the schematic drawing which follows, it can be seen that a charge is placed on the collecting electrode by contacting the charging condenser. This charge can leak off by shorting the charging end through leaking insulators because of moisture, dirt, or physical breakdown, or via ionized air in the chamber.

Radiation which can penetrate the chamber walls will ionize the air and permit the charge to leak off in a uniform manner.

The quartz fibre, attached to the central electrode, has the same charge as the central electrode and is repulsed by it (like charges repel). As the charge is dissipated via the ionized air, the quartz fibre is repelled less and less and moves toward the central electrode. This movement is viewed through the lens system on a calibrated scale. Because of the other means for the charge to leak off, a leak test is made by charging the dosimeter to zero reading and allowing the charged meter to remain in a minimal radiation area for 24 hr.

1. Greater than 10 per cent of full scale leakage (other than that resulting from normal radiation) over a 24-hr period is considered too much, and the dosimeter should either be repaired or replaced.
2. Because of variations in the manufacture of the dosimeters, each meter must be calibrated by exposure to a source of known size. The necessary correction factor is calculated and attached to the side of the chamber. All subsequent readings should be multiplied by this correction factor.

$$\frac{\text{True Exposure}}{\text{Dosimeter Reading}} = \text{Correction Factor}$$

3. The calibrated scale on most dosimeters is completely linear; that is, the response over the range is proportional to the amount of radiation. However, any travel of the hair-line beyond the calibrated scale cannot be estimated or extrapolated because of physical limitations. Whenever such an off-scale or near full-scale reading is expected, a higher range dosimeter should be worn, along with the lower range meter.

ALPHA MONITORING

The alpha particle has a large mass and a double charge, both of which limit its travel in matter. For this reason, with the exception of accelerators wherein the alpha may be given energies greater than those of the isotope sources (maximum energy of about 7 Mev), alpha control means the prevention of ingestion, inhalation, and spread of alpha contamination.

The property which makes alpha so easily shielded (a thickness of 0.015 gm/cm² or 0.006 in. of paper, wood, or any light material will stop all alphas) makes the construction of detecting instruments and the use of these same detectors very difficult. To maintain a constant volume (for changes in volume change calibration), prevent vibrations (in an electric field these will appear on the meter as spurious counts), and yet have a rugged, efficient, portable alpha detecting instrument, requires some compromises which make these instruments distinctive. The PeeWee is a proportional counter (if properly adjusted, alphas can be detected in the presence of other types of radiation) with a separate thin-walled probe.

Since all known natural alpha rays have ranges of less than 12 cm (5 in.) in normal air, it is essential that the detecting device be held close to the surface being surveyed (within less than 1/2 in.) Moisture (a damp sink or wet clothing) effectively reduces most alpha energies below the detecting threshold. The different energies of alphas from various isotopes make possible some differentiation of the material producing the count when filtration is added in the form of thin rubber hydrochloride shields over the window of the detector. For example: Po alpha - 5.29 Mev; tuballoy alpha - 4.18 Mev. With 1 mil (5 layers, 4 in the shield and 1 on the probe) of rubber hydrochloride, tuballoy will read no more than 250 c/m with a PeeWee probe which has an effective area of 55 cm². All extra count indicates Po when both tuballoy and Po are present.

Routine alpha monitoring usually is only a qualitative determination of alpha contamination, but it requires tedious, meticulous survey work. Special cases, such as wounds, require determination of the exact location of the contaminant. This is most easily done by tearing a small hole in a piece of paper and locating the count through the hole.

BETA-GAMMA MONITORING

The problem is mainly that of detecting a penetrating type of radiation. Most survey work is done with a Geiger-Mueller tube type of instrument. These instruments are calibrated with a radium source and give only an indication of beta radiation when the tube is unshielded. Ion chamber instruments, when modified with thin walls to permit the entry of beta particles, will give a more nearly accurate response to beta radiation because they are essentially air ionization instruments.

When monitoring for beta or gamma radiation, rapid coverage can be made by checking at a distance (2 to 6 in.) from the object of the survey. X-radiation below 100 kilovolts peak (kvp) is not so penetrating and should be checked with no shielding on a G-M tube or with a thin-walled ion chamber. Due to the energy dependence (see Fig. 5) of G-M tube instruments and pocket dosimeters, readings in x-ray or gamma ray fluxes of energies around 70 kvp may be high. When monitoring a pulsing beam (e.g., the beam from a betatron), a G-M tube instrument is not reliable because it may respond only to the frequency of the pulses and give no real indication of the amount of radiation present.

For recording individual exposures, some form of the equipment shown in Fig. 3 is used. The badges shown in the picture are engraved with identifying numbers which, with the date of issue, are transferred to the film by an x-ray exposure prior to issue. Ring badges are used for empirically determining the finger-to-wrist exposure ratio. This ratio is then applied to subsequent wrist readings to estimate the extremity exposures. Dosimeters are used as guides for exposure estimation in areas of high fluxes.

ENERGY - RANGE RELATIONS

<u>Energy (Mev)</u>	<u>Range (cm in air)</u>		
	<u>Proton</u>	<u>Deuteron</u>	<u>Alpha Particle</u>
0.2	0.29	0.28	0.17
0.6	1.10	0.90	0.38
1.0	2.30	1.72	0.57
2.0	7.20	4.61	1.05
4.0	23.10	14.40	2.49
7.0	61.2	36.6	5.90
10.0	114.8	67.8	10.55

Beta Characteristics

<u>Maximum Energy (kev)</u>	<u>Range</u>	
	<u>Aluminum (mg/cm²)</u>	<u>Air (cm)</u>
2.55	0.05	0.04
10.5	0.27	0.23
24.7	1.20	1.0
46.6	4.1	3.4
79.1	8.7	7.3
127.8	21.5	17.9
214.7	45	37.5
341	100	83.0
662	260	217
1127	525	437
2058	1030	860
3114	1570	1300

HALF-VALUE LAYERS* IN INCHES FOR GAMMA RADIATION

Ref: KLX-24, 1948

<u>Energy (Mev)</u>	<u>Water</u>	<u>Concrete</u>	<u>Steel</u>	<u>Lead</u>
0.5	2.91	1.46	0.425	0.159
0.8	3.60	1.76	0.533	0.273
1.0	4.00	1.96	0.597	0.350
1.5	4.85	2.49	0.744	0.478
2.0	5.59	2.99	0.894	0.573
3.0	7.0	3.59	1.13	0.625

*See Glossary for definition

Figure 4. Penetration Ability of Beta Radiation

Ref: SRI-361

Figure 5. Energy Dependence of Several Instruments as Determined by Exposure to X-radiation. Correction Factor Vs Potential Applied to X-ray Tube.

Averages of data from NBS Circular 507, 1951 and Ellery Storm, LASL, personal communication (dashed portions - beta shield off).

INSTRUCTIONS FOR POINT SOURCE NOMOGRAM

Any source may be considered a point source if there is not appreciable self-absorption and if the half angle subtended at the observer is less than 20° .

For Ra use an energy of 1.8 Mev, Co-60 - 2.5 Mev, Ba-La - 1.5 Mev. For other radioactive materials, consult the General Monitoring Office for the energy to be used.

Example: How much lead shielding is needed to reduce to 50 mr/hr the radiation from 0.3 curie of Ra at a working distance of 1 ft.

This source strength is less than that shown in column (A). Therefore, it is necessary to divide the curie strength (S_p) by some power of 10 to get a value in the range of column (A); in this case 10^{-1} will give $0.3/10^{-1} = 3.0$. Set a straight edge on this point (3.0) and on the point corresponding to the energy in Mev of the radiation (1.8) on column (B). This gives a reference value in column (C) of 53. Reset the straight edge on the reference point (53) and a point in column (D) corresponding to the working distance of 1 ft. The value I_0 indicated in column (E) of 3.0×10^4 must be multiplied by the factor by which the curie strength was divided, that is 10^{-1} , which gives 3.0×10^3 mr/hr as the dose rate at the working distance of 1 ft without shielding. Divide the corrected I_0 by the desired radiation level (I) of 50 mr/hr and multiply by the B factor (to correct for scattering) which for lead is 1. This latter step then becomes $\frac{3000 \times 1}{50}$ or 60. Now set the straight edge on this

value in column (F) and on the point in column (G) corresponding to the shielding material, and the energy of gamma radiation involved, which is lead, at 1.8 Mev. The thickness of the lead shielding required in this case is then read from column (H) to be 3.0 in.

Figure 6. Point Source Nomogram for Calculating Gamma Shielding or Dose with Known Shielding.

Ref: AECD-2934, 1948

Figure 7. Penetration Ability of Gamma Radiation

Ref: SRI-361

NEUTRON MONITORING

The "Converted PeeWee" (No. 3 in Fig. 2) counts the alpha particle produced by the reaction of a neutron with boron, $B^{10}(n,\alpha)Li^7$. The boron response is inversely proportional to the incident neutron velocity or the square root of the energy, with the efficiency being low for energies above 1 kev. In order to compensate in part for this effect, the 1-in. thick polyethylene moderator is used around the tube to reduce a fraction of the neutron flux to energy levels which will interact with the boron. To correct for the response at various energies, multiply the flux values (readings taken with the moderator over the tube) by the following correction factors taken from Fig. 8:

Neutron Energy	Correction Factor
Thermal (0.03 ev)	1.9
Thermal (bare tube - no moderator)	1.25
5 Mev	1.0
14 Mev	3.0
22 Mev	4.0 (Estimated)
28 Mev	5.0 (Estimated)

The difference in $n/cm^2/sec$ ($\times 1.25$) between a reading taken with the bare tube and a reading taken in the same spot with only the cadmium shield over the tube is a measure of the thermal neutron flux. A ratio of these readings (bare/cadmium-shielded) is the cadmium ratio, R_{cd} . Readings taken with the tube enclosed in both moderator and shield, after energy corrections, are measures of the neutron flux of energies above the cadmium cut-off (approx. 1 ev) and are interpreted as the high energy or fast neutrons. An approximate evaluation of the number of neutrons in the important energy region between the thermal and fast categories may be obtained from a calculation (Ref. Hughes, Pile Neutron Research, 1953) based on certain restricted conditions. The determination of whether or not these conditions are met, or how far they may be extended, is complicated. Therefore, it is suggested the following values be used until a more precise system may be devised.

R_{cd}	Intermediate Tolerance Factor (ITF)	Multiply the thermal per cent of the maximum permissible exposure (per cent MPE - thermal $n/cm^2/sec$ divided by 2000) by the ITF for the cadmium ratio determined above to obtain the per cent MPE contributed by both thermal and intermediate energy neutrons. Add to this latter figure the per cent MPE for gamma and for fast neutrons to determine the overall per cent MPE.
10	16.0	
15	11.0	
20	8.0	
33	5.0	
50	3.5	
100	2.25	
200	1.7	
333	1.4	
500	1.25	

The Rudolph (No. 4 in Fig. 2) reads directly in mrep/hr since the chamber has a response essentially equivalent to tissue for neutrons of energies ranging from about 0.2 to 10 Mev. Therefore, the per cent MPE in this case is the observed mrep/hr divided by the permissible mrep/hr (0.75 mrep/hr, assuming an RBE of 10 for fast neutrons.)

For recording individual exposures, either the boron-lined pocket chamber (see Fig. 3) or excessive density on the beta-gamma film under the cadmium filter may be used as an indication of thermal neutron exposure. The Ilford C-2 nuclear emulsion measures the exposure to neutrons above 0.5 Mev. A special Eastman NTA film packet is being tested.

Under certain restricted conditions, it is possible to interpret readings made on the regular beta-gamma film in terms of the thermal neutron exposure. This results from the activation of the cadmium filter by thermal neutron capture which, by the release of gamma radiation, produces additional density on the film in that area. At present, thermal neutron exposures at the Water Boiler are being estimated by this method.

Notes on Neutron Sources

1. Fissioning material. Usually found in reactors. Highest fluxes. Average energy, 1 to 2 Mev. Around reactors the energy may vary from 1 Mev down to thermal energies.
2. Photoneutron sources. Gamma, neutron (γ, n) reactions using the lighter elements (D, Be, B). Average energies usually less than 1 Mev.
3. Most common sources are intimate mixtures using an alpha, neutron (α, n) reaction with lighter elements (Be, B). Average energies, 2 to 5 Mev).
4. The Q-value is the total neutron emission rate (n/sec) from a source. The flux at any distance (R in cm) from a source of known Q is:

$$n/cm^2/sec = \frac{Q}{4\pi R^2}$$

5. An intimate mixture of 1 gm of Ra with an excess of Be powder will give a maximum yield of 17×10^6 n/sec - normal mixtures give from 40 to 80 per cent of that figure (7 to 14×10^6 n/sec).
6. Mixtures of paraffin and boron are good neutron shields. The boron captures the slow neutrons (moderated by interaction with the paraffin) and releases an alpha particle.

Figure 8. Correction Factors to be Applied to Ra-Be Calibration of Converted PeeWee.

Ref: LA-1528

Figure 9. Fast Neutron Attenuation in Cylindrical Containers of Paraffin and Water (PoBe & PoB Neutrons).

Ref: HW 21169

INFORMATION ON NEUTRON SOURCES

Source	Average Energy (Mev)	Plausible Size* (n/sec/curie)	Characteristics - Problems
Fissioning Materials	1-2 (reactors-0.4)	10^{12} n/cm ² /sec	Beams of neutrons, gamma fluxes, beta and alpha contaminates
Ga ⁷² -Be	0.78	1.04×10^6 (5×10^4)	Gamma (2.5 Mev)
Ga ⁷² -D ₂ O	0.16	0.69×10^6 (5×10^4)	Gamma (2.5 Mev)
In ¹¹⁶ -Be	0.15, 0.46	0.14×10^6 (8×10^3)	Gamma (2.1 Mev)
La ¹⁴⁰ -Be	0.75	1×10^4 (2.5×10^3)	Gamma (1.5 Mev)
La ¹⁴⁰ -D ₂ O	0.15	1×10^4 (7×10^3)	Gamma (1.5 Mev)
Mn ⁵⁶ -Be	(80%)0.15, 0.30	1×10^5 (2.9×10^4)	Gamma (2.8 Mev)
Mn ⁵⁶ -D ₂ O	0.25	1×10^4 (3×10^3)	Gamma (2.8 Mev)
MsTh-Be	0.15, 0.84	(3.5×10^4)	Gamma-alpha contaminate
MsTh-D ₂ O	0.2	(9.5×10^4)	Gamma-alpha contaminate
Na ²⁴ -Be	0.8-1.0	1×10^6 (1×10^5)	Gamma (2.7 Mev)
Na ²⁴ -D ₂ O	0.2-0.3	1×10^6 (2×10^5)	Gamma (2.7 Mev)
Po ²¹⁰ -B	2.5	1.5×10^5	Alpha contaminate
Po ²¹⁰ -Be	4.6	2×10^6	Alpha contaminate
Po ²¹⁰ -F		2×10^5	Alpha contaminate
Pu ²³⁹ -Be	4		Alpha contaminate
Ra ²²⁶ -B	2.9		Gamma, alpha, radon gas
Ra ²²⁶ -Be	5 (0.12)	1×10^7 (3×10^4)	Gamma, alpha, radon gas
Rn ²²² -Be	5	1×10^7	Gamma, alpha, radon gas
Sb ¹²⁴ -Be	0.03	1×10^6 (2×10^5)	Gamma (1.7 Mev)
Y ⁸⁸ -Be	0.2, 1.0	(1×10^5)	Gamma (2.7 Mev)
Y ⁸⁸ -D ₂ O	0.31		Gamma (2.7 Mev)

*Nominal sizes for photoneutron sources are indicated in parentheses.

Ref.: Hanson, Phys. Rev. 75; Graves, Froman, NNEs, V-3; AECD-3302

TRITIUM MONITORING

By Dean Meyer

Tritium, the only known radioactive isotope of hydrogen, is a beta emitter with an average energy of about 6 kev. Because of the low energy, regular monitoring instruments will not detect its presence. The Sniffer (No. 1 in Fig. 2) measures the ionization produced inside the ion chamber by radiation from tritium (gas or water vapor) drawn into the chamber by a blower. Although a calibration (LA-1683) of the Sniffer indicates full scale on #5 is about $75 \mu\text{c}/\text{m}^3$ and half scale on #4 is about $1000 \mu\text{c}/\text{m}^3$, the meter should be used primarily for qualitative detection since it responds to any ion in the air. Its sensitivity depends upon the ion concentration in the air sampled, hence the mean life of the ions (i.e., the average time interval between formation and recombination), the sampling rate, and the location of the instrument with respect to the source of tritium. In general, any reading on #5 scale indicates concentrations which are permissible for 40 hr per week exposures, any indication on #3 requires the use of supplied air breathing equipment, and readings on #2 call for immediate evacuation of the area.

For a continuous recording tritium monitor, a meter (LA-1270) utilizing the vibrating reed electrometer to measure the current from an ion chamber supplements the use of the Sniffer. The response of this instrument is quantitative and, when equipped with a 10^{12} ohm resistor, a full scale reading on the X100 position indicates a concentration of $80 \mu\text{c}/\text{m}^3$ and on the X1000, $800 \mu\text{c}/\text{m}^3$.

It is of interest to note that 1 cc of tritium as a gas contains about 2.5 curies, and 1 cc of tritium water about 3000 curies. As water vapor, tritium is absorbed equally through the lungs and skin and, therefore, supplied air equipment reduces the exposure only by 50 per cent. Rubber gloves should be worn when handling tritium-contaminated equipment. Precautions to be taken when handling large quantities of tritium include the wearing of rubber gloves and operating under a hood (either of the drybox type with a negative pressure of about 1 in. of water, or any other type with a linear air flow of 100 to 200 fpm), or with all personnel wearing rubber gloves and supplied air masks. Gloves should be changed frequently since water vapor will pass through rubber.

Low energy, penetrating radiation, which may limit the handling time, is emitted from certain tritium compounds for which regular survey meters require corrections to obtain the true dosage rate. Contact the Group H-1 office for these correction factors. The current permissible concentration for air-borne tritium water vapor is $50 \mu\text{c}/\text{m}^3$ for a 40-hr work week, and the permissible body burden 10 mc. With this body burden, the urine assay will be $250 \mu\text{c}/\text{liter}$ and the internal body dose 0.3 rep/week. The internal dose from 8 curies may be 400 rep

in the first 15 days (IA-1469) or 1 breath (10 per cent saturation, 25°C) can give 300 rep total dose, if no effort is made to decrease the body concentration by increased water turnover. To determine the body burden, all personnel working with tritium should submit urine specimens. The frequency of urine assay is determined by the amount of material handled and the working conditions. In case of accidents where instrumentation indicates a large exposure, a urine specimen should be collected immediately and a second one of 10 to 15 cc as soon as possible after the initial voiding since the first may be diluted by urine in the bladder at the time of the exposure. Group H-5 will, at any time, run an emergency analysis within 2 hr. If an excessive exposure is indicated, the doctor may then prescribe a large intake of liquids. Unless otherwise prescribed by a doctor, intake should be limited to no more than 1 pint per hour for 10 hr or no more than 5 quarts in any 24-hr period.

For disposal, laboratory waste containing tritium must be packaged so transfer personnel and disposal personnel cannot be accidentally exposed. Instructions should be obtained from Group H-1 office for disposal of more than 1 curie of tritium.

URINALYSES

<u>Element</u>	<u>Sample Collected</u>	<u>Tolerances with Methods Used at LASL*</u>
Pu-239 and Am-241,-243	24-hr or overnight voiding	7 d/m/24-hr sample Recheck if 2 d/m/24-hr sample
Po-210	Spot sample	500**d/m/liter Recheck if 100 d/m/liter
U-235	Morning spot sample	100 to 200 d/m/24-hr sample
Sr-90	Spot sample	660 d/m/liter
H-3	Spot sample	250 μ c/liter
Ra-226	24-hr or overnight voiding	22 d/m/24-hr sample
Ba-140 & La-140	Spot sample	6,000 d/m/24-hr sample Recheck if 500 d/m/24-hr sample
U-238 (tuballoy)	Morning spot sample	100 μ g/liter

Urinalyses are routinely made for non-radioactive but otherwise toxic agents also (e.g. mercury, lead). When exposures to these agents are suspected, it is necessary to call Group H-5 for analysis of the situation and corrective suggestions.

*These figures are not standards in the same sense as permissible concentrations in air or permissible dosages of external radiation. The primary purpose is to indicate exposure. The results give no information regarding bodily damage or injury.

**Figures taken from UR-44 (declassified) and NBS Handbook 52 give 50 d/m/24-hr sample or about 33 d/m/liter.

AIR SAMPLING

By H. F. Schulte and E. C. Hyatt

Radioactive material inside the body may cause intense irradiation of the tissues in which it is deposited. Inhalation is the principal means by which such material is taken into the body. The amount deposited in the body depends largely on the concentration in the air which is inhaled, the particle size of the contaminant, and the length of time the individual is exposed to this atmosphere. It is essential that the concentration of radioactive substances in the air be kept to a minimum. Maximum permissible concentrations for various isotopes have been established, and to determine whether such standards are being met, routine air samples are collected and analyzed.

Atmospheric Contaminants

The type of atmospheric contaminant depends on the operation from which it evolves. Contaminants may occur as dusts, fumes, smokes, gases, vapors or mists. Experience has shown that some radioactive gases and vapors may become all or partially adsorbed on common dusts found in the air (e.g., silicates, lint, etc.) and will be collected on dust filters. In general, the method employed for air sampling will depend on the type of contaminant encountered.

Dusts, fumes, smokes and mists are particulate matter, the "particles" being liquid droplets in the case of mists. The distinction between dusts and fumes is based on their method of formation and particle size, fumes being material of very small particle size. The term "fume" is frequently used very loosely to include all types of air contaminants, although this is technically incorrect.

Methods of Air Sampling

Particulate matter is most conveniently sampled by means of filter papers of various types, although other methods (impaction, impingement, electrostatic precipitation) may be used in special cases. Other types of air contaminants - gases and vapors - are less frequently encountered and require special equipment for sampling.

Air samples may be divided into two principal groups, based on the length of time involved in the collection. They may be taken instantaneously (spot or grab samples) or over a measured period of time (continuous or integrated samples).

Spot samples, when analyzed, will indicate the concentration of airborne contamination at a precise time and thus may prove very valuable in identifying a specific source of contamination. A series of samples of this type, when taken during a known period, will show whether the operation produces cyclic variations in the concentration. These

samples are taken by means of evacuated flasks or bottles (e.g., 1-liter flask for radon gas samples) or, for emergency evaluations, by using a hand-operated pump (Samplair pump) drawing air through a filter paper. One of the chief disadvantages of spot samples is that a large number of such samples is required to evaluate the worker's daily exposure. Another limitation is that no indication of contamination will be found unless high concentrations are present or a very sensitive counter is used for analysis of the sample.

Continuous samples more nearly represent the type of exposure to which the worker is subjected, although they give less information than spot samples about how the contamination is produced. Various sampling rates may be used as long as the rate and the collecting efficiency of the sampling apparatus at that rate is known. When very low air concentrations must be measured, or where the counting or analytical method is very insensitive, higher than normal sampling rates may be used or samples may be collected over a long period. Continuous sampling is the method predominantly used at Los Alamos and the most widely used sampler is the Filter Queen.

General Air Sample vs Breathing Zone Sample

A common practice at Los Alamos is to collect a general air sample in the workroom over an 8-hr work period with a Filter Queen at the breathing level of the workmen. This then represents the average concentration in the section of the room sampled. A breathing zone sample is collected within 1 ft of the worker's nose for 5 to 60 min. These are usually taken with a small filter paper holder attached to a vacuum pump by a rubber hose and supported by hand or attached to the worker's head or chest. This latter type of sample more nearly represents the concentration of contaminants actually breathed during the sampling period. Either of the above types of samples or a combination of both types may be used to evaluate the worker's exposure to airborne contaminants. For example, a general air sample may adequately evaluate the exposure in a workroom where all the radioactive materials are processed in dry boxes and any airborne contaminants will be dispersed uniformly into the room air, but only a breathing zone sample can be used in evaluating the exposure during the machining of tuballoy on an open lathe. To estimate the airborne contamination in an open uranium foundry, both types of samples are necessary; the general air sample for the longest exposure during the melting and pouring processes, and a breathing zone sample for the worker who stands over the casting during its removal from the mold and "shakeout."

Types and Calibration of Air Samplers

All sampling units must be carefully calibrated for flow rate in order to evaluate the activity per unit volume of air (e.g., d/m³). Commercial instruments which have been

calibrated at sea level must be recalibrated at Los Alamos because of the lower air density at this altitude. Various devices are used for routine calibration of air samplers and Group H-5 will do any special type of calibration work.

The Filter Queen is a commercial vacuum cleaner adapted to draw air through a piece of 4" x 9" filter paper at a rate of 4 cfm (0.113 m³/min). It is equipped with a variable orifice regulator which maintains a constant air flow with variations in voltage from 90 to 125 volts and in pressure differential from 5 to 14 in. of water. This sampler should be calibrated weekly with a Seico or orifice meter (See Fig. 10) as well as serviced regularly (by CMR-7) on the preventive maintenance program.

The Hi-Volume Sampler, as indicated by the name, draws a large volume of air (30-70 cfm) and can be used for sampling very low concentrations of particulate matter. Such concentrations are encountered in atmospheric pollution studies and in populated areas, such as during tests which disperse radioactive dusts over great distances. This unit which is commercially available uses an Electrolux motor and fan and will operate with intermittent use, not to exceed 12 hr at a time, up to a total of 1500 hr before requiring service. Servicing consists principally of replacing brushes in the motor. After 3000 hr of use the armature commutator may require turning down.

An adaptor is provided for mounting the unit on a camera tripod (Fig. 11) for sampling at the breathing level. The flow rate varies from 30 cfm with glass fiber paper to 70 cfm with the fluted Type-S paper. The BM-2133 respirator pad as a filter permits sampling at 50 cfm. This paper is principally used for sampling for beta-gamma emitters since the thick paper has a high absorption factor for alpha rays. The sampler unit calibrated for air flow with a pitot tube or orifice meter is equipped with a flow meter covering the range from 10 to 70 cfm. The air flow varies with voltage and if the latter varies appreciably during the sampling period a record of voltage variations must be kept and necessary corrections made.

The 1-1/8 In. Diameter Sampler (see Fig. 12) consists of a small brass sampling head connected to a vacuum pump (usually a Gast pump). The Gast pump is equipped with a rotameter on which the flow rate is set from 5 to 30 liters per minute by adjusting a valve so the middle of the float is at the desired value. The rotameter must be calibrated at regular intervals with the spirometer (operated by H-5) because of the possibility of collecting dust and moisture in the flow-indicating tube or on the float. The calibration chart is usually attached to the pump. Whatman #41 is the most popular type of filter paper of this (1-1/8 in. diameter) size. Other types of filter paper include Whatman #2 and #4, a molecular or membrane filter, and a fine glass fiber filter paper. The molecular filter is used extensively at Los Alamos

because it is more efficient than any other type of filter tested and it can be examined directly with a microscope. This filter has made possible a statistical particle size analysis of collected dust by taking a series of pictures with the electron microscope. The last type of filter mentioned, the glass fiber filter paper, has a collecting efficiency equivalent to that of the H-70 and is particularly useful in stack sampling where high temperatures and high humidity are problems during collection.

The Modified Cascade Impactor (see Fig. 13) when attached to a vacuum pump samples at a rate of 14 liters per minute and separates the collected dust into five fractions for particle size analysis. It has been calibrated for several radioactive dusts, and when the density of the dust is known an individual calibration for each collecting stage can be readily calculated. The mass median diameter of the dust is determined by counting the activity on the four glass slides and the follow-up filter paper and plotting on log probability paper the accumulated percentage found on each stage. The Casella model of this sampler operates at 17-1/2 liters per minute.

The A.I.&S.I. Air Sampler, which can be run 24 hr per day, when connected to a Gast pump (equipped with a rotameter) has an adjustable flow rate of 5 to 30 liters per min but is usually operated at 20 liters per minute. The sample is collected on a continuous strip of Whatman #4 filter paper 1-1/2 in. wide and at Los Alamos is set to change the collecting area every hour. The strip of filter paper is automatically wound on a spool, marked, and cut into individual samples. These are then counted to determine the hourly concentration in the room which was sampled. This unit has been used successfully on tuballoy and or alloy dust. (A.I.&S.I. - American Iron and Steel Institute)

The MSA Samplair Pump is a small hand-operated device used to collect samples on a 1-1/2 in. diameter filter paper (Whatman #41, 1-1/8 in. diameter paper will work) at a sampling rate of 0.6 liter per stroke. It is used primarily for emergency evaluations of airborne contamination. A single stroke may be considered to be a spot sample but 30 strokes, suggested for field surveys after which the filter is checked with an alpha or beta-gamma survey meter, constitutes an integrated sample.

Evacuated Flasks of 1 liter capacity are generally used for radon or thoron gas and can be used for collecting spot samples of either the breathing zone or general room air. A radon gas counter located in the Health Research Laboratory is used for counting radon gas samples.

6-Volt Sampler - A combination of the 1-1/8 in. filter holder and a small 6-volt Gast pump has been used for sampling on trucks or wherever 110-volt power is not available. (This type of sampler is also used for field surveys.) These pumps will draw a maximum of approximately 15 liters per minute

through a 1-1/8 in. glass fiber paper (Fig. 14).

The ultimate in air sampling would be a unit operating continuously that samples the air, counts the collected dust, and records the count. Several types of such units have been built at Los Alamos and elsewhere but they are large and cumbersome and restricted in their applications.

Counting and Calculations

Counters for alpha or beta measurements have been adapted to count practically all samples, including the entire 4" x 9" Filter Queen sample, and are located in the count room in CMR Building (SM-29) and the Health Research Laboratory.

Any air filter sample will show an appreciable background due to naturally occurring radon, thoron and their daughters. The radon and radon daughters, whose longest half-life is only 30 min, may be considered as completely decayed six hr after completion of the sampling. The thoron and thoron daughters, whose longest half-life is 10.6 hr, will not completely decay before several days. Decay can be estimated, however, by taking two counts, one 6 hr and another 24 hr after sampling is completed.

Maximum permissible concentrations for air found in the Table of Isotopes are given in d/m/m³. To transform the c/m given by the counter to d/m, the efficiency* of the counter (E) must be known. For alpha, the counters at CMR Building are adjusted (by meter deflection) so the E is 50 per cent for plutonium standards. For beta-gamma counters, the E will vary from 0.1 to 35 per cent.

Example: A Filter Queen sampler operated from 2:00 P.M. to 5:00 P.M. at the normal rate of 4 cu ft per minute (cfm). The entire filter paper when counted on a counter with an efficiency of 4 per cent has an activity of 50 c/m.

Find: The concentration of airborne contamination in d/m/m³ of air.

Solution:

(a) Total d/m for the filter paper = $\frac{\text{c/m filter paper}}{\text{counter efficiency in per cent}}$

$$= \frac{50 \text{ c/m}}{4\%} = \frac{50 \times 100}{4} = 1250 \text{ d/m}$$

*See Glossary for definition

(b) Volume of air sampled

Time of sampling - 2:00 P.M. to 5:00 P.M. = 3 hr or 180 min

Rate of sampling = 4 cfm and

since 1 m³ = 35.3 cu ft

$$4 \text{ cfm} = \frac{4}{35.3} = 0.113 \text{ m}^3/\text{min}$$

Total volume of air sampled = 0.113 m³/min for 180 min = 20.6 m³

(c) Therefore $d/m/m^3 = \frac{1250 \text{ d/m}}{20.6 \text{ m}^3} = 61 \text{ d/m/m}^3$

Note: The final value is given to only two significant figures because of several inherent errors in the determination.

In the event it is impossible to count the entire filter paper, a portion of the paper may be counted. Assuming uniform distribution over the paper, it is only necessary to obtain an area correction factor which is the ratio of the total effective filtering area to the filtering area of the portion to be counted.

Example: The Filter Queen sampler uses a filter paper approximately 4" x 9", but the effective filtering area consists of 21 one-inch squares so that the effective filtering area is 21 sq in. and not 36 sq in. If a portion of the paper is to be counted, care should be taken so as to be able to measure the effective filtering area of the portion. In the case of the Filter Queen, a whole number of squares should be taken in order to simplify the area correction factor.

Assume that a Filter Queen filter was cut in order to count only two of the 1-in. squares. In this case, the count per minute for the two squares would be multiplied by the area correction factor of $21/2 = 10.5$ in order to obtain the count per minute value for the entire filter paper.

Collecting Efficiencies of Filter Media in Per Cent*

	Particle Diameter (μ)					
	below 0.4	0.4-0.6	0.6-0.8	0.8-1.0	1.0-2.0	above 2.0
Whatman #41	23	28	64	74	70	100
Whatman #4	23	32	38	79	74	100
MSA Type "S"	48	47	77	92	94	100
H-70 (18 mil)	99.3					
CWS-6	99.9					
Glass Fiber	99.9					
Millipore	99.9					

*Ref: Smith and Surprenant (A.D. Little, Inc.), 1953

Characteristics of Filter Papers

	<u>Relative Alpha Count Absorption*</u>	<u>Special Advantages</u>
Whatman #41	55	Availability, low resistance, ashless
Whatman #4		Availability, low resistance
MSA Type S		Low resistance
BM-2133		Low resistance, easily counted
H-70	40	High efficiency, long record of use
CWS-6		High efficiency
Glass Fiber	20	High efficiency, good for wet or hot air
Millipore		Can be examined in microscope, low alpha absorption

*Ref: AECU-2853

Figure 10. Filter Queen Air Samplers

The sampler on the left is being calibrated for air flow rate of 4 cu ft per minute by using an orifice-type flowmeter. On the right the calibration is being made with a Seico meter.

Figure 11. Hi-Volume Sampler

This is a commercially available unit which samples at a high flow rate, hence warrants the name of high-volume sampler. Note the fluted paper used because of its lower pressure drop.

Figure 12. The 1-1/8 In. Sampling Head with a Gast Pump

A second head is disassembled in the right foreground. Note the rotameter mounted on the Gast pump with the single flow adjustment valve at the top.

Figure 13. Modified Cascade Impactor

Note the decreasing width of deposit from the stages 1 through 4 (top to bottom). Number 1 collects large particles and No. 4 collects very small particles. The fifth and final stage uses a 1-1/8 in. filter paper (not shown) and is collected in the cap pictured at the very top.

Figure 14. The 6-volt Gast Pump and Filter Head
This small unit is conveniently operated from a car battery.

CONVERSION FACTORS

Multiply	By	To Obtain
acres	43,560	square feet (ft ²)
Angstrom units (Å)	10 ⁻⁸	centimeters (cm)
bars	10 ⁶	dynes per square centimeter
centimeters (cm)	10	millimeters (mm)
coulombs	6.3 x 10 ¹⁸	number of electrons
cubic centimeters (cc)	1	milliliters (ml)
cubic feet (cu ft)	0.06102	cubic inches (in. ³)
	28.317	liters (l)
	7.481	gallons (gal)
	0.028317	cubic meters (m ³)
cubic meters (m ³)	35.31	cubic feet (cu ft)
curies (c)	10 ⁶	microcuries (μc)
	3.7 x 10 ¹⁰	disintegrations per second (d/s)
	2.22 x 10 ¹²	disintegrations per minute (d/m)
dynes per square centimeter	1.0198 x 10 ⁻³	grams per square centimeter (gm/cm ²)
electron volts (ev)	1.60203 x 10 ⁻¹²	ergs
ergs	1	dyne centimeters
	1 x 10 ⁻⁷	joules
	9.4805	British thermal units (Btu)
	6.24 x 10 ⁵	million electron volts (Mev)
Faradays	96,500	coulombs
grams (gm)	0.03527	ounces (oz)
inches (in.)	2.54001	centimeters (cm)
joules (absolute)	2.778 x 10 ⁻⁷	kilowatt hours
	3.725 x 10 ⁻⁷	horsepower hours
kilograms (kg)	2.20462	pounds (lbs)
liters (l)	1000.027	cubic centimeters (cc)
	33.8147	fluid ounces (fl oz)
	1.0567	quarts (qt)
meters (m)	39.37	inches (in.)
	3.28083	feet (ft)
microcuries (μc)	3.7 x 10 ⁴	disintegrations per second (d/s)
microcuries per cubic centimeter (μc/cc)	2.22 x 10 ¹²	disintegrations per minute per cubic meter (d/m/m ³)
microns (μ)	10 ⁻⁶	meters (m)
	10 ⁻⁴	centimeters (cm)
mils	10 ⁻³	inches (in.)
ounces (oz)	28.34953	grams (gm)

CONVERSION FACTORS (cont'd)

Multiply	By	To Obtain
pounds (lb)	16	ounces (oz)
	453.592	grams (gm)
pressure in atmos-	1.0133	bars
pheres (atm)	14.696	pounds per square inch (lbs/in. ²)
	1033.2	grams per square centi- meter (gm/cm ²)
	760	millimeters of mercury (mm Hg)
rads (units of absorbed dose of ionizing radiation)	100	ergs per gram of irradi- ated material (ergs/gm)
roentgens (r)	1	electrostatic unit of charge per cubic centi- meter of air (esu/cc)
(under standard conditions: 0°C and 760 mm Hg)	83.8	ergs per gram of air (ergs/gm)
	6.77 x 10 ⁴	million electron volts per cubic centimeter of air (Mev/cc)
	2.083 x 10 ⁹	ion pairs per cubic centimeter of air (ion pairs/cc)
roentgens equivalent physical (rep)	93	ergs per gram of tissue (ergs/gm)
square centimeters (cm ²)	0.155	square inches (in. ²)
square feet (ft ²)	929.03	square centimeters (cm ²)
square inches (in. ²)	6.45163	square centimeters (cm ²)
square meters (m ²)	10.76387	square feet (ft ²)
square yards (yd ²)	0.83613	square meters (m ²)
statute miles	5280	feet (ft)
	1760	yards (yd)
	1.60935	kilometers (km)
	0.86836	nautical miles

CONSTANTS OF INTEREST

alpha particle mass - 6.6442×10^{-24} gm
 atomic mass unit (a.m.u.) - 1.66035×10^{-24} gm or 931.04 Mev
 Avogadro's number (N - molecules in 1 mole) - 6.0228×10^{23}
 barn (σ) - 10^{-24} cm²
 Boltzmann's constant (k) - 1.38032×10^{-16} erg/degree

circular mil - area of a circle 1 mil in diameter
 day (mean solar) - 1440 minutes or 86,400 seconds
 electronic charge (e) - 1.60203×10^{-20} absolute electro-
 magnetic unit (e.m.u.) or 4.8024×10^{-10} electro-static
 unit (e.s.u.)
 electron mass - 9.1066×10^{-28} gm or 0.00054862 m.u. or
 0.51079 Mev
 electron radius - 2.807×10^{-13} cm

frequency associated with 1 ev - 2.41856×10^{14} cycles/sec
 gravity (g) - 32.174 ft/sec² or 980.665 cm/sec²
 kilogram - weight of 1 liter of water at 4°C and 760 mm Hg
 light year - 5.9×10^{12} miles
 month (work period) - 4.2 work weeks or 168 hours

neutron mass - 1.67517×10^{-24} gm or 1.008937 m.u.
 pi (π) - 3.1415926535
 Planck's constant (h) - 6.624×10^{-27} erg sec
 proton mass - 1.67248×10^{-24} gm or 1.007581 m.u.
 radian - 57.3 degrees

universal gas constant (R) - 8.31436×10^7 ergs/degree/mole
 velocity of light (c) - 2.99776×10^{10} cm/sec
 velocity of sound in air (0°C and 760 mm Hg) - 330.6 meters/
 sec
 volume of 1 mole of ideal gas (0°C and 760 mm Hg) - 22.414×10^3 cc
 wave length associated with 1 ev - 12395×10^{-8} cm
 work week - 40 hours or 144,000 seconds

GLOSSARY

Reference: Radiological Health Handbook, Environmental Health Center, 1954

ABSORPTION: The process by which the number of particles or quanta in a beam of radiation is reduced as the particles pass through some medium. The absorbed radiation may be transformed into mass, other radiation, or energy by interaction with the electrons or nuclei of the atoms upon which it impinges.

ACUTE EXPOSURE: Term used to denote radiation exposure of short duration.

ADSORPTION: The adhesion of one substance to the surface of another.

AIR DOSE: X-ray or gamma-ray dose expressed in roentgens delivered at a point in free air. In radiologic practice it consists only of the radiation of the primary beam, and that scattered from surrounding air.

ALPHA PARTICLE: A helium nucleus, consisting of two protons and two neutrons, with a double positive charge. Its mass is 4.002764 a.m.u. (atomic mass units).

ANEMIA: Deficiency of blood as a whole, or deficiency in the number of the red corpuscles or of the hemoglobin.

ASSOCIATED CORPUSCULAR EMISSION: The full complement of secondary charged particles (usually limited to electrons) associated with an x-ray or gamma-ray beam in its passage through air. The full complement of electrons is obtained after the radiation has traversed sufficient air to bring about equilibrium between the primary photons and secondary electrons. Electronic equilibrium with the secondary photons is intentionally excluded.

ATOM: Smallest particle of an element which is capable of entering into a chemical reaction.

ATOMIC NUMBER: Number of protons in the nucleus, hence the number of positive charges on the nucleus. Also, the number of electrons outside the nucleus of a neutral atom. Symbol: Z.

ATOMIC WEIGHT: Relative weight of the atom of an element compared with the weight of one atom of oxygen taken as 16; hence, a multiple of 1/16 the weight of an atom of oxygen. Symbol: A.

BACKGROUND COUNTING RATE: Rate of radiation counting due to cosmic rays, to radioactive materials in the vicinity, and to a slight radioactive contamination of the materials

of which the instrument is made.

BACKSCATTERING: The process of scattering or reflecting into the sensitive volume of a measuring instrument radioactive radiations originally having no positive component of motion in that direction. It is dependent, therefore, on the nature of the mounting material, the nature of the sample, the type and energy of the radiations, and the particular geometrical arrangement.

BETA PARTICLE: Charged particle emitted from the nucleus of an atom and having a mass and charge equal in magnitude to those of the electron.

BETATRON: A device for accelerating electrons by means of magnetic induction.

BONE SEEKER: Any compound or ion which migrates in the body preferentially into bone.

BREMSSTRAHLUNG: Secondary photon radiation produced by deceleration of charged particles passing through matter. Conversion of part of the kinetic energy of an electron into electromagnetic radiation in the force field of an atomic nucleus.

CALIBRATION: Determination of variation from standard, or accuracy, of a measuring instrument, to ascertain necessary correction factors.

CARRIER: 1. A quantity of an element which may be mixed with radioactive isotopes of that element giving a ponderable quantity to facilitate chemical operations. 2. Substance in ponderable amount which when associated with a trace of another substance will carry the trace with it through a chemical or physical process, especially a precipitation process. If the added substance is a different element from the trace, the carrier is called a non-isotopic carrier.

CATARACT: A clouding of the crystalline lens of the eye, which obstructs the passage of light.

CHAIN REACTION: Any chemical or nuclear process in which some of the products of the process or energy released by the process are instrumental in the continuation or magnification of the process.

CHARACTERISTIC (DISCRETE) RADIATION: Radiation originating from an atom following removal of an electron or excitation of the nucleus. The wavelength of the emitted radiation is specific depending only on the element concerned and the particular energy levels involved.

CHRONIC EXPOSURE: Term used to denote radiation exposure of long duration, by fractionation or protraction.

CLOUD CHAMBER: A device for observing the paths of ionizing particles, based on the principle that supersaturated vapor condenses more readily on ions than on neutral molecules.

COINCIDENCE: The occurrence of ionizing events in one or more detectors simultaneously or within an assignable time interval, as a result of the passage of a single particle or of several generically related particles.

COLLIMATOR: A device for confining the elements of a beam within an assigned solid angle.

COLLISION, ELASTIC: Collision in which kinetic energy and momentum of each colliding system are conserved.

COLLISION, INELASTIC: Collision in which at least one system gains internal excitation energy at the expense of the total kinetic energy of their center-of-gravity motion.

COMPTON EFFECT: An absorption effect observed for x- and gamma radiation in which the incident photon interacts with an orbital electron of the absorber atom to produce a recoil electron and a photon of energy less than the incident photon.

CONDENSER R-METER: An instrument consisting of an "air-wall" ionization chamber together with auxiliary equipment for charging and measuring its voltage; it is used as an integrating instrument for measuring the quantity of x- or gamma radiation in roentgens.

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

CONVERTER: A nuclear reactor that converts fertile atoms into fuel by neutron capture. Two different ways of using the words converter and breeder are in use at present:
1. A converter is a reactor that uses one kind of fuel and produces another (e.g., consumes U-235 and produces some Pu from U-238). 2. A breeder is a converter that produces more fissionable atoms than it consumes.

COSMIC RAYS: Radiation both particulate and electromagnetic which originates in outer space.

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

COUNTING ERROR: Specifies the reliability of a measurement yielding a certain number of counts x by $\pm\sqrt{x}$. For x greater than 100, $\sqrt{x}$ is the standard deviation (σ) or the number usually given to specify that part of the uncertainty of a measurement arising from the statistical fluctuation inherent in the rate of decay. The probability that the error is not greater than 1σ is 33 per cent, 2σ is 5 per cent and 3σ is 0.2 per cent.

COUNTING RATE METER: A device which gives a continuous indication of the average rate of ionizing events.

CRITICAL SIZE: For a fissionable material, the minimum amount of a material which will support a chain reaction.

CUMULATIVE DOSE (Radiation): The total dose resulting from repeated exposures to radiation of the same region, or of the whole body.

CYCLOTRON: A device for accelerating charged particles to high energies by means of an alternating electric field between electrodes placed in a constant magnetic field.

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

DECAY CONSTANT: The fraction of the number of atoms of a radioactive isotope which decay in unit time. Symbol: λ

DENSITOMETER: Instrument utilizing the photoelectric principle to determine the degree of darkening of developed photographic film.

DENSITY: (Photographic): Logarithm of opacity of exposed and processed film. Opacity is the reciprocal of transmission; transmission is the ratio of transmitted to incident intensity. Density is used to denote the degree of darkening of photographic film.

DEPTH DOSE: The radiation dose delivered at a particular depth beneath the surface of the body. It is usually expressed as a percentage of surface dose or as a percentage of air dose. .

DEUTERIUM: A heavy isotope of hydrogen having one proton and one neutron in the nucleus. D or ${}_1\text{H}^2$.

DEUTERON: Nucleus of a deuterium atom, containing one proton and one neutron.

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

DOSE (DOSAGE): According to current usage, the radiation delivered to a specified area or volume or to the whole body. Units for dose specification are roentgens for x- or gamma rays, reps or equivalent roentgens for beta rays. The subject of dose units for particulate radiation and for very high energy x-rays has not been settled. In radiology the dose may be specified in air, on the skin, or at some depth beneath the surface; no statement of dose is complete without specification of location. The entire question of radiation dosage units is under consideration by the International Congress of Radiology, and it is expected that new units based on the energy absorbed in tissue will be adopted.

DOSE, FRACTIONATION: A method of administration of radiation in which relatively small doses are given daily or at longer intervals.

DOSE RATE (DOSAGE RATE): Radiation dose delivered per unit time.

DOSIMETER: Instrument used to detect and measure an accumulated dosage of radiation; in common usage it is a pencil-size ionization chamber with built-in self-reading electrometer; used for personnel monitoring.

EFFECTIVE ATOMIC NUMBER: A number calculated from the composition and atomic numbers of a compound or mixture. An element of this atomic number would interact with photons in the same way as the compound or mixture.

EFFICIENCY (Counters): A measure of the probability that a count will be recorded when radiation is incident on a detector. Usage varies considerably. Window absorption, sensitive volume, energy dependence, geometry, backscatter, etc., are included in most cases since the values are arrived at by empirical means.

ELECTROMETER: Electrostatic instrument for measuring the difference in potential between two points. Used to measure change of electric potential of charged electrodes resulting from ionization produced by radiation.

ELECTRON: Negatively charged particle which is a constituent of every neutral atom. Unit of negative electricity equal to 4.80×10^{-10} electrostatic unit. Its mass is 0.000548 mass unit.

ELECTRON CAPTURE: A mode of radioactive decay involving the capture of an orbital electron by its nucleus. Capture from a particular electron shell is designated as K-electron capture, L-electron capture, etc.

ELEMENT: Pure substance consisting of atoms of the same atomic number, which cannot be decomposed by ordinary chemical means.

EMULSION, NUCLEAR: A photographic emulsion specially designed to permit observation of the individual tracks of ionizing particles.

ENERGY DEPENDENCE: The characteristic response (of a radiation detector) to a given range of radiation energies (or wave lengths) as compared with the response of a standard open-air chamber.

ENRICHED MATERIAL: 1. Material in which the relative amount of one or more isotopes of a constituent has been increased.
2. Uranium in which the abundance of the U-235 isotope is increased above normal.

EPILATION (DEPILATION): The temporary or permanent removal of hair.

ERYTHEMA: An abnormal redness of the skin, due to distension of the capillaries with blood. It can be caused by many different agents, e.g., heat, certain drugs, ultraviolet rays, ionizing radiation.

EXCRETION: The discharge of waste materials formed in metabolism.

EXTRAPOLATION IONIZATION CHAMBER: An ionization chamber with electrodes whose spacing can be adjusted and accurately determined to permit extrapolation of its reading to zero chamber volume.

EXTREMITIES: The hands, forearms, and (with restrictions) the head and feet, are considered to be extremities. The permissible exposure of these areas is greater chiefly because they include less blood-forming material and have smaller volumes for energy absorption than other parts of the body.

FILM BADGE: A packet of photographic film used for approximate measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or three films of differing sensitivity, and it may contain a filter which shields part of the film from certain types of radiation.

FISSION PRODUCTS: Elements or compounds resulting from fission.

FLUORESCENCE: The emission of radiation of particular wavelengths by a substance as a result of absorption of radiation of shorter wavelength. This emission occurs essentially only during the irradiation.

FLUOROSCOPE: A fluorescent screen, suitably mounted with respect to an x-ray tube for ease of observation and protection, used for indirect visualization by means of x-rays of internal

organs in the body or internal structures in apparatus or in masses of metal.

FREE AIR IONIZATION CHAMBER: An ionization chamber in which a delimited beam of radiation passes between the electrodes without striking them or other internal parts of the equipment. The electric field is maintained perpendicular to the electrodes in the collecting region; as a result the ionized volume can be accurately determined from the dimensions of the collecting electrode and the limiting diaphragm. This is the basic standard instrument for x-ray dosimetry at least within the range from 5 to 400 kv.

FREQUENCY: Number of cycles, revolutions, or vibrations completed in a unit of time.

GAMMA RAY: Short wavelength electromagnetic radiation of nuclear origin with a range of wave lengths from 10^{-9} to 10^{-12} cm, emitted from the nucleus.

GEIGER-MUELLER (G-M) COUNTER: Highly sensitive gas-filled radiation-measuring device which operates at voltages in the region of avalanche ionization.

GENETIC EFFECT OF RADIATION: Inheritable changes, chiefly mutations, produced by the absorption of ionizing radiations. On the basis of present knowledge these effects are purely additive, and there is no recovery.

GEOMETRY FACTOR: The fraction of the total solid angle about the source of radiation that is subtended by the face of the sensitive volume of a detector.

GRENZ RAYS: X-rays produced at voltages of 5 to 20 kv.

HALF-LIFE, RADIOACTIVE: Time required for a radioactive substance to lose 50 per cent of its activity by decay.

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

HEALTH PHYSICS: A term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.

HETEROGENEOUS REACTOR: A nuclear reactor in which the fissionable material and moderator are arranged as discrete bodies (usually according to a regular pattern) of such dimensions that a nonhomogeneous medium is presented to the neutrons.

HOMOGENEOUS REACTOR: A nuclear reactor in which the fissionable material and the moderator (if used) are combined in a mixture such that an effectively homogeneous medium is

presented to the neutrons. Such a mixture is represented either by a solution of fuel in the moderator or by discrete particles having dimensions small in comparison with the neutron mean free path.

IMPLANT (Radiology): Radioactive material in a suitable container to be embedded in a tissue for therapeutic purposes. It may be permanent (seed) or temporary (needle).

INDUCED RADIOACTIVITY: That activity produced in a substance after bombardment with neutrons or other particles.

INTEGRAL DOSE (VOLUME DOSE): A measure of the total energy absorbed by a patient or any object during exposure to radiation. According to British usage the integral dose of x- or gamma rays is expressed in gram-roentgens.

INTENSIFYING SCREEN: Sheet of cardboard or other substance coated with fluorescent material, placed in contact with the film in radiography. The x- or gamma rays excite the fluorescent substance and the light thus emitted adds to the radiation effect on the film and produces an image of greater density for a given exposure. Sheets of thin lead may be used for the same purpose in industrial radiography with very high energy radiation. In this case the increased effect is due largely to secondary electrons and x-rays emitted by the lead.

INTENSITY (Radiology): Amount of energy per unit time passing through a unit area perpendicular to the line of propagation at the point in question. Often this term is used incorrectly in the sense of dose rate.

INTERNAL CONVERSION: A mode of radioactive decay in which the gamma rays from excited nuclei cause the ejection of orbital electrons from the atom. The ratio of the number of internal conversion electrons to the number of gamma quanta emitted in the de-excitation of the nucleus is called the "conversion ratio."

INTERNAL RADIATION HAZARD: The danger to an individual from ionizing radiations originating within his body, as from radium atoms deposited in the bones.

ION: Atomic particle, atom, or chemical radical (group of chemically combined atoms) bearing an electrical charge, either negative or positive.

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

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

ISODOSE CHART: Chart showing the distribution of radiation in a medium by means of lines or surfaces drawn through points receiving equal doses. Isodose charts have been determined for beams of x-rays traversing the body, for radium applicators used for intracavitary or interstitial therapy, and for working areas where x-rays or radioactive isotopes are employed.

ISOTOPE: -One of several different nuclides having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons, and hence in the mass number or in energy content (isomers). Almost identical chemical properties exist between isotopes.

K-CAPTURE: A colloquialism for K-electron capture. Also, loosely used to designate any orbital electron capture process.

KELOID: Excessive scar formation following irradiation or other forms of skin injury.

LEAD EQUIVALENT: The thickness of lead affording the same reduction in radiation dose rate under specified conditions as the material in question.

LESION: Any hurt, wound, or local degeneration.

LIGHT SENSITIVE: Responds to light. Glass Geiger-Mueller tubes are more subject to this undesirable feature than are metal tubes.

LINEAR ABSORPTION COEFFICIENT: A factor expressing the fraction of a beam of radiation absorbed in unit thickness of material. In the expression $I = I_0 e^{-\mu x}$, I_0 is the initial intensity, I the intensity after passage through a thickness of material x , μ is the linear absorption coefficient.

LINEAR ACCELERATOR: A device for accelerating particles employing alternate electrodes and gaps arranged in a straight line, so proportioned that when their potentials are varied in the proper amplitude and frequency, particles passing through them receive successive increments of energy.

MASS ABSORPTION COEFFICIENT: The linear absorption coefficient per cm divided by the density of the absorber in grams per cc. It is frequently expressed as μ/ρ , where μ is the linear absorption coefficient and ρ the absorber density.

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

MEAN FREE PATH: Average distance a particle travels between collisions.

MEDIAN LETHAL DOSE (MLD): Dose of radiation required to kill, within a specified period, 50 per cent of the individuals in a large group of animals or organisms.

MESON: Short-lived particle carrying a positive or negative charge or no charge and having a variable mass in multiples of the mass of the electron. Also called MESOTRON.

METABOLISM: The sum of all the physical and chemical processes by which living organized substance is produced and maintained and by which energy is made available for the uses of the organism.

METASTABLE STATE: An excited state of a nucleus which returns to its ground state by the emission of a gamma ray over a measurable half life.

METASTASIS: The transfer in the body of malignant neoplastic cells from the original or parent site to a more distant one.

MODERATOR: Material used in a nuclear reactor to moderate, i.e., slow down, neutrons from the high energies at which they are released.

MOLECULE: Ultimate unit quantity of a compound which can exist by itself and retain all the properties of the original substance.

MONITORING: Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region, as a safety measure for purposes of health protection. Area Monitoring: Routine monitoring of the level of radiation or of radioactive contamination of any particular area, building, room or equipment. Usage in some laboratories or operations distinguishes between routine monitoring and survey activities. Personnel Monitoring: Monitoring any part of an individual, his breath, or excretions, or any part of his clothing. (See also RADIOLOGICAL SURVEY)

MONOCHROMATIC RADIATION: Electromagnetic radiation of a single wavelength, or in which all the photons have the same energy.

MONOENERGETIC RADIATION: Particulate radiation of a given type (alpha, beta, neutron, etc.) in which all particles have the same energy.

NEUTRON: Elementary nuclear particles with a mass approximately the same as that of a hydrogen atom and electrically neutral; its mass is 1.00893 mass units.

NUCLEAR FISSION: A nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.

NUCLEAR FUSION: Act of coalescing two or more atomic nuclei.

NUCLEAR REACTOR: An apparatus in which nuclear fission may be sustained in a self-supporting chain reaction. The usual components of a nuclear reactor are as follows: 1) fissionable material (fuel) such as uranium or plutonium, 2) moderating material (unless it is a fast reactor), 3) usually a reflector to conserve escaping neutrons, 4) provision for heat removal, and 5) measuring and control elements. The terms "pile" and "reactor" have been used interchangeably.

NUCLEON: Common name for a constituent particle of the nucleus. At present applied to protons and neutrons, but will include any other particle found to exist in the nucleus.

NUCLEUS (Of a cell): A definitely delineated body within the cell, containing the chromosomes.

NUCLEUS (Of an atom): That part of an atom in which most of the mass and the total positive electric charge are concentrated.

PAIR PRODUCTION: An absorption process for x- and gamma radiation in which the incident photon is annihilated in the vicinity of the nucleus of the absorbing atom, with subsequent production of an electron and positron pair. This reaction does not occur for incident radiation energies of less than 1.02 Mev.

PERMEABLE: Affording passage or penetration.

PERMISSIBLE DOSE: The amount of radiation which may be received by an individual within a specified period with expectation of no harmful result to himself. For long-continued x- or gamma ray exposure of the whole body it is 0.3 r per week measured in air.

PHANTOM (Radiology): A volume of material behaving in essentially the same manner as tissue, with respect to the radiation in question, used to simulate a portion of the human body, and into which ionization chambers can be placed. Measurements made in a phantom permit the determination of the radiation dose delivered to the skin and points within the body. Materials commonly used are water, Masonite pressedwood (unit density), beeswax.

PHOSPHORESCENCE: Emission of radiation by a substance as a result of previous absorption of radiation of shorter wavelength. In contrast to fluorescence, the emission may continue for a considerable time after cessation of the exciting irradiation.

PHOTOELECTRIC EFFECT: A process by which a photon ejects an electron from an atom. All the energy of the photon is absorbed in ejecting the electron and in imparting kinetic energy to it.

PHOTOGRAPHIC DOSIMETRY: Determination of the accumulative dosage of radiation by use of photographic film.

PHOTON: A quantity of electromagnetic energy whose value in ergs is the product of its frequency in cycles per sec and Planck's constant. The equation is: $E = h\nu$.

PITCHBLEND: A mineral consisting largely of uranium oxides, important as a source of uranium and radium.

PLATEAU: As applied to radiation detector chambers, the level portion of the counting rate-voltage curve where changes in operating voltage introduce minimum changes in the counting rate.

POSITRON: Particle equal in mass to the electron and having an equal but opposite charge. Its mass is 0.000548 mass units.

PROMPT GAMMA: Gamma radiation emitted at the time of fission of a nucleus.

PROPORTIONAL COUNTER: Gas-filled radiation detection tube in which the pulse produced is proportional to the number of ions formed in the gas by the primary ionizing particle.

PROTON: Elementary nuclear particle with a positive electric charge equal numerically to the charge of the electron and a mass of 1.007575 mass units.

QUANTUM: Synonymous with PHOTON.

PULSE HEIGHT SELECTOR: A circuit designed to select and pass voltage pulses in a certain range of amplitudes.

QUENCHING: The process of inhibiting continuous or multiple discharge in a counter tube which uses gas amplification.

RADIATION SICKNESS: In radiation therapy: A self-limited syndrome characterized by nausea, vomiting, diarrhea, and psychic depression, following exposure to appreciable doses of ionizing radiation, particularly to the abdominal region. Its mechanism is unknown and there is no satisfactory remedy. It usually comes on a few hours after a treatment and may subside within a day. It may be sufficiently severe to necessitate interrupting the treatment series, or to incapacitate the patient. In atomic bomb disaster: A syndrome following intense acute exposure to ionizing radiations. A few hours after exposure nausea and vomiting appear, last a few hours, and then subside for a variable interval. After this quiescent period, a recurrence of nausea and vomiting is accompanied by mucous or bloody diarrhea, purpura, epilation, and agranulocytic infections. The illness may vary in severity and may go on to death, or partial or apparently complete recovery may ensue. The more intense

the early symptoms and the shorter the period of remission, the more serious the final outcome.

RADIOACTIVE EQUILIBRIUM: Among the members of a radioactive series, the state which prevails when the ratios between the amounts of successive members of the series remain constant.

Secular equilibrium: If a parent element has a very much longer half-life than the succeeding ones, so that there is no appreciable change in its amount in the time interval required for the later products to attain equilibrium, then, after the condition is reached, equal numbers of atoms of all members of the series disintegrate in unit time. This condition is never actually attained, but is essentially established in such a case as radium and its series through Radium C. The half-life of radium is 1600 years, of radon, 3.82 days, and of each of the subsequent members, a few minutes. After about a month essentially the equilibrium amount of radon is present, and then for a long time all members of the series disintegrate the same number of atoms per unit time. **Transient equilibrium:** If the half-life of the parent is sufficiently short, so that the quantity present decreases appreciably during the period under consideration, but is still longer than that of successive members of the series, a stage of equilibrium will be reached, after which all members of the series decrease in amount exponentially with the period of the parent. An example of this is radon, with a half-life of 3.82 days, and the successive members of the series through Radium C.

RADIOACTIVITY: Process whereby certain nuclides undergo spontaneous disintegration in which energy is liberated, generally resulting in the formation of new nuclides. The process is accompanied by the emission of one or more types of radiation, such as alpha particles, beta particles, and gamma radiation.

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

RADIOLOGY: The medical science of radioactive substances, x-rays, and other ionizing radiations, and the application of the principles of this science to diagnosis and treatment of disease.

RECOMBINATION: The return of an ionized atom or molecule to the neutral state.

RECOVERY (Radiology): The return toward normal of a particular cell, tissue, or organism, after radiation injury.

RECOVERY RATE: The rate at which recovery takes place following radiation injury. It may proceed at different rates for different tissues. Differential recovery rate: Among tissues recovering at different rates those having slower rates will ultimately suffer greater damage from a series of successive irradiations. This differential effect is taken advantage of in fractionated radiation therapy if the neoplastic tissues have a slower recovery rate than surrounding normal structures.

REGENERATIVE PROCESS: The process by which damaged cells are replaced by new ones of the same type.

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE): The ratio of gamma-ray or x-ray dose to the dose that is required to produce the same biological effect by the radiation in question.

RETICULOENDOTHELIAL SYSTEM: Networks of phagocytic cells found mainly in the spleen, lymph glands, liver, lungs, and bone marrow.

ROENTGEN: The quantity of x- or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign.

ROENTGEN EQUIVALENT PHYSICAL (REP): The amount of ionizing radiation which will result in the absorption in tissue of 93 ergs per gram.

SCALER: An electronic device that produces an output voltage pulse whenever a prescribed number of input pulses have been received.

SCATTERING: Change of direction of subatomic particle or photon as a result of a collision or interaction.

SCINTILLATION COUNTER: The combination of phosphor, photomultiplier tube and associated circuits for counting light emissions produced in the phosphors.

SECONDARY RADIATION: Radiation originating as the result of absorption of other radiation in matter. It may be either electro-magnetic or particulate in nature.

SELF ABSORPTION: Absorption of radiation emitted by radioactive atoms by the matter in which the atoms are located; in particular, the absorption of radiation within sample being assayed.

SENSITIVE VOLUME: That portion of a counter tube or ionization chamber which responds to a specific radiation.

SIGMOID CURVE: S-shaped curve, often characteristic of a dose-effect curve in radiobiological studies.

SKIN DOSE (Radiation therapy): Dose at center of irradiation field on skin. It is the sum of the air dose and back scatter.

SLUG: A bar-shaped piece of material prepared especially for insertion in a nuclear reactor. The term often refers to the fuel unit of a natural uranium-graphite reactor.

SPECIFIC ACTIVITY, ISOTOPE: Total radioactivity of a given isotope per gram of the radioactive isotope.

SPECIFIC IONIZATION: Number of ion pairs per unit length of path of the ionization particle in a medium, e.g., per centimeter of air or per micron of tissue.

SPURIOUS COUNT: Count caused by any agency other than the radiation which it is desired to detect.

STABLE ISOTOPE: An isotope of an element which is not radioactive.

STERILITY (Biological): Temporary or permanent inability to reproduce.

SYNCHRO-CYCLOTRON: A cyclotron in which the radio frequency of the electric field is frequency-modulated to permit acceleration of particles to relativistic energies.

SYNCHROTRON: A device for accelerating particles, ordinarily electrons, in a circular orbit in an increasing magnetic field applied in synchronism with the orbital motion.

TARGET THEORY (HIT THEORY): Theory explaining some biologic effects of radiation on basis of ionization occurring in a very small sensitive region within the cell. One, two, or more "hits", i.e., ionizing events within the sensitive volume, may be necessary to bring about the effect.

TEMPERATURE SENSITIVE: Responds to changes or extremes in temperature. The meters mentioned as being temperature sensitive will go completely off scale or change calibration to a great extent when operated at temperatures below freezing. It is said the desert sun will ruin a G-M tube in a few hours with temperatures above 100°F. For these reasons, extreme temperatures, high or low, must be avoided in the use of most G-M tube instruments.

THIMBLE IONIZATION CHAMBER: A small cylindrical or spherical ionization chamber, usually with walls of organic material.

THRESHOLD DOSE: The minimum dose that will produce a detectable degree of any given effect.

TISSUE DOSE: Dose received by a tissue in the region of interest. In the case of x-rays and gamma rays, tissue doses are expressed in roentgens. At the present time there is no generally accepted unit of tissue dose for other ionizing radiations. In radiobiological studies it is customary to think of the tissue dose in terms of the energy absorbed per gram of tissue. Several units related to the roentgen have been suggested, such as the rep.

TISSUE EQUIVALENT IONIZATION CHAMBER: Ionization chamber in which the material of the walls, electrode, and gas are so selected as to produce ionization essentially equivalent to that characteristic of the tissue under consideration. In some cases it is sufficient to have only tissue equivalent walls, and the gas may be air, provided the air volume is negligibly small. The essential requisite in this case is that the contribution to the ionization in the air made by ionizing particles originating in the air is negligible compared to that produced by ionizing particles characteristic of the wall material.

TOLERANCE DOSE: A term based on the assumption that an individual can receive such a dose of radiation without any harmful effect. A more acceptable term is permissible dose.

TRACK: Visual manifestation of the path of an ionizing particle in a cloud chamber or nuclear emulsion.

VAN DE GRAAFF GENERATOR: An electrostatic generator which employs a system of conveyor belt and spray points to charge an insulated electrode to a high potential.

WAVE LENGTH: Distance between any two similar points of two consecutive waves; for electromagnetic radiation the wave length is equal to the velocity of light (c) divided by the frequency of the wave (ν).

X-RAYS: Penetrating electromagnetic radiations having wavelengths very much shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays, and to those originating in the extranuclear part of the atom as x-rays. These rays are sometimes called Roentgen rays after their discoverer, W. C. Roentgen.

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APPENDIX A

LABORATORY ORGANIZATION

Director
Norris E. Bradbury

Assistant to the Director
Jane H. Hall

<u>Ass't Director</u> <u>for</u> <u>Administration</u> Henry R. Hoyt	<u>Ass't Director</u> <u>for Classification</u> <u>and Security</u> Ralph Carlisle Smith	<u>Ass't Director</u> <u>for</u> <u>Engineering</u> John Bolton	<u>Ass't Director</u> <u>for Scientific</u> <u>Personnel</u> William H. Crew	<u>Ass't Director</u> <u>for</u> <u>Production</u> Max F. Roy	<u>Special</u> <u>Assignments</u> Marshall Holloway
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<u>Divisions</u>			<u>Departments</u>	
<u>CMR Division</u> <u>(Chemical Metallurgical</u> <u>Research)</u> Eric R. Jette	<u>H Division</u> <u>(Health)</u> Thomas L. Shipman	<u>P Division</u> <u>(Physics)</u> J.M.B. Kellogg	<u>Accounting</u> A. D. Richardson	<u>Shops</u> Gus H. Schultz
<u>D Division</u> <u>(Documentary)</u> Ralph Carlisle Smith	<u>J Division</u> <u>(Weapons Field Testing)</u> Alvin C. Graves	<u>T Division</u> <u>(Theoretical)</u> Carson Mark	<u>Business Office</u> A. E. Dhyre	<u>Supply and Property</u> Harry S. Allen
<u>GMX Division</u> <u>(Explosives)</u> Duncan P. MacDougall	<u>K Division</u> <u>(Special Projects)</u> Darol K. Froman	<u>W Division</u> <u>(Weapons)</u> Raemer E. Schreiber	<u>Engineering</u> John Bolton	<u>Wage and Salary</u> J. A. Woodward
			<u>Personnel</u> John V. Young	

APPENDIX B

H-DIVISION ORGANIZATION

Thomas L. Shipman, M.D., Leader
Harry O. Whipple, M.D., Alternate Leader
Wright H. Langham, Assistant Leader for Bio-Medical Research
Thomas N. White, Assistant Leader for Radiological Safety
Lynn Anderson, Division Secretary

Group H-1 (Monitoring)
Dean D. Meyer, Leader
Leo G. Chelius, Assoc. Leader

Group H-2 (Industrial Medicine)
Harry O. Whipple, M.D., Leader

Group H-3 (Safety)
Roy Reider, Leader

Group H-4 (Bio-Medical Research)
Wright H. Langham, Leader
Ogden S. Johnson, Asst. Ldr. for Adm.

Group H-5 (Industrial Hygiene)
Harry F. Schulte, Leader
Edwin C. Hyatt, Alt. Leader

Group H-6 (Radiological Physics)
Thomas N. White, Leader