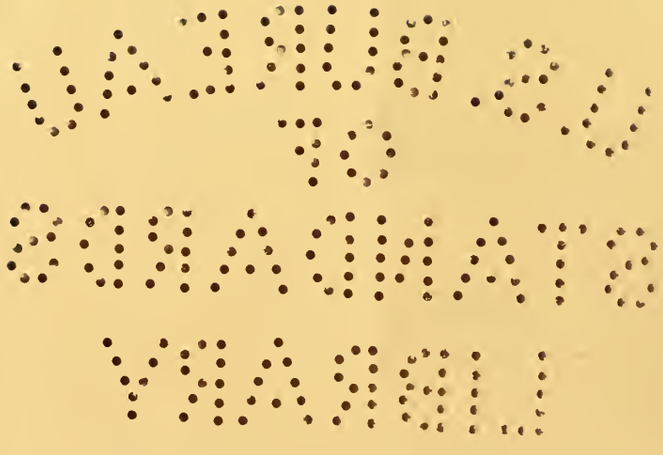
U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

RADIUM PROTECTION

NATIONAL BUREAU OF STANDARDS HANDBOOK H23
Superseding Handbook H18



U. S. DEPARTMENT OF COMMERCE
DANIEL C. ROPER, Secretary
NATIONAL BUREAU OF STANDARDS
LYMAN J. BRIGGS, Director

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RADIUM PROTECTION

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PREFACE

The rapid increase in the use of radium during the last few years, resulting in the acquirement of large amounts of radium by various institutions, has brought with it the need for better safeguards and rules to protect the users from the radiation. The dangers arising from exposure to the radiation from radium are in some cases now well known, in others, still obscure and uncertain. Sufficient experience and data are now available, however, to show fairly conclusively that with reasonable precautions radium can be handled over a considerable period of years with no apparent harm.

On the other hand, serious injury has resulted from relatively short periods of work with radium where certain precautions were overlooked. Even when proper working conditions and suitable regulations exist, there is still the potential danger of excessive exposure as a result of improper use of safety equipment and violation of good practice. Since the injury does not become apparent immediately, workers may frequently be tempted to neglect routine precuations.

The National Bureau of Standards has been engaged in the standardization of radium for medical purposes since 1913 and during this period has measured nearly all radium offered for sale in this country. The large amount of radium which has passed through our laboratory has made it necessary to give considerable attention to this problem of radium protection. But, the study of the biological effects of the radiation falls outside the field of our activities, and when the problem arose of revising Handbook H18, which sets forth proper conditions for handling radium based on present-day knowledge, we turned again to the Advisory Committee on

X-ray and Radium Protection. The following members compose this committee:

Representing International Safety Committee and National Bureau of Standards for X-rays:
LAURISTON S. TAYLOR, physicist.
Representing American Roentgen Ray Society:
E. R. PENDERGRASS, M. D., University of Pennsylvania Hospital, Philadelphia, Pa.
J. L. WEATHERWAX, physicist, Philadelphia General Hospital, Philadelphia, Pa.
Representing Radiological Society of North America:
R. R. NEWELL, M. D., Stanford University Hospital, San Francisco, Calif.
G. FAILLA, physicist, Memorial Hospital, New York, N. Y.
Representing the American Medical Association:
FRANCIS CARTER WOOD, M. D., St. Lukes Hospital, New York, N. Y.
Representing X-ray equipment manufacturers:
W. D. COOLIDGE, director, research laboratory, General Electric Co., Schenectady, N. Y.
Representing the American Radium Society:
CURTIS F. BURNAM, M. D., Howard A. Kelly Hospital, Baltimore, Md.

In response to the Bureau's request, Drs. Burnam, Failla, Newell, Weatherwax, and Wood kindly undertook the revision of the handbook. Dr. Curtiss, representing the National Bureau of Standards for radium, acted as secretary to the committee.

The regulations set forth in the following pages are the results of their joint recommendations regarding safe methods of handling preparations of radium used in radium therapy. I wish to express to the committee my sincere thanks for their cooperation in the preparation of this handbook.

LYMAN J. BRIGGS, *Director.*

RADIUM PROTECTION

CONTENTS

I. GENERAL CONSIDERATIONS

Protection rules and their application.—It is well known that overexposure to the radiations emitted by radium, or other radioactive substances, may result in serious injuries. However, the experience of the last 25 years provides a satisfactory basis for the protection of those engaged in radium work.

The most important point is for the radium worker to have an ever present realization of the danger and to carry out all manipulations in such a way as to reduce the exposure to a minimum. It is possible, by being careful, to handle this dangerous substance without injury, but care must be used as a thoughtful policy and never relaxed, for injuries by radium are insidious and may not become visible until a long time after they have occurred.

The recommendations given in the following paragraphs are intended to serve as a guide to radium workers and employers. Naturally, they must be followed judiciously to meet special problems which may arise in different laboratories. It should be borne in mind, however, that whatever means of protection are provided in any particular laboratory or clinic, they must be sufficient to prevent permanent

injury whether local or systemic, when instructions are properly followed by the worker.

Before an individual is employed to handle radium, he shall be informed of the dangers involved. He shall then be instructed to make proper use of the necessary safety measures provided in the laboratory or clinic. It is suggested that radium workers familiarize themselves with the recommendations contained in this handbook.

1.01. Protection for radium workers is required from the effects of (1) local overexposure to radiation—especially upon the hands—and (2) overexposure of the entire body.

1.02. In either case adequate protection may be secured most readily by distance and brevity of exposure.

1.03. All manipulations shall be carried out as rapidly as possible and with the hands and body as far from the radium as practicable. No radium preparations must be allowed to come in contact with any part of the technician's body (especially the hands) at any time.

1.04. Radium workers must not remain in proximity to radium when not engaged in necessary manipulations.

1.05. The chart, figure 1, gives the combinations of lead thickness and distance for different amounts of radium, which provide adequate protection for exposures not exceeding 7 hours daily.

NOTE.—Continued exposure of technicians for a number of years, under the conditions stipulated in the chart, has been found to be safe at Memorial Hospital, New York, N. Y. The tolerance gamma ray intensity derived from the chart is approximaetly 0.1 *r* per day.

Table 1 gives typical values obtained from the chart to illustrate its use.

1.06. All storage containers shall be at as great a distance as convenient from any place habitually occupied by any person, but in no case shall the combination of distance and screening (whether by lead or equivalent thicknesses of other materials) be less than indicated in the above-mentioned chart.

1.07. It is recommended that whenever possible the amount of radiation to which a person is subjected during the entire working day be measured by a suitable integrating device over a long enough period to be representative of average working conditions.

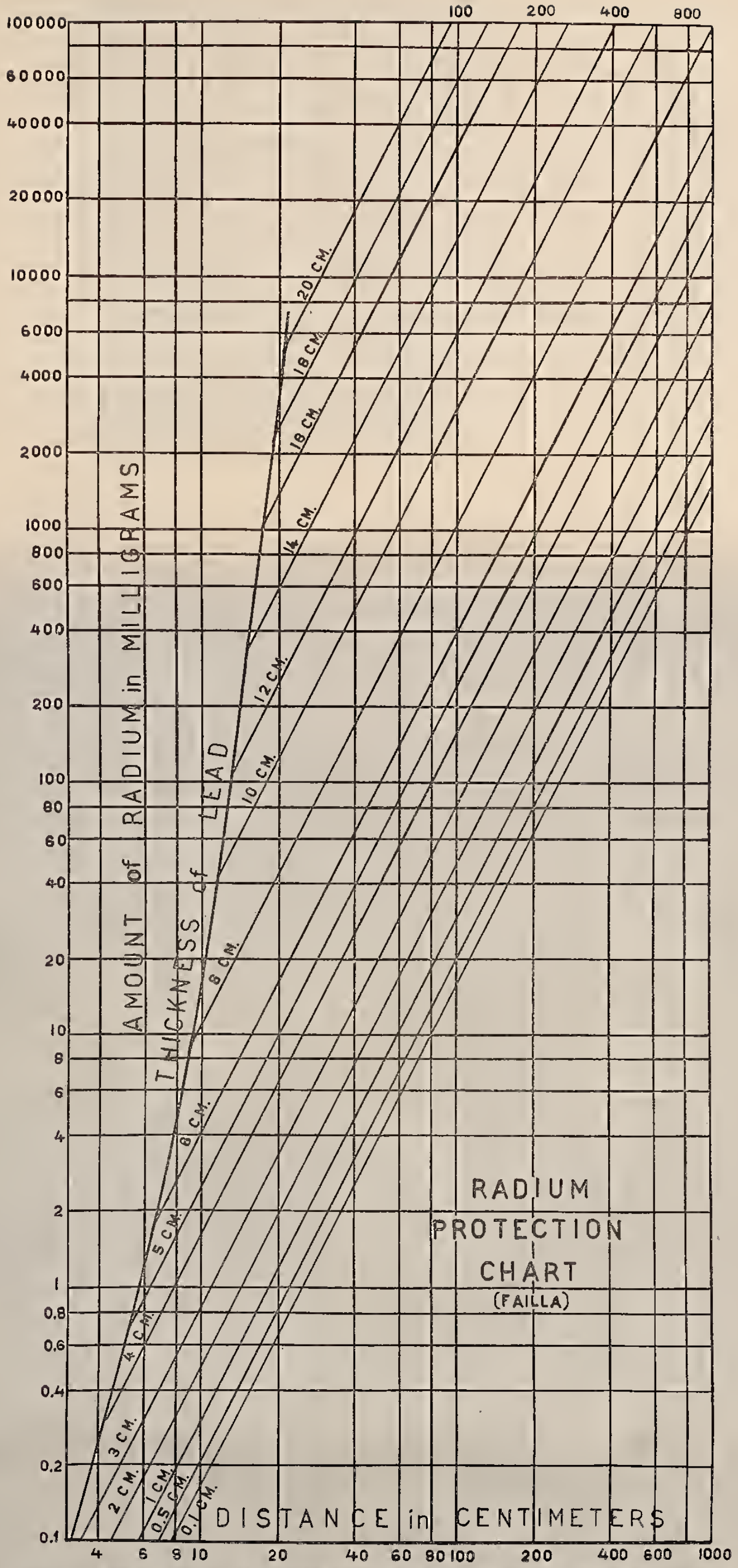

FIGURE 1.—*Radium protection chart showing distances at which it is considered safe for an individual to be for a number of years during working hours (not exceeding 8 hours daily) for various amounts of radium and lead screening.*

The chart is based on actual experience with radium technicians. It is interesting to note that under the conditions stipulated in the chart, the individual is exposed to approximately 0.1 *r* per day, which is within the range of tolerance intensity generally accepted for X-ray workers.

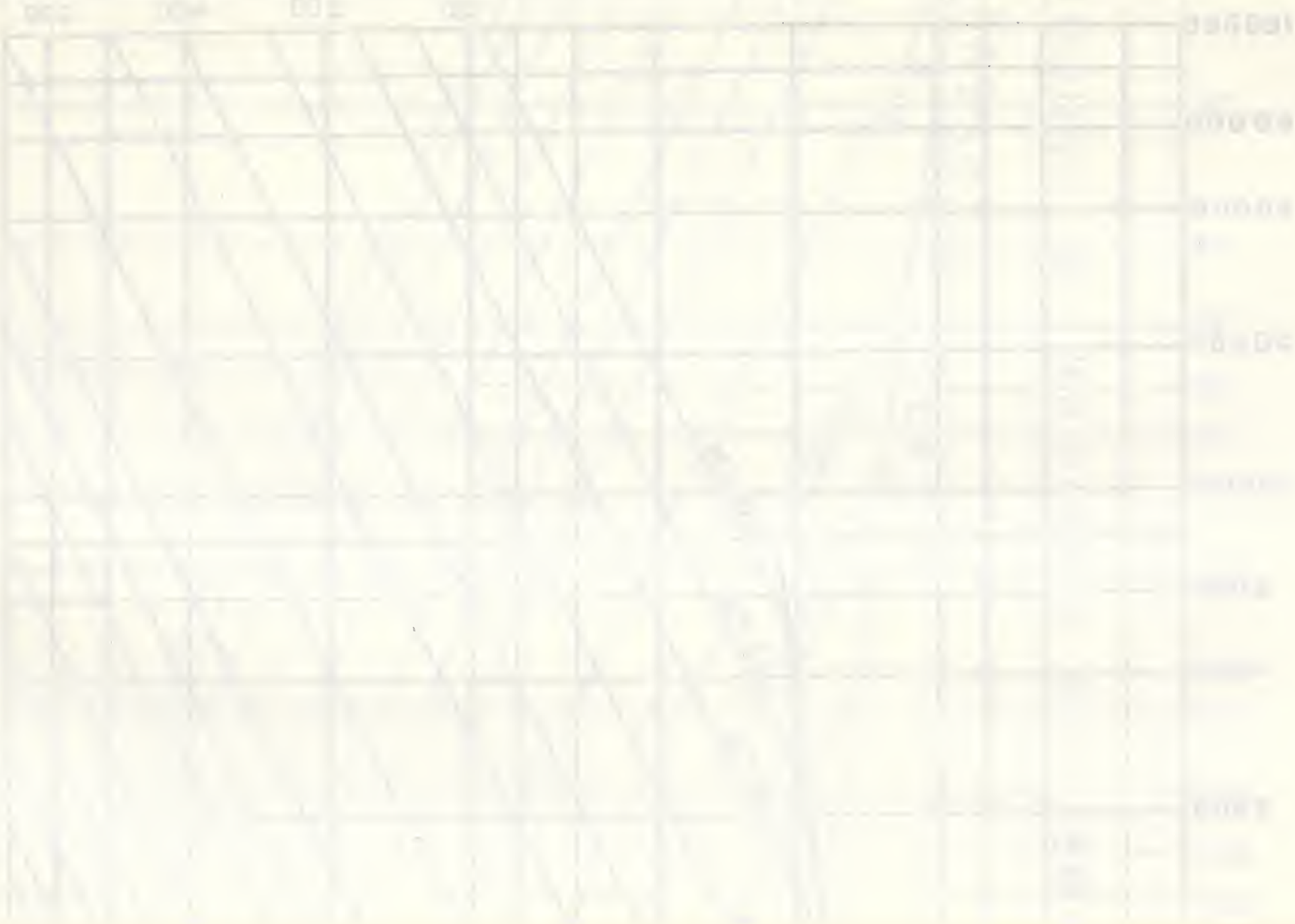

TABLE 1.—*Illustrations of use of chart*

Amount of radium	Thickness of lead	Distance	
Milligrams	*Centimeters*	*Centimeters*	*Feet*
10	0.5	70	2¼
	1	60	2
	2	45	1½
100	1	185	6
	2	140	4½
	3	105	3½
1,000	1	570	19
	3	340	11
	6	160	5
5,000	4	550	18
	6	350	11½
	10	220	7

1.08. Photographic films carried in a pocket during working hours may be used as a rough test of protection. Ordinary "dental film" with a paper clip is convenient for this purpose. The paper clip helps to distinguish between exposure to hard gamma rays and exposure to soft radiation—largely beta rays. If the film shows decided blackening after being carried 2 weeks, conditions should be investigated to determine whether this is due to local exposure or is indicative of the exposure which the entire body receives. In the latter case steps should be taken to reduce the general exposure of the body to a safe limit. Moderate darkening of ordinary dental films in 2 weeks' exposure may be taken as a rough indication that the general radiation is within the tolerance limit. It should be borne in mind that film tests of this sort are not very satisfactory. X-ray films are so sensitive that a certain degree of darkening is always found in dental films carried by radium workers for 2 weeks. It is impossible to make a close estimate of the radiation received by the film without elaborate experiments and careful measurements of the photographic density. A film showing marked blackening from *local exposure* does not necessarily indicate dangerous working conditions.

II. PERSONNEL

2.01. The effects on the human body of continued exposure to low radiation intensities are not well known.

(*a*) Overexposure of the entire body or a large part thereof may cause, eventually, a lowering vitality with a general feeling of lassitude and frequent headaches.

(*b*) Extreme overexposure of the entire body may result in the development of anemia or possibly leukemia.

(c) Overexposure of some part of the body (e. g., the hand) may result in local "radium burns" which are very refractory to treatment and may eventually become cancerous.

2.02. Complete blood counts shall be taken every month for persons regularly working with radium.

(*a*) A complete blood count consists of the following determinations: Hemoglobin test, red, white, and differential counts, the latter including percentages of polymorphonuclear cells, small and large lymphocytes (separately), eosinophiles and basophiles. In addition a blood platlet, sedimentation and coagulation tests are of value.

(*b*) Blood counts of one individual taken at different times of the day may vary considerably. Accordingly, they should always be taken at the same hour, particularly, with respect to meals. If possible the same technician employing the same method and technique should take all counts for one individual.

(*c*) Blood counts of different individuals may vary considerably within normal limits. Therefore, the absolute values of the different counts are not so important as the relative values of corresponding counts from month to month. A downward trend of the white count and of the percentage of polymorphonuclear lymphocytes, over a period of a few months, may be taken to indicate the possibility of overexposure. The matter should be investigated immediately.

(*d*) Before employing a technician for radium work a complete blood count should be taken. This, together with the first few monthly counts (before appreciable change from radiation may occur) may be taken as the normal count for the individual. No one should be employed as a radium technician if there are unaccountable abnormalities in his blood count.

(*e*) In appraising the significance of changes in blood counts within the first few months, all factors should be considered, including particularly the previous occupation of the individual (e. g., whether outdoors in indoors).

(*f*) Since blood counts of normal individuals ordinarily vary within wide limits among themselves and from time to time for the same person, one must beware lest a blood count which is within these limits, lull one into a false sense of security. As already pointed out, more attention must be paid to the trend of successive counts than to absolute values. It is suggested that all counts be made under the direction of a skilled hematologist to detect the earliest deviation from normal.

2.03. A thorough physical examination of a radium worker should be made before he is employed and at any time that the blood count shows suggestive changes or that the worker complains of some obscure ailment. In the physical examination, particular attention should be given to teeth, tonsils, and focal infections; also to the condition of the skin on the hands.

(*a*) Persons with dry skin having a tendency to crack, a skin with warts, or a skin showing signs of abuse (cuts, cracks, etc.) should not be employed for radium work. (Dirty nails indicate that an individual is apt to abuse his hands in manual work and he should not handle radium.)

2.04. The hands of a radium technician shall be examined at regular monthly intervals.

(*a*) The first effect of local exposure manifests itself as a reddening and shiny appearance of the skin of the fingers next to the nails.

(*b*) Later nails may assume an abnormal curvature, either up or down and with continued exposure become brittle.

(*c*) The skin at the end of the index finger and the thumb may become somewhat leathery and may lose its characteristic ridges. This may be taken as a definite indication that the individual is careless and on occasion handles radium with his fingers.

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(*d*) At what stage the individual should stop working with radium depends on circumstances. However, a radium technician should be informed of the occupational hazards at the outset and should be reminded of them from time to time. He should not be promised permanent employment.

2.05. Individuals with faulty vision, which cannot be corrected properly by glasses, shall not be employed for radium work.

2.06. Radium technicians who have been employed more than a year should have 4, and preferably 6 weeks vacation a year. This should be arranged to permit 4 weeks during the summer and 2 in winter. Technicians should be urged to spend as much time as possible outdoors, both during vacation and after working hours. If other methods of reducing exposures, such as intermittent employment in radium work, are used, the vacation period can be reduced.

2.07. Precautions shall be taken to protect nurses in charge of patients receiving radium treatments, and other persons who, in the performance of their duties, are subjected to radiation from patients under treatment.

(*a*) Distance and length of exposure are the two factors which can be controlled most readily for the protection of such personnel.

(*b*) Table 2 gives the distances at which it is safe for a person to be, for a period of years, from patients receiving different milligram-hour doses daily. (The influence of walls and objects in the path of the rays has not been taken into account in table 2.)

TABLE 2.—*Safe working distances*

Daily exposure	Safe distance	
Milligram-hours	*Meters*	*Feet*
100	1	3
200	1½	4
400	2	6
800	2½	8
1,600	3½	11
3,200	5	15

(*c*) Nurses who regularly attend to patients being treated with radium should perform their duties which bring them

close to the radium as rapidly as possible and should then remain as far as practicable from the patient or patients.

2.08. In institutions where large quantities of radium are used for the treatment of patients special precautions shall be taken to prevent overexposure of nurses and secretaries as well as radium technicians.

(*a*) The nature of these precautions depends largely on local factors and conditions. It is suggested that whenever possible nurses assigned to radium cases be rotated and that patients receiving radium treatments be widely separated.

(*b*) Monthly blood counts should be taken if a preliminary survey based on the figures of table 2 suggests the possibility of overexposure.

III. STORAGE

3.01. When not in use or transit, all radium shall be stored in a protective inclosure.

3.02. This inclosure shall provide sufficient protection to all persons, whether employees or not, who may periodically come within the "danger range" of radium. The "danger ranges" of different quantities of radium filtered by no less than 1 mm of lead or its equivalent, for different daily exposures are given in table 3.

TABLE 3.—*Danger ranges* [1]

Amount of radium element (milligrams)	Daily exposure (in hours)				
	1	2	4	8	16
	Danger range (in meters)				
100	0.9	1.3	1.8	2.5	3.6
200	1.3	1.8	2.6	3.6	5.1
400	1.8	2.5	3.5	5	7.1
1,000	2.9	4	5.7	8	11.3

[1] Values based on protection chart, figure 1.

3.03. The amount of absorbing material to be provided in any one direction depends on:

(*a*) The distance at which the person to be protected may be.

(*b*) The period of time during which the person may remain at this distance.

(*c*) The influence which the amount of absorbing material affording sufficient protection in any given direction may have on the intensity of radiation at other points to be protected.

NOTE.—It is not sufficient to place a large quantity of radium near an outside corner of a room behind a lead plate, no matter how thick. The protection for people outside will be more than sufficient, but inside the room there may be too much scattered radiation.

3.04. In any event, sufficient protection shall be provided to reduce the general body radiation to which a person may be exposed to 0.1 *r* per day for the person in question.

3.05. In the case of persons who are apt to handle radium for a number of years, account must be taken of the exposures and correspondingly greater protection from stored radium must be provided.

3.06. The protective enclosure may be constructed of any suitable material. If any material other than lead is used, it is important that the equivalence to the necessary lead thickness, derived from the protection chart for any given case, be determined under proper conditions. Absorption measurements made with narrow beams of gamma rays are not satisfactory for this purpose.

3.07. The protective material should surround the radium and should be as close thereto as practicable. This is not only more economical but makes the source of scattered radiation (the inclosure itself) smaller.

NOTE.—A large concrete wall of insufficient thickness to absorb *all* the radiation provides more scattered radiation into an adjacent room than the same thickness of concrete placed immediately around the radium.

3.08. The protective enclosure shall be constructed in such a way as to minimize, as much as possible, the exposure of technicians in the handling of the radium. The most important factors to consider are:

(*a*) Distribution of the radium.

(*b*) Protection of subdivided amounts.

(*c*) Time required by technician to remove or return a particular applicator to the enclosure.

3.09. The radium supply should be subdivided into small lots in the protective enclosure, each lot being placed in a suitable, protected compartment. The number of tubes or needles which may be placed in each compartment, depends on the radium content of the preparations and the number of units which are generally grouped together in the treatment of average cases.

3.10. Separate compartments should be provided for different types of applicators and for those of distinctly different radium content.

3.11. Each compartment should be labeled or otherwise marked so as to permit immediate and certain identification of its contents from the outside.

3.12. It is highly desirable that tubes, cells, needles, etc., be readily identifiable from a considerable distance as to their radium content. When sizes and shapes are not adequate other means should be employed, such as plating or enameling with different colors.

3.13. The protection of the individual compartments and the enclosure as a whole should be such that a technician standing in front of the enclosure in performance of his duties receives in that time only a fraction of the allowable daily body dose.

IV. MANIPULATION AND PREPARATION

4.01. The exposure to radium radiations of technicians, nurses, and all individuals who handle radium, shall be reduced as much as practicable by providing suitable equipment and accessories.

4.02. Such equipment shall be designed to permit the necessary operations to be carried out expeditiously at a considerable distance, and behind protective screens—the three factors being properly adjusted with respect to the influence of one upon the others.

4.03. The preparation of radium applicators or similar operations shall be carried out behind a lead L-block of a minimum thickness of 5 cm in the direction of the technician, and of such size as will shield the entire body.

(*a*) The block should be of such height that when placed on a table, the technician can look over the edge comfortably when standing.

(*b*) The top of the L-block should be provided with an inclined lead-glass "visor" equivalent to at least 1 mm of metallic lead if unfiltered radium or radon is to be handled.

(*c*) The side of the block next to the technician should have a protective pad to keep his body at least 20 cm from the point where the radium is handled.

(*d*) The inside corner of the L should be curved so as to increase the lead thickness at the level where the radium is closest to the body and to insure that the manipulations are carried out at a considerable distance from the corner.

(*e*) The lead block should be covered with wood, "linoleum," or other material of low atomic weight.

4.04. Vises or clamping devices should be provided at the lead block to facilitate preparation of applicators. Preferably these devices should be operated by foot pedals.

4.05. Forceps for handling radium should be designed specially for this use. In general:

(*a*) They should be as long as the operation to be carried out permits, taking into account speed and preciseness of manipulation.

(*b*) They should grip the radium containers firmly with a minimum of force exerted by the fingers. Spring-operated self-clamping forceps are desirable where practicable. The jaws should be notched, grooved, or otherwise formed to fit the applicators to be handled.

(*c*) Forceps 25 to 30 cm long are recommended for general purposes. They should be light in weight to permit rapid and accurate manipulation. If unfiltered specimens are to be handled, forceps should be provided with metal gauntlets of ½-mm lead equivalent for absorption of primary beta rays.

(*d*) Forceps used to lift easily-damaged preparations should have a "spring tip" adjusted to prevent excessive pressure on the specimen.

(*e*) Cross-action forceps are desirable for some delicate manipulations.

4.06. A suitable device should be provided for threading needles or tubes expeditiously with the fingers protected as much as possible by distance and lead barriers.

4.07. Rooms in which radium is handled must be properly lighted and ventilated. Special operations may require individual lighting.

4.08. A lead-lined "well" should be provided near the lead L-block, to hold radium preparations required for an applicator while it is being made up. The "well" should be covered by a heavy lead top on suitable rollers so that it can be moved to the open position by a foot lever and returned to the closed position by gravity.

4.09. Radium technicians should be supervised to make sure that they take advantage of the protective devices provided. Injuries from overexposure to radium rays do not manifest themselves for days, weeks, or months. This is apt to lead to carelessness. New technicians must be instructed properly at the start, and the dangers of overexposure impressed on them. All operations should be planned outside the preparation room and then carried out rapidly, so that the time spent in handling the radium is only that absolutely necessary to carry out the required manipulations.

4.10. In spite of all precautions, radium technicians who work with large quantities of radium are subjected to higher radiation intensities than that to which it is definitely safe to be exposed for several years. Where this is the case blood counts and fingers should be watched carefully, and appropriate steps taken as soon as indications of slight overexposure appear. Where large quantities of radium are used the responsibility of the director is very great and he must watch very closely to see that protective measures are actually carried out and also must watch his workers closely to discover the first signs of injury to hands or bone marrow, so that faults can be stopped or the worker removed.

V. RADON PLANTS

5.01. To avoid danger of inhalation of radon by the operator, thorough ventilation (at least eight complete changes per hour) of the room in which radon pumping equipment is located is essential. Exhaust fans should draw air from near the floor and discharge it into the open air through as short ducts as practicable. Ventilation fans

should be turned on at least a half hour before the room is to be occupied, unless means are provided to detect possible leakage of radon.

5.02. Lead screening shall be provided for all parts of the radon apparatus in which radon accumulates, including the connecting glass tubing where the most radon will collect.

5.03. Manipulations of radon bulbs and seeds shall be carried out as far as possible immediately after they have been sealed from the pumping apparatus while the active deposit is at a minimum.

5.04. Automatic pumping equipment or apparatus equipped with remote controls is recommended for radon pumping.

5.05. Exposures are of the same character as for radium of the equivalent amount and filtration. Therefore, all recommendations contained in this handbook for screening, storage, and manipulation of radium preparations apply equally to preparations of radon.

VI. TRANSPORTATION WITHIN AN INSTITUTION

6.01. Containers for carrying radium shall provide adequate protection from local injury (e. g., burns) and general systemic disturbances in individuals handling the container, based on the longest possible time that the individual may carry the package or packages at any one time or repeatedly in the performance of his duties.

6.02. The required protection may be obtained by a suitable combination of lead screen completely surrounding the radium.

(*a*) Radium carriers should be designed to conform with the specifications given in table 4 as to lead thickness and distance of the radium from the handle.

(*b*) The handle of the carrier should be so arranged that it is easier to carry it by the handle than in any other way.

(*c*) Hand carriers should not weigh more than 10 kg and should be provided with long handles which bring the radium close to the floor in the normal carrying position. The lead lining at the bottom may be half as thick as that of the sides and top.

(*d*) Radium carriers which weigh much more than 10 kg should be mounted on wheels.

TABLE 4.—*Specifications for carriers*

Amount of radium	Lead thickness (or equivalent)	Minimum distance from radium to handle
Milligrams	*Centimeters*	*Centimeters*
10	0.1	25
	1.0	18
20	0.1	35
	1.0	26
40	0.1	50
	1	37
100	1	60
	2	45
200	2	64
	3	50
400	2	90
	3	70
1,000	2	140
	3	110
	4	80

(*e*) All radium carriers should be constructed so as to reduce to a minimum the time required to place applicators therein and remove them and at the same time permitting all operations to be carried out with the technician's hands at a considerable distance from the radium.

6.03. In the case of an individual who may transport radium for many years, the average total dose must not exceed 0.1 *r* per day. In estimating the body dose one may take the distance of the radium from the umbilicus as a rough approximation to the average effective distance.

6.04. It is suggested that, especially in institutions or laboratories where large quantities of radium are handled, radium technicians be relieved as far as practicable from the task of transporting radium preparations from one room to another. This may well be done by employees who are not continually exposed to radiation. It should be noted in this connection that the specifications of table 4 are not so stringent as those for the storage of radium. The body dose

resulting from carrying radium 7 hours a day under the conditions set forth in the table is approximately 1 *r* per day.

6.05. When radium is transported from a hospital or laboratory to a doctor's office or patient's home, precautions should be taken to prevent injury to the person carrying it.

(*a*) The radium carriers for this purpose may be those used for tranpsorting radium within the hospital proper, or they may be specially designed, depending on conditions.

(*b*) So far as practicable, technicians regularly engaged in radium work should not be required to transport radium in this way. At any rate the exposure to which a technician is subjected in the course of transporting radium must be taken into account.

TABLE 5.—*Protection of a messenger from local radium injury*

Amount of radium	Lead thickness (or equivalent)	Minimum distance from surface
Milligrams	*Centimeters*	*Centimeters*
10	0.1	3.5
20	0.1	5.0
	.5	4.4
	1.0	3.75
50	0.1	7.9
	.5	6.9
	1.0	5.9
100	0.1	11.1
	.5	9.8
	1.0	8.3
200	0.1	15.7
	.5	13.7
	1.0	11.7

(*c*) Individuals who transport radium regularly in public conveyances shall be instructed to place the container on the floor and to stand, rather than sit, near it. In automobiles, radium should be placed as far as possible from persons who work with it regularly.

6.06. When radium is sent out of the hospital or laboratory by a messenger who is not familiar with the dangers of overexposure, the container or package shall be such as to preclude the possibility of local injury.

(*a*) The combination of lead thickness and minimum distance of the radium from the surface of the container given in table 5 provide sufficient protection from *local injury* with a large factor of safety.

(*b*) It is desirable to add a handle to the box or container to bring the radium close to the floor in the normal carrying position.

(*c*) Special carrying cases may be provided for such transportation of radium. If they are constructed in such a way that in the obviously most comfortable carrying position the radium is close to the floor, they may be of smaller dimensions than indicated in table 5.

VII. TRANSPORTATION BY COMMON CARRIERS

7.01. Shipment of radium, radon, or similar radioactive substances through the mails is prohibited by postal regulations in the United States. This regulation is intended to prevent fogging of photographic films.

7.02. Shipment of radium up to 100 mg in a single shipment may be made by railway express when the package is plainly marked as containing radium and is provided with lead screening sufficient to protect superspeed X-ray films. Details may be obtained from local express agents.

VIII. UNUSUAL CONDITIONS

8.01. It is impossible to deal with unusual conditions within the scope of this handbook. Among such are refineries of considerable amounts of radium and unusually large amounts of radium in a single institution. It is the opinion of the committee that in such situations a special survey should be made with competent expert advice to determine necessary safeguards.

Washington, April 25, 1938.

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