SAFE HANDLING OF RADIOACTIVE ISOTOPES

Handbook 42

U. S. Department of Commerce
National Bureau of Standards

U. S. Department of Commerce Charles Sawyer, Secretary
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National Bureau of Standards Handbook 42
Issued September, 1949

For sale by the Superintendent of Documents, Washington 25, D. C. - Price 15 cents

Preface

The Advisory Committee on X-ray and Radium Protection was formed in 1928 under the sponsorship of the National Bureau of Standards and with the cooperation of the leading radiological organizations upon the recommendation of the International Commission for Radiological Protection. The Committee, small in size, functioned effectively until the advent of atomic energy which introduced a large number of new and serious problems in the field of radiation protection.

At a meeting of this Committee in December 1946, the representatives of the various participating organizations agreed that the problems in radiation protection had become so manifold that the Committee should enlarge its scope and membership and should appropriately change its title to be more inclusive. Accordingly, at that time the name of the Committee was changed to the National Committee on Radiation Protection. At the same time the number of participating organizations was increased and the total membership considerably enlarged. In order to distribute the work load, eight working subcommittees were established as noted below. Each of these committees is charged with the responsibility of preparing protection recommendations in its particular field. The reports of the subcommittees are approved by the main committee before promulgation.

The following parent organizations and individuals comprise the main committee:

H. L. Andrews, United States Public Health Service.
E. G. Williams, M. D., United States Public Health Service.
Shields Warren, M. D., United States Atomic Energy Commission.
K. Z. Morgan, United States Atomic Energy Commission.
L. F. Curtiss, National Bureau of Standards.
L. S. Taylor, National Bureau of Standards.
E. E. Charlton, National Electrical Manufacturers Association.
L. L. Call, National Electrical Manufacturers Association.
H. B. Williams, M. D., American Medical Association.
R. S. Stone, M. D., Radiological Society of North America.
G. Failla, Radiological Society of North America.
R. R. Newell, M. D., American Roentgen Ray Society.
J. L. Weatherwax, American Roentgen Ray Society.
E. Quimby, American Radium Society.
J. E. Wirth, American Radium Society.
L. S. Taylor, International Commission for Radiological Protection.
R. C. Peavey, Secretary, National Bureau of Standards.

The following are the subcommittees:

Subcommittee 1. Permissible dose from external sources, G. Failla, chairman.
Subcommittee 2. Permissible internal dose, K. Z. Morgan, chairman.

Subcommittee 3. X-rays up to two million volts, H. O. Wyckoff, chairman.
Subcommittee 4. Heavy particles (neutrons, protons, and heavier), Dean Cowie, chairman.
Subcommittee 5. Electrons, gamma rays, and X-rays above two million volts, L. Marinelli, chairman.
Subcommittee 6. Handling of radioactive isotopes and fission products, H. M. Parker, chairman.
Subcommittee 7. Monitoring methods and instruments, H. L. Andrews, chairman.
Subcommittee 8. Waste disposal and decontamination.

With the increasing use of radioactive isotopes by industry, the medical profession, and research laboratories, it is essential that certain minimal precautions be taken to protect the users and the public. The recommendations contained in this handbook represent what is believed to be the best available opinions on the subject as of this date. As our experience with radioisotopes broadens, we will undoubtedly be able to improve and strengthen the recommendations for their safe handling and utilization.

Through the courtesy of the National Research Council about a year ago, several hundred draft copies of this report were circulated to all leading workers and authorities in the field for comment and criticism. The present handbook embodies all pertinent suggestions received from these people. Further comment will be welcomed by the committee.

One of the greatest difficulties encountered in the preparation of this handbook lay in the uncertainty regarding permissible radiation exposure levels—particularly for ingested radioactive materials. The establishment of sound figures for such exposure still remains a problem of high priority for many conditions and radioactive substances. Such figures as are used in this report represent the best available information today. If, in the future, these can be improved upon, appropriate corrections will be issued. The subject will be under continuous study by the two subcommittees mentioned above.

The present Handbook has been prepared by the Subcommittee on the Handling of Radioactive Isotopes and Fission Products. Its membership is as follows:

H. M. Parker, Chairman.
L. F. Curtiss.
P. C. Aebersold.
J. E. Rose.
L. Marinelli.
G. Failla.
J. G. Hamilton.
M. M. D. Williams.

E. U. Condon, *Director*.

CONTENTS

SAFE HANDLING OF RADIOACTIVE ISOTOPES

I. General Considerations

1. Scope of This Handbook

Prior to World War II the use of radioisotopes was essentially limited to a few locations having access to cyclotron-induced activities. The addition of pile-induced activities, either as fission products or as special irradiations, has changed the magnitude of the related protection problems. Widespread laboratory and industrial use of radioistopes is foreseen. This involves the protection of scientists and technicians in one case, of industrial employees in the other, and of the public in both cases. This handbook cannot give detailed recommendations, necessary and sufficient for all cases. It is, therefore, planned to give the general recommendations suitable for typical laboratory or small industrial operations. In all cases management specifically assumes the responsibility for the proper selection and maintenance of the standards necessary for safe operation. The small laboratory, handling low levels of radioactivity, may modify or omit some of the following recommendations. A periodic review of such modifications by a competent radiation protection authority may be desirable. The large laboratories and industries will require more detailed control. The employment of full-time personnel qualified in radiation protection is then desirable, and should be mandatory where the staff working regularly with radioactive material exceeds 25.

Specific attention is directed to the usage of "shall" and "should" throughout the recommendations. The former is used in a mandatory sense. The latter applies to those recommendations that may be redundant at low activity levels, optional at intermediate levels, and essential at high levels.

2. Available Radioisotopes

Table 1 lists the radioisotopes of generally greatest interest, and indicates the order of magnitude of the amounts normally available. A knowledge of the sites of deposition and elimination routes is a partial requirement for the hazard evaluation and tests for each particular isotope. Severe radiation hazard is associated with those isotopes that have unfavorable combination of long half-life, high uptake, deposition in small organs or in bone, and low elimination rates.

TABLE 1. *Properties of the principal radioisotopes*

	Isotope	Half-life y=years d=days h=hours	Energy (Mev) Beta	Energy (Mev) Gamma	Estimated quantities available (mc)	Principal uses
1	H^3	31y	0.014	None	mc	Trace for H; auxiliary trace for C.
2	C^{14}	5,100y	0.154	do	mc	Labeled organic compounds.
3	Na^{24}	14.8h	1.4	1.4, 2.8	200	Tracer studies of Na metabolism; diagnostic tests.
4	P^{32}	14.3d	1.69	None	1,500	Therapy; diagnosis; P chemistry; $PO_4^{=}$ tracers.
5	S^{35}	87.1d	0.17	do	1.0	Tracer on sulfur drugs; analytical chemistry.
6	Cl^{36}	10^6y	0.66	do	0.005	Cl chemistry; tracer gas.
7	K^{42}	12.4h	75 per cent: 3.58. 25 percent: 2.07.	1.51 (25 percent).	130	Tracer study of K compounds.
[a] 8	Ca^{45}	180d	0.25	None	1.0	Studies of Ca deposition; analytical chemistry; alloy studies.
9	Mn^{52}	6.5d	K, e+	0.56, 0.73, 1.46.	100	Trace biology.
	Mn^{54}	310d	K	0.835	1.0	
[b] 10	Fe^{55}	4y	K	0.07	1.0	Tracer on Fe drugs; blood chemistry.
	Fe^{59}	44d	0.26, 0.46	1.1, 1.3	1.0	Fe chemistry.
11	Co^{60}	5.3y	0.3	1.1, 1.3	200	Trace biology; gamma source; Co chemistry; alloy studies.
12	Cu^{64}	12.8h	0.58B− / 0.66B+ } K	1.2 (weak)	1.0	Trace biology; alloy studies; Cu chemistry.
[c] 13	As^{76}	26.8h	1.1, 1.7, 2.7	0.57, 1.25	30	Tracer studies with arsenical drugs.
	As^{77}	40h	0.8	None	1.0	Alloy studies.
[d] 14	Sr^{89}	55d	1.5	do	1,000	Sr chemistry.
	Sr^{90}	25y	0.65	do	mc	
15	Mo^{99}	6.7h	1.3	0.24, 0.75		Plant growth; animal metabolism.
[e] 16	I^{130}	12.6h	0.61, 1.03	0.42, 0.54, 0.67, 0.74.	250	Thyroid tracers; thyroid therapy.
	I^{131}	8d	0.6	0.367, 0.080	130	I chemistry.
17	Ba^{131}	12d	K, e−	1.2 (weak)	6.0	
	Ba^{140}	12.8d	1.05	0.542	mc	Analytical chemistry
18	Au^{198}	2.7d	0.97	0.44	80	Alloy studies
	Au^{199}	3.3d	1.01	0.45	10	Au chemistry
19	Hg^{197}	64h / 25h	K, e− / K, e−	0.075 / 0.13, 0.16	100	Low-energy gamma source.
	$Hg^{203, 205}$	51.5d	0.3	0.28	150	Alloy studies
20	Bi^{210}	5d	1.17	None	10	Tracer studies of Bi drugs.

[a] Calcium absorption and excretion is dependent on blood calcium level.
[b] Iron absorption from the gut is influenced by the level of iron present in the blood and liver. Once iron enters into the metabolism of the animal, the excretion rate for that iron is very low.
[c] As: Retention in all tissue is very low.

TABLE 1. *Properties of the principal radioisotopes*—Continued

Metabolism									
Ingestion			Inhalation			Parenteral			
Absorbed	Deposition [f]	Eliminated	Absorbed	Deposition [f]	Eliminated	Absorbed	Deposition [f]	Eliminated	
(g)	(g)	(g)	Same	Same	Same	Same	Same	Same	1
(g)	Bone: L. (g)	Lung Feces. Urine	do	do	do	do	do	do	2
High	Body fluids: H.	Urine	do	do	do	do	do	do	3
Do	Bone: M	do	High	Bone: M	Urine	High	Bone: M	Urine Feces	4
(g)	Liver All protein.	do	Same	Same	Same	Same	Same	Same	5
High	Body fluids: H.	do	do	do	do	do	do	do	6
Do	Blood: H Muscle	do	do	do	do	do	do	do	7
-------	Bone: H	Feces Urine	do	do	do	do	do	do	8
-------	----------	Feces	do	do	do	do	do	do	9
-------	Blood: H	do	do	do	do	do	do	do	10
-------	Bone(?) Liver	Urine Feces	do	do	do	do	Kidney Liver	Urine	11
(g)	Liver: M	Urine Feces	do	do	do	do	Same	Same	12
Low	Bone: M Hair: L	Feces Urine	do	Bone: M Hair: L	Urine	(g)	Bone: M Hair: L	Urine	13
-------	Bone: H	Feces Urine	(g)	Bone: H	Feces Urine	(g)	Bone: H	Feces Urine	14
High	Bone: M Liver: M Kidney: M.	Feces Urine	Same	Same	Same	Same	Same	Same	15
Do	Thyroid: 20 percent.	Urine	do	do	do	do	do	do	16
-------	Bone marrow.	Feces	do	do	do	do	do	do	17
(g)	Liver: M	Feces Urine	(g)	Liver: M	Urine	(g)	Liver: M	Urine	18
(g)	Liver Kidney	-------	Same	Same	Same	Same	Same	Same	19
Low	Kidney Liver	-------	--------	Low	do	do	do	do	20

[d] Sr: Absorption and deposition (5 to 80 percent in bone) vary with age and existing Ca level.
[e] Doses in excess of 0.1 gm give a low retention.
[f] H, L, and M indicate high, low, or moderate percentage of deposit out of total amount absorbed.
[g] Indicates chiefly dependent on compound.

TABLE 2. *Hazard from absorption into the body*

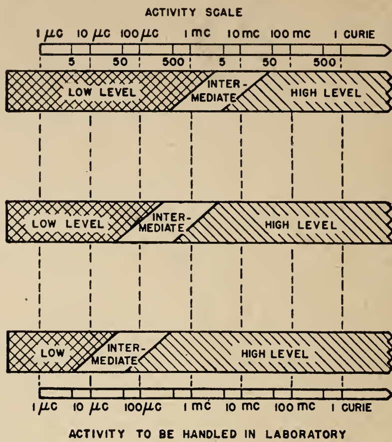
Selected radioisotopes grouped according to relative radiotoxicity, with the amounts considered as low, intermediate, or high level, in laboratory practice.

GROUP

I. SLIGHT HAZARD
$^{*}Na^{24}$, K^{42}, Cu^{64}, $^{*}Mn^{52}$, $^{*}As^{76}$, As^{77}, Kr^{85}, $^{*}Hg^{197}$

II. MODERATELY DANGEROUS
H^{3}, C^{14}, P^{32}, $^{*}Na^{22}$, S^{35}, Cl^{36}, $^{*}Mn^{54}$, $^{*}Fe^{59}$, $^{*}Co^{60}$, Sr^{89}, $^{*}Cb^{95}$, $^{*}Ru^{103}$, Ru^{106}, Te^{127}, Te^{129}, I^{131}, $^{*}Cs^{137}$, $^{*}Ba^{140}$, $^{*}La^{140}$, Ce^{141}, Pr^{143}, $^{*}Nd^{147}$, $^{*}Au^{198}$, $^{*}Au^{199}$, $Hg^{203, 205}$

III. VERY DANGEROUS
Ca^{45}, Fe^{55}, Sr^{90}, Y^{91}, $^{*}Zr^{95}$, Ce^{144}, Pm^{147}, Bi^{210}



NOTES

Effective radiotoxicity is obtained from a weighting of the following factors:

Half-life.
Energy and character of radiations.
Degree of selective localization in the body.
Rates of elimination.
Quantities involved and modes of handling in typical experiments.

The slant boundaries between levels indicate border-line zones, and emphasize that there is no sharp transition between the levels and the associated protection techniques.

The principal gamma-emitters are indicated by asterick (e. g., $^{*}NA^{24}$). The above level system does not apply to the hazards of external irradiation.

Table 2 shows the common isotopes subdivided into three groups, according to relative radiotoxicity following accidental intake into the body. The diagram attempts to define the ranges of low level, intermediate level, and high level activity used in the laboratory, with respect to intake hazards.

When the hazard is confined to that from external radiation, low, intermediate, and high levels are normally considered in terms of the emitted gamma radiation. These levels are not defined in this report, because the required safeguards are more widely understood in this case. It will be clear from the context whether a level is considered from the toxicity or external irradiation standpoint. Those isotopes that are preeminently gamma emitters are indicated by an asterisk in the table. The handling of those few isotopes that are alpha emitters is not specifically included in this report.

3. Hazards in Handling Radioisotopes

The known hazards may be classified in the order of their importance as follows:

1. Deposition of radioisotopes in the body.
2. Exposure of the whole body to gamma radiation.
3. Exposure of the body to beta radiation.
4. Exposure of the hands or other limited parts to beta or gamma radiation.

The hazards may be briefly described as follows:

1. Deposition may result from ingestion, inhalation, or absorption through the intact or injured body surface. Ingestion may occur as an acute problem through the accidental drinking of an active solution.

More generally, it will be a chronic problem caused by accumulation of small amounts of activity on contaminated hands, cigarettes, and other items brought to the mouth, or as a secondary result of inhalation. Following ingestion, the hazard may be due to direct irradiation of the alimentary tract, or more probably due to chronic irradiation of the organs in which the particular active materials are concentrated (e. g., strontium isotopes will accumulate in the bone, and iodine isotopes in the thyroid gland). Inhalation of active gas, vapor, spray, or dust may occur. Exposure to spray or dust is considered particularly hazardous because of the large fraction of such contamination retained by the lungs. Following inhalation, the hazard is threefold:

1. Direct irradiation of the lungs, etc.
2. Absorption of the active material directly from the lung.
3. Elimination from the lung by ciliary action followed by ingestion.

Chronic deposition of unabsorbable particles in the lungs is a major hazard since it is extremely difficult to demonstrate the accumulation of such particles. Once radioactive types of isotopes are in use, the following values form a provisional guide to maximum permissible contamination:

(1) For atmospheric contamination: 10^{-9} $\mu c/cm^3$
(2) For water contamination: 10^{-7} $\mu c/cm^3$

II. Personnel

1. Selection and Instruction of Personnel

Persons who are neat and careful are preferred workers with radioisotopes. A rigid physical examination should be made of all prospective workers. Careful inspection of the hands, and evaluation of possible previous exposure to radiation, are recommended. All individuals employed in radiation work shall be informed in detail of all known dangers involved. They shall be instructed regarding local rules and regulations for protection, and should be expected to observe them in all details. It is particularly important that all users of radioisotopes should be considered as potential full-time users.

2. Effects of Radiation

Effects of external radiation are adequately described in the National Bureau of Standards Handbooks 23 and 41.

When the active materials are deposited in the body, the effects depend upon the site of deposition, the physical half-life, and the biological half-life, which is determined by the elimination rate. The bone-seekers (for example, strontium) will produce effects similar to those found in radium poisoning. Other materials may produce changes in liver or kidney function, and occasionally in other organs. An essential feature of all the effects is that they may not appear until the dangerous material has resided in the body for many years, and irreparable latent damage may have been produced. There usually are no definite clinical symptoms which can be relied upon to guard against possible impending injury.

3. Blood Count

A complete blood count shall be made by a qualified hematologist before any individual begins work involving the handling of radioactive materials. Counts on two successive days at a stated hour are desirable. No one should be employed who shows pertinent abnormalities in the blood count. Blood counts should be made at regular intervals (normally 3 months) during employment, with more attention given to the trend of successive counts and especially of the differential count than to absolute values. It should not be considered that overexposure of the individual will be detected by changes in blood count.[4] Poor protection techniques may be detected by blood count findings before permanent injury to the individual occurs.[5]

4. Physical Examinations

(a) General

A thorough medical examination should be made of each individual potentially exposed to significant amounts of radiation before employment, and annually thereafter. An examination for possible radioactivity, by a person with special knowledge and equipment, should be given each individual, and form a part of the annual physical examination, whenever the exposure potential includes significant internal deposition. More frequent examinations are warranted when the exposure potential is high. The nature of such tests will depend upon the particular isotopes to which the individual may have been exposed. Sufficiently sensitive tests for the deposition of all relevant isotopes may not exist.

(b) Urinalysis and Other Tests

An analysis of radioactivity of the urine is a desired procedure. Normal urine contains radiopotassium in amounts which may mask the added radioisotopes for which tests are made. Either potassium should be separated from the sample and the residual activity measured, or when the possible exposure is restricted to one isotope, this should be chemically separated from the urine. Examination of the feces may be required when the predominant elimination is by feces. Special tests for specific isotopes are in order when they exist (e. g., radioiodine may be estimated in the thyroid gland in terms of the emitted gamma radiation measured by a Geiger counter or ionization chamber). Where exposure

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[4] A single exposure of 25 r can apparently escape detection by standard blood counting techniques.

[5] A more detailed discussion on blood counts will be found in National Bureau of Standards Handbook 41, Medical X-ray Protection up to Two Million Volts.

to radioisotope dust or spray is a possibility, it may be desirable to test the activity of a nasal smear, or of the sputum.

5. Personal Cleanliness

Radioactive isotopes must be treated like other poisonous substances. Extreme personal cleanliness in the laboratory is, therefore, desired. The material must not be spilled or scattered, and must not come in contact with the hands or clothing to any appreciable extent. At the end of each work period, the hands shall be carefully washed. No edibles of any kind, including chewing gum, candy, or beverages, shall be brought into the laboratories, nor shall they be touched before removing all washable traces of radioisotopes from the hands. The use of cigarettes or application of cosmetics in the laboratory may result in transference of activity to the lips. Radioisotopes burned on the cigarette may be drawn into the lungs.

The hands should be tested frequently with a Geiger counter or other instruments of suitable sensitivity to determine whether contamination exists. Immediate steps to remove contamination shall be taken when found.

6. Housekeeping

Neatness in the laboratory is a prime requisite for elimination of the spread of contamination. The work area should be free from equipment and materials not required for the experiment at hand, and equipment used should be decontaminated and stored in a controlled location after use.

7. Supervision

The supervisor of a work group or the leader of a laboratory group has the responsibility for seeing that the radiation work under his guidance is performed in a safe manner. The supervisor is required to see that the established rules regarding food handling, checks of personnel activity, waste disposal, etc., are maintained. The objective is the education of each and every worker to follow these necessary procedures for his own protection and the protection of others. In a radioisotope laboratory, skill in radiation protection is as necessary as skill in chemical or biological manipulations. Persons failing to develop such skills should be advised to transfer to other occupations.

III. Laboratory Design and Equipment

1. General Working Conditions

Successful work with radioisotopes other than in true tracer amounts requires the use of laboratories and equipment specially designed for the purpose. No work should be undertaken in these rooms other than that concerned with the application of radioisotopes.

2. Floors

The floors shall have smooth and continuous surfaces, as far as possible, such as stainless steel, painted concrete, or linoleum. Absorbent floors, for example, wood, should be avoided. Asphalt tile and similar materials are permissible, provided that the laboratory supervisor is aware of the hazards of accumulation of radioisotopes in the cracks. The ease of replacement of sections of tile floor may compensate for the hazard of crack contamination. Floors should be cleaned daily by wet mopping, or by the use of moist compound. Dry sweeping may lead to an active dust hazard.

3. Walls, Ceiling, and Woodwork

Walls, ceiling, and woodwork shall be finished with a nonporous washable surface, which may be cleaned to remove accumulation of radioactivity. Projecting ledges, hanging lamps, etc., which may accumulate dust should be avoided.

4. Ventilation

All laboratory operations with more than low-level activity should be conducted in hoods which will be provided with forced ventilation sufficient to maintain the activity content of the room air below 10^{-9} $\mu c/cm^3$ at any place at any time. The linear velocity of air flow should be in the range of 100 to 150 feet/minute. Specially hazardous operations (e. g., handling long-lived bone-seeking isotopes in injection or inhalation studies on animals) should be conducted by personnel wearing suitable respirators or supplied-air masks. Hoods with individual filter systems for the exhaust air are preferred. Multiple hood systems are dangerous because reverse air currents may occur.

5. Equipment

Special equipment suitable for the type and level of activity being used should be provided for each type of operation. This should include handling tools such as tongs, forceps, trays, and mechanical holders. Long-handled tools provide adequate protection by distance where millicurie amounts of beta or gamma activity are encountered. Semi-remote-control sampling and stirring devices should be included. Operations with larger amounts require the use of specially designed, remote-control equipment including a shielded optical system (e. g., a periscope or mirror arrangement). When the isotopes concerned are primarily beta emitters, efficient use can be made of transparent plastic shields [6] fitting closely around the equipment to allow close handling with good visibility. Containers for the active material should incorporate the necessary shielding as close to the source as possible. Containers for liquid samples should always be reinforced by an outer, unbreakable container.

6. Hoods and Benches

Laboratory benches should be free from cracks, crevices, or sharp corners. Suitable surfaces for work tables are stainless steel, Monel metal, plate glass, and some smooth-surfaced plastics. The work surface should be covered with absorbent paper [7] to catch minor spills, and this paper should be changed after each laboratory experiment. The work in hoods should similarly be performed over an inner washable tray covered with the absorbent paper. The work bench should be equipped with wiping papers for the prompt removal of spills. Drawers in work benches, if provided at all, should be washable and have removable liners.

7. Disposal of Contaminated Wastes [8]

(a) Absorbent Papers, Wipes, etc.

Waterproof disposable containers to hold the discarded absorbent bench paper and wiping papers should be provided at each laboratory station. Regular collections of these dis-

[6] See appendix 1 for thickness.
[7] A "diaper" paper is available that has a waterproof backing to reduce penetration of spills to the work surface.
[8] This subject will be covered more extensively in the report of the Subcommittee on Waste Disposal and Decontamination.

posal vessels from the laboratory should be made. The eventual disposal of such items is conditioned by the half-life and toxicity level of the isotopes involved. With short half-lives, retention of the materials in a controlled area, until their residual activity is insignificant, is a preferred method. With long-lived isotopes, the laboratory management is committed to a prevention of contamination of the public domain. The association of groups of laboratories to provide a single controlled and economical disposal area may be feasible.

(b) Active Solutions

The disposal of active solutions to the public sewers can only be considered safe when the possible subsequent chemical, physical, and biological concentrations will still leave the materials at safe concentrations. Disposal to a water system should include consideration of the accumulation of activity in soil or mud, and in algae and similar organisms. Concentration of the order of 100,000 fold may occur. Whenever possible, the principal activity in the waste solution should be removed, and discarded as active solid material.

Excreta from isotope-injected animals or patients, and liquors from equipment or clothing decontamination, may require attention as active solutions.

(c) Tools

Tools and other miscellaneous equipment used in handling radioisotopes should be regarded as contaminated, and should not be released for other work until proven otherwise.

8. Protective Clothing

The degree of protection required is a function of the activity used. Even tracer amounts should be handled with laboratory coats protecting normal attire. Where routine radiochemical or biological work is done, coveralls or other clothing that completely clothes the body shall be worn and must be restricted to this operation. Rubber gloves should be worn while handling active materials which may give rise to contamination of the hands. If the material may be spilled on the floor, special cloth or rubber overshoes should be used. In some cases, the provision of shoes to be used only in the laboratory is preferable.

Good protective practice in many respects is similar to, but usually less stringent than, that employed in the manipulation of virulent bacteriological organisms.

IV. Hazard Instrumentation

1. Personnel Meters

(a) Pocket Ion Chambers

Each radiation worker should wear a pocket ionization chamber throughout the course of his work. The chamber should be effective in the range up to 200 mr. Daily measurements of the integrated gamma-ray dose should be recorded. It has been found preferable in many cases to wear two identical pocket chambers, in which case the lower of the two readings is considered valid. This eliminates casual errors due to accidental discharge of one chamber. The usual chambers are not sensitive to beta radiation. Where the isotopes used do not emit gamma rays, specially constructed beta chambers should be provided.

(b) Film Badges

Pocket chambers should be supplemented by a film badge that contains film partially covered by a suitable metallic filter, such as 1 mm. of silver or cadmium. Blackening of the film in the shielded area is then approximately independent of the energy of the gamma radiation (above 80 Kev). Blackening of the unshielded portion may be caused by beta or gamma radiation, especially low-energy gamma radiation. Such film badges give a sufficiently quantitative record of the integrated weekly gamma-ray dose. The beta-ray dose can be obtained quantitatively when exposure to soft gamma radiation is excluded. Special film packets containing two films of different sensitivity are available for badge monitoring. Sensitive film is effective in the range 25 mr to about 5 r. The insensitive film is effective up to about 40 r, and is read only in the event of a major exposure.

(c) Finger Rings

Workers who manipulate radioactive solutions or handle sources should wear film rings or other suitable devices on the fingers to estimate the hand exposure. Rings which include the metal shield with open window can be used. In many cases, a simple film disk covered with thin rubber is an effective substitute, which introduces very little inconvenience in handling laboratory tools. Strictly quantitative results are obtained only when calibrations can be made with the particular isotopes used in the laboratory.

2. Beta-Gamma Survey Meters

These meters fall into two classes:

1. Sensitive detection instruments primarily used for qualitative estimation of contamination. Whenever contamination is found, it is customary to remove it, and there is consequently no need to determine the exposure, quantitatively. Geiger counters in various circuit combinations are frequently used for this purpose. The "Zeuto" survey meter is also convenient for detection purposes.

2. Quantitative survey meters consisting of ion chambers with suitable indicating circuits, for the measurement of radiation transmitted through shields, or in other cases where it is necessary to evaluate the potential radiation exposure. When properly designed, the response of these chambers is independent of the wavelength of the incident radiation over a wide range. The chambers are made optionally sensitive to both beta and gamma radiations or to gamma radiation only. This is effected by provision of a removable shield over a thin window on the chamber. Table 3 includes some of the currently available radiation meters.

3. Beta-Gamma Hand Counters and Shoe Counters

The small laboratory can use the simple Geiger counter equipment for the detection of contamination on the hands and shoes of workers. Where the procedure is economically justified, it is preferred to use combinations of G. M. tubes assembled so as to register the activity on both sides of the hands and on the shoes. Ten-tube combinations are available for this purpose. Registration may be either by scaler and registers, or by multiple counting-rate meters. Whenever it is required to make a permanent record of the hand and shoe counts, the scaler-register combination is more effective, and can be made on an automatic printing basis.

Table 3. *Typical radiation survey meters*

Instrument	Radiation detected	Description [1]	Ranges [2]	Remarks
Lauritsen electroscope	Beta, gamma	Quartz fiber electroscope, Fred C. Henson Co., Pasadena, Calif.	Single range, nominal maximum: 1 r/hr.	Incomplete saturation gives nonlinear response and requires specialized calibration. May be equipped with 0.0002-in. window for alpha detection and used with alpha (e. g., 0.002-in. paper) and beta (e. g., 3 mm Al) shields for almost all necessary small laboratory surveys.
L–W (Landsverk-Wollan) survey meter.	do	Improved quartz fiber electroscope; 100-cm^3 ion chamber; timing circuit flash illuminates microscope scale indicating limits of preselected time interval. Sliding metal screen to eliminate beta radiation, Kelly Koett Mfg. Co., Covington, Ky.	Dual range, nominal maxima: 100 mr/hr, 1 r/hr.	Rugged; holds calibration well. Relatively slow but otherwise convenient and versatile. Satisfactorily free from wavelength dependence.
Victoreen survey meter	Gamma	Compact chamber and amplifier circuit. Wide variety of ranges available on special order, Victoreen Instrument Co., Cleveland, Ohio.	Single range, nominal maximum: 200 mr/hr.	Readily adaptable to operating chamber on a long probe, providing distance protection for the operator.
Portable Geiger-Müller counters.	Beta, gamma	Audible signal and/or counting rate meter. Numerous commercial forms available.	Multiple range, nominal maximum: 80,000 c/m.	For rapid radiation detection. Normally improper for quantitative work. Each type should be tested for temperature and failure at high counting rates.
Poppy	Alpha	Audible signal and counting rate meter. Raytheon Mfg. Co., Newton, Mass.	3 ranges, nominal maximum: 7,500 c/m.	Normally used as qualitative audible indicator. Detects minimum of about 150 d/m.

C. P. meter	Beta, gamma	Chamber 3-in diam. by 6-in. long of Bakelite with detachable end cap for beta-gamma discrimination. Simple electrometer circuit. Technical Associates, Glendale, Calif.	3 ranges, nominal maxima: 50, 500, 5,000 mr/hr.	Weighs 4 pounds, easily set to zero in radiation field. Excellent general purpose instrument for radiation field or surface contamination measurements.
Juno	Alpha, beta, gamma.	Ion chamber similar to Zeuto. Has built-in shields controlled from handle to discriminate between alpha, beta, and gamma. Simple electrometer circuit. Technical Associates, Glendale, Calif.	3 ranges, nominal maxima: 50, 500, 5,000 mr/hr.	Combines many of the advantages of the C. P., Zeuto, and Zeus.
Zeus	Beta, gamma (alpha).	"Shoe box" type with 1 to 2 liter ion chamber, with wire-mesh window. Thin screen slides in to eliminate alpha radiation and thick plastic screen further discriminates between beta and gamma rays. Amplifier has favorable time constant, e. g., Rauland Corp., Chicago, Ill.	4 scales up to 25, 100, 500 mr/hr, 2.5 r/hr.	Rugged and reliable general purpose instrument. Not entirely free from wavelength dependence, but this is not a critical defect.
Zeuto	Beta (alpha)	Similar to Zeus circuit, but with feedback to increase sensitivity. Designed for alpha measurements, but suitable for beta radiation, e. g., Victoreen Instrument Co., Cleveland, Ohio.	2 scales up to 4 mrep/hr, up to 40 mrep/hr.	High sensitivity and fair stability. Good for surface contamination measurements and can be applied to C^{14} and S^{35} contamination.

[1] Indication of a manufacturer's name does not constitute endorsement of the instrument nor deny the superiority of other makes.

[2] For beta-gamma instruments, the gamma rays are quoted. Calibrations for beta radiation may depend on the energy of the particles and the geometrical distributions of the source.

4. Dust, Gas, and Vapor Samplers

(a) Dust Samplers

Dust or spray may be sampled by drawing air through a filter, or by electrostatic precipitation. The filtration method is reliable, provided that leaks around the edge of the collection paper are eliminated. The activity on the sample paper is measured on standard laboratory counting equipment. Complications are introduced when the half-life of the collected material is short or comparable with the collection time. The electrostatic precipitation method permits the precipitation onto an aluminum surface which is a suitable source for the evaluation of range and energy of the deposited particles.

(b) Gas and Vapor Samplers

One type of sampler draws air through an ion chamber and measures the ion current with a suitable electrometer circuit. A continuous record of the activity in the atmosphere may be obtained in this manner. The method is unsuitable at low levels because of the difficulty of avoiding disturbance to the chamber insulators by friction, etc. Another method involves the collection of samples in evacuated containers which can be returned to a central location for sampling. In special cases, chemical or adsorption methods are available for specific gases or vapors.

V. Hazard Monitoring

1. Inspection of Personnel

The monitoring of personnel with respect to incident radiation is achieved by the use of pocket ion chambers and/or film badges worn on the person. It is standard practice to process the pocket chambers daily, and the films weekly. Where experience has shown continued low exposure, films read every 2 weeks give an adequate exposure index. Similarly, self-reading pocket chambers may be worn for an extended period if the casual leakage is insignificant. Finger film should be processed at least weekly.

In general, each individual using radiosotopes should be responsible for monitoring himself against contamination. The inspection should include qualitative tests for contamination of the clothing, hands, and other parts that may be contaminated. Hand checks shall be mandatory before leaving the work area for lunch or termination of the work day. In those cases where the risk of absorption of the isotopes through an open cut is important, hands should be inspected by the supervisor or laboratory leader at the beginning of the work day, and injured persons excluded from the program.

Prompt removal of contamination, when found, is a necessary corollary of the inspection.

2. Inspection of Work Areas

The beta- and gamma-ray exposures at points habitually occupied by workers should be determined periodically by properly designed ionization or counter devices, operated by qualified personnel. An instrument, or instruments, should be available to cover the range from 1 mr/hr up to 2 r/hr. Other meters for the qualitative detection of small amounts of active contamination should be available. Under laboratory conditions, each person in the laboratory should be responsible for maintaining an adequate frequency of inspection in his own work area. In larger organizations, it may be expedient to employ personnel specifically for these inspections. Continuous monitoring equipment, which may have an alarm feature, is very desirable for locations handling "curie" amounts of radioisotopes. Such meters, and many portable survey meters, give an inadequate indication of the hazard arising from contaminated surfaces. Such surfaces may give a direct contact exposure hazard, or offer a means of transfer to the body.

The instrument response corresponding to a permissible level of beta contamination is a function of the active materials involved, and each laboratory should properly evaluate these levels for its own purpose. In general, if a Geiger counter of flat-plate area about 2 square inches is passed with a normal hand motion over a suspected surface, contamination is present in undesirable amounts if there is an obvious instrument response. This policy will result in the cleaning of some areas which were not specifically dangerous to personnel. This in general is offset by the easier definition of this particular limit, and the benefits arising from the maintenance of an extremely clean work area. Care must be taken to ensure that the test instrument used is reasonably responsive to radiations emitted by the available isotopes (for example, if C^{14} is used, rather specialized search equipment may be necessary).

The amount of activity in the form of gas, vapor, dust, or spray in the air must be determined routinely in the laboratory if the activities used are compatible with the production of an inhalation hazard.

3. Inspection of Protective Clothing

The first inspection of protective clothing should be made by the wearer prior to removal. Very active items should be discarded as active solid waste, in closed containers. The remaining items should be washed and monitored under controlled conditions. Special laundry facilities should be used by all groups regularly engaged in radioisotope work. Preferred solvents for laundry rinses depend on the chemistry of the isotopes used. Where miscellaneous isotopes may be present, dilute acetic or citric acid is recommended. Dilute nitric acid may be used on rubber items. Before contaminated garments are considered for release to public laundry service, the extent of hazard shall be very carefully evaluated.

4. Inspection of Wastes

Laboratory personnel is responsible for the inspection of the disposable containers for solid waste. Tests for emitted beta and gamma radiation, and in some cases for radioactive contamination of surrounding air, are required. Radiation monitoring of the assembly of these containers at a central depot may be necessary.

Monitoring and segregation of active liquid waste is similarly required. The inspection of gaseous and dust effluents, etc., is mandatory in the larger installations where such effluents may be hazardous. Tests for possible deposition and accumulation beyond the confines of the laboratory may be required. Detection methods sufficiently sensitive to give large-scale deflections when subjected to natural radioactive contamination in air, water, or soil, are required, because the maximum permissible additional contamination is of this same order of magnitude.

5. Management of Radiation Accidents

(a) External Radiation

A person presumed significantly overexposed to external radiation should be removed promptly from the hazardous area. Such a person should not be allowed to return to work involving radiation unless it is evident that radiation damage will not result. If investigation indicates that the overexposure may be serious, the exposed person should be referred to a physician qualified to ascertain the extent of the radiation injury, if any.

(b) Ingestion

Persons swallowing radioactive solutions should be treated as for poisoning. The material should be removed by an emetic or by stomach pump, and the residue rendered insoluble to reduce absorption. Addition of carrier element may be indicated. Blood samples and subsequent urine samples should be analyzed to compute the body content of contaminant. Where this approximates the maximum permissible load, radical corrective procedures are indicated. Similar protocol applies to other forms of potential intake described below.

(c) Surface Contamination

Persons splashed with active solutions should wash the affected parts immediately, and if still contaminated, apply recognized decontaminating agents. Where the chemistry of the active solution is not immediately known, an application of titanium dioxide paste, or a saturated solution of potassium permanganate followed by a 5-percent sodium bisulfite solution rinse, is frequently effective. Care should be taken to ensure that no activity is left under the fingernails.

When the hand is known to be contaminated with a small spot of high specific activity, it is better not to wash the hand, as this unnecessarily spreads the contamination. Such spots are removed by masking off the surrounding areas, and by cleaning the affected part with cotton applicators dipped in suitable decontaminants. Care should be taken not to scratch or erode through the epidermal skin layer when scrubbing the body to remove surface contamination.

(d) Minor Injuries

Persons cut by glassware, injured by hypodermic needles, etc., should wash the injured part under a strong stream of water immediately following the injury. A venous-return tourniquet may be applied if the material is unusually toxic. If it is ascertained that the injury was caused by an item bearing a hazardous amount of material, a biopsy section of the wound should be analyzed. Excision of the part to reduce further body absorption may be indicated in extreme cases.

(e) Inhalation

Persons inhaling radiotoxic fume, spray, or dust, should be treated to stimulate removal of the toxic material from the lung.

VI. Transportation

1. Shipment of Isotopes

The shipment of radioisotopes should be made in accordance with the regulations of the Interstate Commerce Commission, and with any further specific restrictions of authorized distributors of radioactive material (see appendix 3). The formal regulations cover interstate rail, truck, and water transportation. Transportation by air operates under an interim arrangement (see appendix 3).

2. Movements in the Laboratory

Each laboratory or institution should have a central controlled storage location for incoming isotope shipments. The minimum amounts of active material necessary for the intended processing should be withdrawn from this store, and any excess returned promptly after the operation. Movements of millicurie or greater amounts should be governed by written transfers. Each laboratory supervisor is then aware of the total activity problem in his group. Transfers from the central store to each laboratory should be made in properly shielded containers, and liquid shipments should be protected against spills. Within the laboratory, the active material shall be kept in a specified safe work place. Transfers from one place to another should be reduced to a minimum, and, when necessary, should be made with shielding adequate to protect all personnel in the laboratory. The general rules for such shielding may be deduced from the regulations prescribed for the shipment of isotopes outside the laboratory (see appendices 2 and 3).

Appendix 1. Beta-Ray Shielding

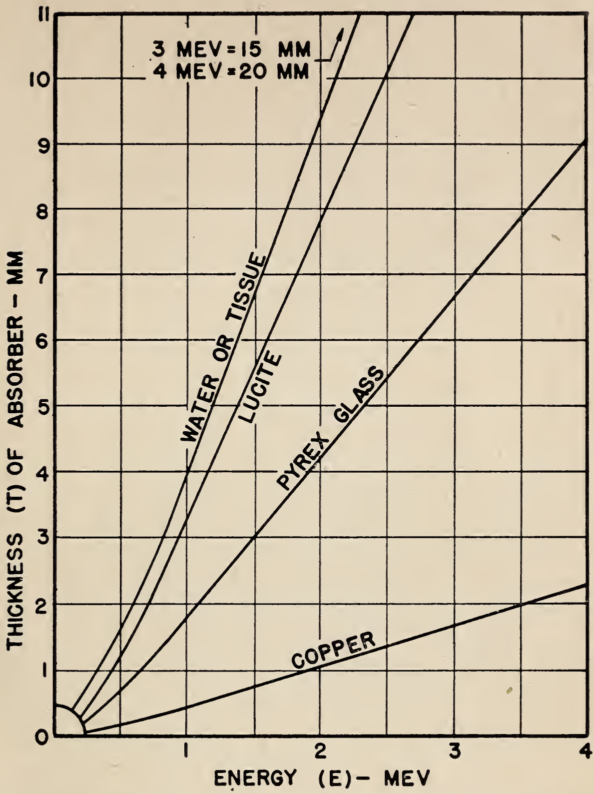

FIGURE 1.—*Thickness, T mm, of typical materials required to stop completely beta-rays of maximum energy, E MEV.*

Appendix 2. Gamma-Ray Shielding

1. Required Shield Thickness

The table given below may be used to determine the required thicknesses for shielding from gamma-ray sources in the laboratory.

Select column for energy required (use next higher if exact value is not given). Entry gives thickness in centimeters of lead for different source strengths at 1 m for 8 hr/day to give 50 mr. *Add* algebraically the correction terms for other working ranges or times, and *multiply* by factor for shield material.

Example: An iron shield is required for the manipulation of 500 mc of radioactive material emitting 1.8-Mev gamma rays at a minimum working distance of 50 cm, and for 4 hr/day.

Shield thickness $= (\underset{(a)}{8.60}+\underset{(b)}{2.77}-\underset{(c)}{1.39})\times\underset{(d)}{1.43}=14.3$ cm of Fe, in which

a = basic entry.
b = correction for danger range = 50 cm.
c = correction for 4 hr/day.
d = conversion from Pb to Fe.

Activity	ENERGY (Mev)								
	0.2	0.5	0.8	1.0	1.5	2.0	2.5	3.0	4.0
10 mc	−0.14	−0.36	−0.27	−0.11	+0.37	+0.78	+1.15	+1.40	+1.70
20 mc	−.09	.00	+.41	+.76	+1.57	+2.16	+2.63	+2.91	+3.21
50 mc	−.01	+.47	+1.31	+1.90	+3.15	+4.00	+4.57	+4.90	+5.20
100 mc	+.06	+.82	+1.99	+2.77	+4.34	+5.38	+6.05	+6.41	+6.71
200 mc	+.10	+1.17	+2.67	+3.63	+5.54	+6.77	+7.52	+7.92	+8.21
500 mc	+.17	+1.64	+3.57	+4.78	+7.12	+8.60	+9.47	+9.91	+10.21
1 c	+.23	+1.99	+4.25	+5.65	+8.31	+9.99	+10.95	+11.41	+11.71
2 c	+.28	+2.35	+4.93	+6.52	+9.51	+11.37	+12.42	+12.92	+13.22
5 c	+.36	+2.81	+5.82	+7.66	+11.09	+13.21	+14.37	+14.91	+15.21
10 c	+.41	+3.17	+6.50	+8.52	+12.28	+14.59	+15.85	+16.42	+16.72
20 c	+.47	+3.52	+7.18	+9.39	+13.48	+15.98	+17.32	+17.93	+18.23
50 c	+.54	+3.99	+8.08	+10.54	+15.06	+17.81	+19.27	+19.92	+20.22
100 c	+.60	+4.34	+8.76	+11.40	+16.25	+19.20	+20.75	+21.43	+21.72
Danger range	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus
20 cm	+0.26	+1.64	+3.16	+4.02	+5.55	+6.44	+6.85	+7.00	+7.00
50 cm	+.11	+.71	+1.36	+1.73	+2.39	+2.77	+2.95	+3.01	+3.01
1 m	.00	.00	.00	.00	.00	.00	.00	.00	.00
2 m	−.11	−.71	−1.36	−1.73	−2.39	−2.77	−2.95	−3.01	−3.01
5 m	−.26	−1.64	−3.16	−4.02	−5.55	−6.44	−6.85	−7.00	−7.00
10 m	−.37	−2.35	−4.52	−5.76	−7.94	−9.21	−9.80	−10.01	−10.01
Working time, hr/day	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus
1	−0.17	−1.06	−2.04	−2.60	−3.59	−4.16	−4.42	−4.52	−4.52
2	−.11	−.71	−1.36	−1.73	−2.39	−2.77	−2.95	−3.01	−3.01
4	−.06	−.35	−.68	−.87	−1.20	−1.39	−1.47	−1.51	−1.51
8	.00	.00	.00	.00	.00	.00	.00	.00	.00
24	+.09	+.56	+1.08	+1.37	+1.89	+2.20	+2.34	+2.39	+2.39
Absorber	Times	Times	Times	Times	Times	Times	Times	Times	Times
Pb	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe	8.80	2.88	1.96	1.74	1.49	1.43	1.47	1.48	1.59
Al [1]	41.67	9.80	6.18	5.33	4.83	5.00	5.28	5.68	6.39
H_2O	106.84	21.54	13.42	11.59	10.36	11.11	11.19	12.11	12.78

[1] Or concrete.

NOTES

(1) Source activity is quoted in millicuries or curies, where 1 curie is that amount of radioactive material that disintegrates at the rate of 3.7×10^{10} disintegrations/second. However, the table is computed on the further assumption that each disintegration yields one gamma photon of the selected energy. This will lead to inaccuracies whenever the disintegration is complex. More accurate calculations can be made by obvious methods when the disintegration scheme is known.

(2) The tabulation ignores the increased effective transmission of shields under wide beam irradiation.

(3) This form of shielding table (prepared by C. C. Gamertsfelder) is intended to form a guide to rapid erection of temporary shielding structures in the laboratory. Where permanent installations of maximum economy are planned, more detailed calculations by conventional methods are required.

Appendix 3. Shipping Rules

I. Interstate Commerce Commission Regulations

The Interstate Commerce Commission requested the Bureau of Explosives, Association of American Railroads, to formulate regulations for adoption. The Bureau of Explosives was assisted by the Subcommittee on Shipment of Radioactive Substances of the Committee on Nuclear Sciences of the National Research Council. The regulations became effective January 25, 1948. The following is an excerpt of those rules that will apply to expected shipments of radioisotopes.

MAXIMUM LIMITS OF SHIPMENTS

Not more than 2 curies of radium, polonium, or other members of the radium family, and not more than 10^{11} disintegrations per second of all other radioactive materials may be packaged in one outside container for shipment by rail express except by special arrangements and under conditions approved by the Bureau of Explosives.

EXEMPTIONS FROM PACKING, LABELING, AND MARKING REQUIREMENTS

Radioactive materials are exempted from prescribed packing requirements provided they fulfill all of the following conditions:

1. The package must be such that there can be no leakage of radioactive materials under conditions normally incident to transportation.
2. The package must not contain more than 0.1 millicurie of members of the radium family or the equivalent amount of plutonium, and not more than 5×10^6 disintegrations per second of strontium 89, strontium 90, or barium 140, or 50×10^6 disintegrations per second of any other substance.

3. The package must be such that no significant alpha or beta radiation is emitted from the exterior of the package, and the gamma radiation at any surface of the package must be less than the equivalent of 10 milliroentgens of radium gamma radiation filtered through one-half inch of lead for 24 hours.

PACKAGING AND SHIELDING

Special Hazards.—Radioactive materials which present special hazards due to their tendency to remain fixed in the human body for long periods of time (i. e., radium, plutonium, strontium) must, in addition to the packing described below, be packed in inside metal containers, specification 2R, or other containers approved by the Bureau of Explosives. Quantities and materials considered under this heading will be determined by the Bureau of Explosives.

Packaging and Shielding.—(1) All radioactive materials must be so packed and shielded that the degree of fogging of undeveloped photographic film under conditions normally incident to transportation (24 hours at 15 feet from the package) will not exceed that produced by 11.5 milliroentgens of radium gamma rays filtered by one-half inch of lead,

(2) The design and preparation of the package must be such that there will be no significant radioactive surface contamination on any part of the container,

(3) The smallest dimension of any outside shipping container for radioactive materials must not be less than 4 inches,

(4) All outside shipping containers must be of such design that the gamma radiation will not exceed 200 mr/hr or equivalent at any point of readily accessible surface. Containers must be equipped with handles and protective devices when necessary in order to satisfy this requirement,

(5) The outside of the shipping container for any radioactive material, unless specifically exempt from packaging requirements, must be a wooden box, Specification 15A or 15B, or a fiberboard box, Specification 12B (Bureau of Explosives), except that equally efficient containers may be used when approved by the Bureau of Explosives,

(6) Radioactive materials which emit gamma rays must be packed in suitable inside containers completely surrounded by a shield of lead or other suitable material of such thickness that at any time during transportation the gamma radiation at one meter from any point on the radioactive source will not exceed 10 milliroentgens per hour for hard gamma rays, or that amount of radiation which will have the same effect on film as 10 mr/hr of radium gamma rays filtered through one-half inch of lead. The shield must be so designed that it will not open or break under conditions normally incident to transportation, and must be sufficient to prevent the escape to the exterior of the outside shipping container of any corpuscular electrically charged radiation,

(7) Radioactive materials which emit only corpuscular electrically charged particles must be packaged in suitable inside containers completely shielded so that at any time during transportation the radiation measured from any point on the shipping container will not exceed the following limits:

(*a*) Ten mr/hr for hard gamma rays, or that amount of radiation which will have the same effect on film as 10 mr/hr of radium gamma rays filtered through one-half inch of lead, (*b*) Electrically charged corpuscular radiation which has the same physiological effect as 10 mr/hr of gamma rays.

When more than one type of the above radiations is present, the radiation of each type must be reduced by shielding so that the total emission does not exceed that of paragraphs (*a*) and (*b*). The shielding must be designed so as to maintain its efficiency under conditions normally incident to transportation,

(8) Liquid radioactive materials must, in addition, be packed in tight glass, earthenware, or other suitable inside containers. The inside container must be surrounded on all sides and within the shield by an absorbent material sufficient to absorb the entire liquid contents, and of such nature that its efficiency will not be impaired by chemical reaction with the contents. If the container is packaged in a metal container, Specification 2R, or other container approved by the Bureau of Explosives, the absorbent cushioning is not required,

(9) Radioactive materials emitting electrically charged particles only must be packed in suitable inside containers completely wrapped and/or shielded with such material as will prevent the escape of primary corpuscular radiation to the exterior of the shipping container, and the secondary radiation at the surface must not exceed the equivalent of 10 mr of radium gamma rays filtered through one-half inch of lead in 24 hours.

(10) Empty shipping containers: All containers and accessories which have been used in shipments of radioactive materials, when shipped as empty containers, must be sufficiently free from radioactive contamination, that there is no significant alpha or beta radiation [9] at the surface, and the gamma radiation at any surface shall be less than 10 mr for 24 hours.

LABELING AND MARKING OF PACKAGES

Each outside container of radioactive material, which emits gamma rays or gamma rays plus electrically charged corpuscular rays, unless specifically exempt, must be labeled with a label, red letters on white background, with design and wording as prescribed by the Bureau of Explosives. Each outside container of radioactive material, which emits corpuscular electrically charged particles only must, unless specifically exempt, be labeled with a label, blue letters on white background, as prescribed.

2. Post Office Department Regulations

The Post Office Department has recently issued new regulations controlling the shipment of radioactive materials by mail. In general, these regulations have been revised to conform with the regulations issued by the Interstate Commerce Commission. The following is an excerpt of these rules which may be of interest to small users of radioisotopes.

"6. Radioactive materials (liquid, solid or gaseous; manufactured articles such as instrument or clock dials of which radioactive mate-

[9] By "significant" radiation is meant about 500 alpha disintegrations per 100 cm^2 per minute, or about 0.1 mrep/hr of beta radiation.

rials are a component part; luminous compounds; and ores, residues, etc.) which fulfill all following conditions shall be accepted for mailing provided they are properly packed in a strong tight outside container and marked "Radioactive Material—Gamma Radiation at Surface of Parcel Less than 10 Milliroentgens for 24 hours—No significant Alpha, Beta or Neutron Radiation."

(a) The package must be such that there can be no leakage of radioactive material under conditions normally incident to transportation in the mails in sacks.

(b) The package must contain not more than 0.1 millicuries of radium, or polonium, or that amount of strontium 89, strontium 90, or barium 140 which disintegrates at a rate of more than 5 million atoms per second; or that amount of any other radioactive substance which disintegrates at a rate of more than 50 million atoms per second.

(c) The package must be such that no significant alpha, beta or neutron radiation is emitted from the exterior of the package and the gamma radiation at any surface of the package must be less than 10 milliroentgens for 24 hours.

(d) The design and preparation of the package of radioactive material must be such that there will be no significant radioactive surface contamination of any part of the container. Liquids must be packed in tight glass, earthenware or other suitable inside containers surrounded by an absorbent material sufficient to absorb the entire liquid contents and of such nature that its efficiency will not be impaired by chemical reaction with the contents."

3. Interim Regulations for Shipment by Air

SHIPMENT OF RADIOACTIVE MATERIALS BY AIR

An interim arrangement, under which air express shipments of radioactive substances are currently carried by certain air lines, is given in Rule 13–A of Supplement No. 5 to the Railway Express Agency, Air Express Division, Tariff No. 8. This document is also known as Supplement No. 5 to CAB No. 22. It reads in part:

> The following radioactive materials will be accepted, subject to shipper compliance with the following requirements, except that such shipments will not be accepted for transportation in aircraft operated by All American Aviation, Inc., Inland Air Lines, Inc., National Airlines, Inc., Northwest Airlines, Inc., Transcontinental and Western Air, Inc., and/or Western Air Lines, Inc. (See Rule No. 12–B.)
>
> Characteristics: Emit Gamma and other rays with maximum rating for 1-gram equivalent of radium.
>
> Protective Packaging Required: Encasement in lead of thickness prescribed by "Committee on Standards of Radioactivity—National Research Council" for full protection of undeveloped films at 30 feet (developed films unaffected), and full protection of all air line personnel and passengers.
>
> Special Marking on Package Required: "Do not place in same compartment with undeveloped films or mail."

Appendix 4. Publications

1. Publications of Interest to Radioisotope Laboratories

Atomic Energy Commission, Isotopes Division, Circular B–7, General rules and procedures concerning radioactive hazards.

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Marinelli, L. D., Quimby, E. H., and Hine, G. J., Dosage determination with radioactive isotopes. II. Practical considerations in therapy and protection, Am. J. Roentgenol. Radium Therapy, **59,** 260 (1948).

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Sullivan, W. H., Control of radioactive hazards, Chem. & Eng. News **25,** 1862 (1947).

Tompkins, P. C., Laboratory handling of radioactive material: Protection of personnel and equipment, MDDC 1527.

Western, F., Problems of radioactive waste disposal, Nucleonics, **3,** [2] 43 (1948).

Wirth, J. E., Occupational Med. **2**, 428 (1946).
Wyckoff, H. O., Kennedy, R. J., and Bradford, W. R., Broad and narrow beam attenuation of 500–1400 Kv X-rays in lead and concrete, Nucleonics, **3**, [5] 62 (1948).
American Standards Association, Safety code for the industrial use of X-rays.
Introductory manual on the control of health hazards from radioactive materials. (Prepared for the Medical Research Council by the Ministry of Supply, Atomic Energy Research Establishment) Issue No. 2 (Jan. 1949).
Medical X-ray protection up to two million volts (National Committee on Radiation Protection, Subcommittee 3, H. O. Wyckoff, Chairman) NBS Handbook 41.
Recommendations of the British X-ray and Radium Protection Committee, Seventh Revised Report (Oct. 1948).
Waste disposal symposium, Nucleonics, **4**, 9 (1949).
Symposium on Radiochemistry Laboratories (Ind. Eng. Chem. **41**, 228, 1949):
Impact of radioactivity on chemical laboratory techniques and design, R. C. Tompkins, and H. A. Levy.
Radiobiochemical laboratories, W. P. Norris.
Research with low levels of radioactivity, J. W. Swartout.
Semihot laboratories, N. B. Garden.
A radioisotope building, P. C. Tompkins.
Laboratory for preparation and use of radioactive organic compounds, C. N. Rice.
Remodeling a laboratory for radiochemical instruction or research, H. A. Levy.

Submitted for the National Committee of Radiation Protection.

LAURISTON S. TAYLOR, *Chairman.*

WASHINGTON, March 7, 1949.

U. S. GOVERNMENT PRINTING OFFICE: 1949