U. S. Department of Commerce Charles Sawyer, Secretary
National Bureau of Standards A. V. Astin, Acting Director

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Recommendations for Waste Disposal of Phosphorus-32 and Iodine-131 for Medical Users

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Preface

The Advisory Committee on X-ray and Radium Protection was formed in 1929 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 on Radiological Protection. The committee, small in size, has functioned effectively. However, the advent of atomic energy has 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 listed 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 publication.

The following parent organizations and individuals comprise the main committee:

H. L. ANDREWS, U. S. Public Health Service.
E. G. WILLIAMS, U. S. Public Health Service.
SHIELDS WARREN, U. S. Atomic Energy Commission.
K. Z. MORGAN, U. S. Atomic Energy Commission.
L. S. TAYLOR, National Bureau of Standards, (Chairman).
E. E. CHARLTON, National Electrical Manufacturers Association.
M. J. GROSS, National Electrical Manufacturers Association.
H. B. WILLIAMS, American Medical Association.
R. S. STONE, Radiological Society of North America.
G. FAILLA, Radiological Society of North America.
R. R. NEWELL, American Roentgen Ray Society.
J. L. WEATHERWAX, American Roentgen Ray Society.
J. E. WIRTH, American Radium Society.
E. QUIMBY, American Radium Society.
R. C. PEAVEY, National Bureau of Standards, (Secretary).
J. H. JENSEN, North Carolina State College.
W. S. COWART, Lt. Col., Office of Director of Armament, U. S. Air Forces.
N. BIRNBAUM, Lt. Col., Army Chemical Center.
W. H. SULLIVAN, Naval Radiological Defense Laboratory.

The following are the subcommittees and their chairmen:

Subcommittee 1. Permissible Dose from External Sources, G. Failla.
Subcommittee 2. Permissible Internal Dose, K. Z. Morgan.
Subcommittee 3. X-rays up to Two Million Volts, H. O. Wyckoff.
Subcommittee 4. Heavy Particles (Neutrons, Protons and Heavier), D. Cowie.
Subcommittee 5. Electrons, Gamma Rays and X-rays above Two Million Volts, H. W. Koch.
Subcommittee 6. Handling of Radioactive Isotopes and Fission Products, H. M. Parker.
Subcommittee 7. Monitoring Methods and Instruments, H. L. Andrews.
Subcommittee 8. Waste Disposal and Decontamination, J. H. Jensen.

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, utilization, and disposal of wastes. Comments on those recommendations 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 subcommittees mentioned above.

The best available information on permissible radiation levels and permissible quantities of ingested radioactive material may be found in the Recommendations of the International Commission on Radiological Protection and the Supplement to these recommendations in NBS Handbook 47. It should be borne in mind, however, that even the values given in that Handbook may be subject to change.

As the problem of the disposal of radioactive wastes varies over such wide limits, depending upon the usage to which the isotopes are put, the committee has decided that it will not be feasible to incorporate in one volume broad recommendations covering all situations and materials. Accordingly, individual reports dealing with particular conditions will be put out from time to time. This is the first of a series of such reports.

The present Handbook has been prepared by the Subcommittee on Waste Disposal and Decontamination. Its membership is as follows:

JAMES H. JENSEN, Chairman.
W. F. BALE.
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SERGEI FEITELBERG.
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NATHAN WOODRUFF.

A. V. ASTIN, *Acting Director.*

Contents

Recommendations for Waste Disposal of Phosphorus-32 and Iodine-131 for Medical Users

I. Introductory Remarks and General Considerations

1. The first official recommendations concerning disposal of radioactive wastes by other than Atomic Energy Commission users (e. g., hospitals) was issued some years ago as "Interim Recommendations for the Disposal of Radioactive Wastes by Off-Commission Users, USAEC Isotopes Division Circular B–6". In this, permissible concentrations of P^{32} and I^{131} in sewage were established, but it was left to the individual user to decide how much could be disposed of by various methods under conditions prevailing in his institution.

It is expected that disposal of the greater part of these isotopes will be by sewer. The purposes of the present recommendations are:

(a) To consider permissible concentrations, from the point of view of safety to the general community, and more especially to sanitation workers and sewage plant personnel; and

(b) To formulate rules for disposal practice, for specified isotopes. These should be practical, and easily followed, on the basis of information readily available to the responsible individuals. Methods recommended are similar to the conventional disposal of other wastes, or simple modifications of these.

2. All quantitative data used in this report are based on information on average water consumption. Flow rates are calculated on the basis of flow volumes, and are, therefore, averages. The calculated isotope concentration levels must also be considered as average values. The latter may be expected to vary within a wide range for various single disposal events, within a particular system.

3. Dilutions are estimated for the discharge point from the institution into the sewage system into which the radioactive wastes are discharged (i. e., for the institutional treatment plant, or the main sewer outfall). No account is taken of hazards that may develop in private drain pipes, due to concentration of radioactive wastes or due to the use of certain pipes exclusively for discharge of these materials. This depends on local conditions, which are best controlled by institutional regulations for monitoring of plumbing by personnel responsible for radiation safety. For control of sewage contamination on the community scale (particularly sewage treatment plants) consideration will be given to the total average daily permissible amounts discharged.

4. It is not realistic to insist on dilution of radioactive waste in sewage to the level established as permissible in drinking water. Ingestion of this fluid will occur only as the result of an accident, and the hazard should be considered from this point of view. In actual practice, high concentrations in pipelines will occur over short periods; as will be shown later, the duration of such high transient concentrations will be about 30 sec. It may be assumed that in the case of accidental immersion in sewage, not more than 0.25 liter would be swallowed in 30 sec. It would be reasonable to assume further that this will not happen often, and that therefore the ingestion of a permissible tracer dose of the isotope could be tolerated in the accident. The permissible tracer dose of either P^{32} or I^{131} is approximately 100 μc;[1] this would be contained in 0.25 liter if the concentration were 0.4 μc/ml. To allow for an additional margin of safety, the value for *maximum short-period* contamination of P^{32} or I^{131} in sewage used in the following calculations is 0.1 μc/ml (0.1 mc/liter).

5. In the same sewage plant an external radiation hazard to plant personnel might be thought to exist in case of accidental immersion in a concentration of 0.1 mc/liter. This concentration would be possible, but improbable, because of the dilution of the high transient concentrations in the pipelines by the time they reach the plant (unless the institution has its own treatment plant). Even in a concentration as high as 0.1 mc/liter, however, the radiation received on the surface of the body by such immersion would be relatively low. For an immersion of 1 hour, the calculated dose on the surface of the body is 0.2 rep for P^{32} and 0.1 rep for I^{131}; these are both less than the permissible weekly exposure.

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[1] L. D. Marinelli, E. H. Quimby, and G. J. Hine, Dosage determinations with radioactive isotopes, Am. J. Roentgenology & Radium Therapy 59, 260 (1948).

6. If sludge from institutional or community sewage-treatment plants is to be used as a fertilizer, the hazard to the general population must be considered. It may be assumed *that the concentration of I^{131} in the sludge cake will* not exceed that of the sewage as received, and that this concentration will be reduced depending upon the time involved in digestion, conditioning, filtration, and storage of the sludge. At this level, the danger from exposure to the fertilizer is obviously less than that to the sewage plant worker. The extent to which P^{32} may be concentrated in fresh sludge is not known, but this will be dependent on these same factors.

7. From the above considerations, it appears that the limiting factor in the determination of the quantity of radioactive isotopes that may be discharged daily to a sewage-treatment plant will be the rate of water flow at the plant.

The simplest way to dispose of radioactive wastes encountered in connection with administration of the material to patients is, of course, to allow the patient to use the toilet without restriction. This will be called *toilet disposal*. An alternative is to pour the radioactive material into the sink. In this case it is preferable first to put it into a 1-gallon bottle (see limitation below), fill this to the top, using tap water if necessary, and pour this into the sink. This will be called *batch bottle* disposal. The batch disposal (toilet or bottle) of a single sample takes from 3 to 30 sec; by the time it arrives at the sewage plant it may be considered as diluted with the proportional part of the 24-hour flow. In an institutional or municipal system having an average dry-weather flow of 1 million gallons a day at the treatment plant, the flow in 4 sec is about 100 liters. This will dilute 10 mc to a concentration of 0.1 mc/liter, which has been shown above to be without practical hazard to plant personnel. While it would be expected that this concentration would be further reduced in treatment tanks, it might again be increased in sludge concentration. For lack of accurate data on these points, it is felt wise at present to set the limit of 10 mc for a single-batch discharge, per million gallons of flow a day. In any case where the daily discharge of P^{32} and I^{131} exceeds 10 mc a day per million gallons of sewage flow, the disposal should be made in small batches at intervals, or through a constant head orifice or similar means to maintain a relatively uniform discharge over a period of 6 daylight hours a day or longer. One such device is the *constant-drip discharge bottle*, described in appendix II. With the installation and operation of such a uniform-discharge device, 100 mc of these isotopes may be discharged in any 6-hour daylight period into a system having a 1-million-gallon average dry-weather flow. The permissible discharges for other sewage flows will be proportional to the above, e. g., 50 mc for 0.5 million gallons daily, or 10,000 mc for 100 million gallons daily.

The above limits are subject to revision in any community on the basis of actual radioactive measurements in the sludges. At the present time such measurements in actual sludges will, in general, reveal no significant increases over background. Increased use of radioactive isotopes in the future may permit the obtaining of quantitative information under field conditions. Where quantities of radioactive isotopes of the order suggested by these limits are discharged, radioactive measurements of the sludge should be made and the limits revised, if necessary. Responsible officials at institutions using considerable quantities (100 mc or more a week) of radioactive isotopes, should inform and cooperate with municipal and state health authorities, in order that proper arrangements for monitoring may be made when there is any question regarding safety or hazard.

Definite values for permissible activity in sewage, industrial wastes, and sludges, will ultimately be established on the basis of values set by the Subcommittees on Permissible Internal Dose and Permissible Dose from External Sources. In the meantime, recommendations herein contained should serve as a satisfactory guide.

8. As it does not seem possible that biologic concentration of I^{131} in sewers will lead to dangerous levels, isotopic dilution is not necessary. Phosphorus, on the other hand, is concentrated to a considerable extent by anaerobic sewage slimes and aerobic cultures, such as activated sludge. However, there is adequate isotopic dilution of stable phosphorus in raw sewage, so that concentration of P^{32} cannot reach critical levels.

9. On the basis of the above-discussed general considerations, formulas have been developed for computing permissible discharge of P^{32} or I^{131} by various methods, in systems with different average water flows. The calculations are presented in detail in appendix I. In section II are presented recommendations based on these calculations.[2] An attempt has been made to formulate these simply, in the hope that they will be followed in practice by average users.

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[2] The calculations have not been included in the body of the report since it is felt that many readers will be more interested in the conclusions than in the manner of deriving them, and that the introduction of the mathematical development at this point might obscure the simple recommendations.

II. Recommendations for Disposal

After the daily or weekly waste-disposal level for an institution has been determined, the method of disposal must be decided from considerations of safety both to sanitation workers and to sewage-plant personnel, as discussed in section I. It has therefore been pointed out that for the first, a transient concentration of 0.1 mc/liter should be permissible (section I, 4), while for the second, a single-batch discharge of 10 mc, or a 6-hour constant discharge of 100 mc, per million gallons of water flow is satisfactory (section I, 7). According to a study of water consumption in American cities [3], sewage flow exceeds 1 million gallons in every community surveyed with a population of 15,000 or over. It is unlikely that serious isotope-disposal problems will exist in smaller communities. On the other hand, where a hospital of several hundred beds exists, with its own water flow an appreciable part of a million gallons, it may be assumed that the community flow is at least a few million, unless the institution has its own sewage-disposal plant.

In appendix I are developed formulas for calculation of permissible activities in millicuries for single disposal events, to reduce concentrations to permissible transient levels in sewage. These values are tabulated below (table 1) for institutions of various sizes, provided the dry-weather flow to the sewage treatment plant equals or exceeds a million gallons a day for each 10 mc discharged. If the flow to the sewage treatment plant is not great enough to permit the use of table 1 a constant-drip bottle should be used, on the

TABLE 1. *Permissible activities in millicuries for single disposal events.*

[Calculated according to appendix I, 2, d]

Number of beds	Number of people [a]	Toilet disposal		Batch bottle disposal day [b]
		Day	Night	
		mc	*mc*	*mc*
25	50	1 to 4	1 to 3	1
50	100	2 to 4	1 to 4	2
100	200	2 to 5	2 to 4	4
200	400	2 to 6	2 to 5	8
300	600	2 to 8	2 to 6	12
500	1,000	4 to 11	2 to 8	20
1,000	2,000	6 to 20	4 to 13	40

[a] It is assumed that the hospital population is equal to twice the number of beds.
[b] Batch discharge of a full 1-gal bottle (add tap water if necessary) emptied into a sink, not into a toilet.

[3] A. D. Flinn, R. S. Weston, and C. L. Bogert. Waterworks handbook. Table 172, Water consumption in American cities, p. 576 to 579 (McGraw-Hill Book Co., Inc., New York, N. Y., 1927).

basis of 100 mc discharged in this manner per million gallon per day water flow to the sewage-treatment plant. Thus for less than 10 mc the limiting factor is transient concentration in the pipeline, as determined from the table; for larger amounts the limiting factor may be concentration at the sewage plant, to be determined by total daily flow to this plant.

1. Small-Quantity Disposal

In diagnostic and therapeutic uses of P^{32}, in diagnostic use of I^{131}, and in treatment of hyperthyroidism with I^{131}, patients may use the toilet without any instructions or restrictions.

2. Carcinoma Treatment with I^{131}

(a) Hospitals

It is not possible to formulate simple instructions for the levels excreted in the treatment of carcinoma; millicuries excreted by a particular patient must be calculated on the basis of dose and uptake, and method of disposal must be decided from table 1.

When the quantities for disposal exceed the permissible values either from table 1 or from the general sewage-plant limitations, the following methods can be used:

1. Storage for decay to permissible activity.
2. Distribution of activity in a number of 1-gallon bottles, each containing permissible activity; filling bottles with tap water; successive emptying of these bottles into sink at proper intervals. (Batch bottle discharge.)
3. Six-hour disposal by constant-drip bottle. (See appendix II.)

In deciding on the use of one of the above methods, or of batch bottle disposal in accordance with table 1, radiation exposure to laboratory personnel must be considered. This is a matter for the institutional radiation safety officer, and outside the scope of the present report.

(b) Apartment houses and small homes

On the basis of table 1, it would appear that toilet disposal would rarely be permissible for patients treated without hospitalization. However, it must be considered that in these cases, for one home, only a single patient is involved; the probability of several persons in the same building being treated for cancer with radioactive isotopes at the same time is negligible. High contamination in the local sewage system will thus occur seldom, will be of brief duration, and will be promptly removed by further flow of sewage and by radioactive decay. This consideration permits recommendation of simple toilet disposal for patients who are not hospitalized. *This recommendation does not apply to ambulatory patients in certain treatment centers who live in hotels catering to such people.* Such hotels fall under the same disposal rules as hospitals.

3. Laboratory Disposal

For disposal by laboratories, the following methods may be used:

(a) Batch bottle disposal, according to table 1, or to equations 4 and 5 of appendix I.

(b) Constant-drip bottle, as described in appendix II. The same considerations govern total permissible amount, as in previous sections.

4. Simultaneous Disposal of P^{32} and I^{131}

When P^{32} and I^{131} are used simultaneously in an institution, disposal rules can be based on the sum of the millicuries of both isotopes.

5. Restriction of Total Quantity of Isotopes

Special precautions may have to be considered and introduced in hospitals specializing in treatment with radioactive isotopes. Daily and weekly disposals will have to be scheduled to keep within the permissible limits at all times. However, this does not appear to be an important problem in the immediate future.

Furthermore, it does not appear necessary to restrict generally the total amount of P^{32} and I^{131} used in an entire community, at present or in the near future.

Appendix I. Calculation of Sewage Contamination

1. Quantitative data and descriptive terms used in calculations

(a) Daily water use

Per person, in institutions---------- 550 liters average.

(b) Variations during a day, in percentage of average, for large and average residential communities and institutions

Night (7 p. m. to 7 a. m.)---------- 40 percent.
Day (7 a. m. to 7 p. m.)----------- 60 percent.

(c) Toilet flushings

Duration------------- 3 to 10 seconds.
Water used---------- 12 to 32 liters.

(d) Emptying a full 1-gallon, narrow-mouthed bottle (gallon jug)

25 seconds.

(e) Terminology

M, activity, in microcuries, introduced in a single disposal event.
Q, activity, in millicuries, introduced during a day.
P, number of people occupying a building.
N_m, maximal contamination occurring in a water column flowing through the sewer (microcuries per liter).
"Toilet disposal", patient uses toilet bowl without any instructions.
"Batch bottle disposal", using a full 1-gallon (3.785 liters), narrow-mouthed bottle in a sink (not a toilet bowl).
"Constant-drip bottle disposal", described in appendix II.

(f) Data on P^{32} and I^{131}

Some properties of P^{32} and I^{131} are given in table 1 of NBS Handbook 42. P^{32} has a half-life of 14.3 days and emits a beta ray with an energy of 1.71 Mev. I^{131} has an 8-day half-life and emits beta rays of 0.60 and 0.32 Mev and gamma rays of 0.638, 0.364, 0.284, and 0.080 Mev. Because of evidence of additional beta and gamma rays, considerable experimentation is in progress in various laboratories to establish further details of the decay of I^{131}.

(g) Dilution of activity in sewer

(1) *Toilet disposal.* Flushing time of 3 to 10 sec is 3/43200 to 10/43200 of 12 hours. Activity *M* is diluted by a corresponding fraction of total water flow for a 12-hour interval and by volume of flushing water (see 1, a, c). N_m will be a maximum for a 3-sec flushing time and 12 liters of flushing water, and minimum for 10 sec and 32 liters, respectively.

(a) Hospitals and apartment houses, day: water flow (in liters) in 3 sec $=3/43200\times 0.6\times 550\times P=0.023\,P$. Water flow in 10 sec $=0.08\,P$.

$$N_m=\frac{M}{32+0.08\,P}\text{ to }\frac{M}{12+0.023\,P}. \quad (1)$$

(b) Same, for night:

$$N_m=\frac{M}{32+0.05\,P}\text{ to }\frac{M}{12+0.015\,P}. \quad (2)$$

(c) Small homes; day or night: Amount of general flow during the short flushing time is so small that only flushing water need be considered for N_m calculation:

$$N_m=\frac{M}{32}\text{ to }\frac{M}{12}. \quad (3)$$

(2) *Batch bottle disposal.* Emptying a full gallon jug takes 25 sec. Activity *M* is therefore diluted by water flowing during 25 sec (day: $25/43200\times 0.6\times 550\times P$ liters, and night: $25/43200\times 0.4\times 550\,P$ liters).[4] This gives N_m similarly as in f, (1):

[4] The 1-gallon bottle content itself is disregarded, as it is small compared to the water flow during the interval.

(a) Institutions, apartment houses, day:

$$N_m = 5 \frac{M}{P}. \tag{4}$$

(b) Institutions, apartment houses, night:

$$N_m = 8 \frac{M}{P}. \tag{5}$$

(h) Permissible concentration and amounts per day [5]

$N_m = 0.1$ μc/ml (100 μc/liter)

$Q = 10$ to 100 mc per million gallons per day dry-weather sewage flow.

2. Calculation for Disposal Practice

(a) Tracer and therapeutic doses up to 1 mc

Less than 25 percent is usually excreted during the first day, and this occurs in not less than four evacuations. M is, therefore, usually not more than 6 percent of the administered dose, or 60 μc.

Maximum contamination that can occur if only flushing water is considered, calculated from eq 3:

$$N_m = 2 \times 10^{-3} \text{ to } 5 \times 10^{-3} \ \mu c/ml$$

i. e., below permissible level.

(b) Therapeutic doses of P^{32}

The largest single dose used at present is 7 mc. This results in $M = 420$ μc (6 percent of administered dose).

Again considering toilet-flushing water alone we get from 3

$$N_m = 0.013 \text{ to } 0.035 \ \mu c/ml$$

i. e., also below permissible level.

(c) I^{131} in treatment of hyperthyroidism

A single dose will rarely exceed 10 mc. In cases of hyperthyroidism requiring such a high dose, the first 24-hour excretion will be not more than 30 percent, and it may be assumed that not more than half will be evacuated at one time:

$$M = 1.5 \text{ mc}$$

Maximum contamination that will occur, if only flushing water is considered, calculated from (3)

$$N_m = 0.047 \text{ to } 0.125 \ \mu c/ml$$

i. e., still essentially at permissible level.

(d) Treatment of thyroid cancer

A single dose of 100 mc is rarely exceeded. However, when uptake by metastases is low and thyroidectomy has been performed, up to 90 percent may be excreted within the first 24 hours. Again M is equal to half of this value: $M = 45$ mc.

Consideration of flushing water alone will lead to excessive values of N_m. If we take into account the water used by occupants of apartment houses and hospitals and compute from eq 1, 2, 4, and 5, the

[5] See section I, 4 and 6, pages 2 and 3.

number of people required to reduce N_m to the permissible value for disposal of 45 mc, this number becomes quite high. It is more practical to calculate from these equations how many millicuries may be disposed by toilet and batch bottle disposal for a given number of occupants. Table 1 was prepared in this way, substituting N_m=0.1 mc/liter.

For disposal of larger quantities, the constant-drip bottle described in appendix II may be used. The largest amount that can be excreted by one patient per day will seldom exceed 100 mc. It is permissible to discharge this amount by the constant-drip bottle, provided the dry-weather flow to the sewage-treatment plant is 1 million gallons a day or more.

Appendix II. Constant Drip Discharge Bottle

A simple device for discharging 1 gallon of *liquid waste* at a constant rate is illustrated in figure 1. It consists of a gallon jug and a two-hole stopper with two glass tubes. One glass tube (air-inlet tube) reaches to about 6 cm above the bottom of the bottle. The second glass tube (outflow tube) reaches to the bottom. A rubber tubing is attached to this outflow tube, and a capillary glass tube is attached to the other end of the rubber tubing. The capillary tube is attached to the bottle (with waterproof adhesive plaster) so that the top orifice of the capillary is 5 cm below the lower end of the air-inlet glass tube.

When the bottle is filled and the stopper with the tubings installed, it may be set in a sink and the flow started by pumping air into the open end of the air-inlet tube. This may be conveniently done by attaching a piece of rubber tubing to this open end and using the inflating rubber bulb with a release valve of a blood-pressure manometer. After the liquid begins to flow from the capillary, the flow will be maintained by syphon action.

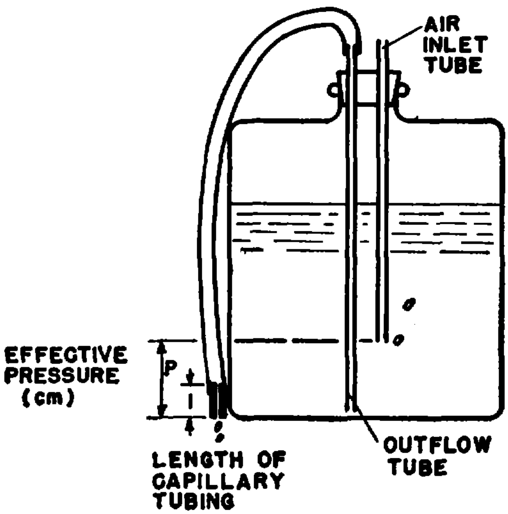

FIGURE 1. *Gallon bottle setup for constant pressure drip discharge.*

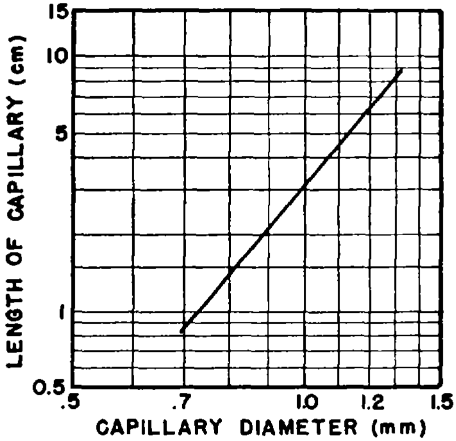

FIGURE 2. *Length of capillary tube as a function of its diameter for an emptying time of 6 hours for a 1-gallon bottle with a water head of 5 cm.*

The pressure is determined by the level difference between the lower end of the air-inlet tube and the capillary orifice (this level difference was made equal to 5 cm). The pressure will remain constant until the liquid level inside the bottle drops below the end of the air-inlet tube; then the pressure will gradually drop until the level sinks below the end of the outflow tube.

Flow rate is determined essentially by this pressure, and by the length and inner diameter of the capillary tubing. Suitable capillary tubes with an inner diameter between ¾ and 1¼ mm are generally available from laboratory-equipment dealers. Figure 2 is an empirical plot indicating the required lengths of capillary tube of various inner diameters, for a flow rate at which the gallon bottle will be emptied in 6 hours.

The actual emptying time with the setup described will generally be within about 30 percent of 6 hours, due to a number of factors which it is difficult to control (for instance: change of viscosity with temperature, variations of the bore of the same capillary, etc.). This uncertainty in emptying time, however, is satisfactory for practical purposes.

Submitted for the National Committee on Radiation Protection.

LAURISTON S. TAYLOR, *Chairman.*

WASHINGTON, September 1951.