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National Bureau of Standards   A. V. Astin, Director

Recommendations for the Disposal of Carbon-14 Wastes

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Preface

The Advisory Committee on X-ray and Radium Protection was formed in 1929 upon the recommendation of the International Commission on Radiological Protection, under the sponsorship of the National Bureau of Standards, and with the cooperation of the leading radiological organizations. The small committee 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, nine working subcommittees have been established, as listed below. Each of these subcommittees 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:

American Medical Association: H. B. Williams.
American Radium Society: E. H. Quimby and J. E. Wirth.
American Roentgen Ray Society: R. R. Newell and J. L. Weatherwax.
National Bureau of Standards: L. S. Taylor, Chairman, and M. S. Norloff, Secretary.
National Electrical Manufacturers Association: E. Dale Trout.
Radiological Society of North America: G. Failla and R. S. Stone.
U. S. Air Force: G. L. Hekhuis, Maj.
U. S Army: T. F. Cook, Lt. Col.

U. S. Atomic Energy Commission: K. Z. Morgan and Shields Warren
U. S. Navy: C. F. Behrens, Rear Adm.
U. S. Public Health Service: H. L. Andrews and E. G. Williams.

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.
Subcommittee 9. Protection against Radiations from Radium, Cobalt-60, and Cesium-137 Encapsulated Sources, C. B. Braestrup.

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 these 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 NBS Handbook 52, Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water. 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 issued from time to time. Two such reports have already been published: NBS Handbook 48, Control and removal of radioactive contamination in laboratories; and NBS Handbook 49, Recommendations for waste disposal of phosphorus-32 and iodine-131 for medical users.

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

J. H. Jensen, Chairman.
W. F. Bale.
R. Chamberlain.
W. D. Claus.
S. Feitelberg.
R. H. Fleming.
J. C. Geyer.
G. W. Morgan.
R. Overstreet.
O. Placak.
E. H. Quimby.
C. C. Ruchhoft.
W. H. Sullivan.
F. Western.

A. V. Astin, *Director*.

Contents

Recommendations for the Disposal of Carbon-14 Wastes

The following recommendations for the disposal of wastes containing carbon-14 are believed by this Committee to be those that on the basis of our present knowledge and experience are best adapted to the needs of the near future. They are considered to be at once very conservative with respect to health hazards involved and very liberal with respect to the needs of users of carbon-14. Subsequent sections of this report give in some detail the considerations upon which these recommendations are based and provide some indication of the factors of safety involved.

I. Disposal Recommendations for Carbon-14

1. Isotopic Dilution

Carbon-14 may be disposed of in any manner provided it is intimately mixed with stable carbon, *in the same chemical form*, in a ratio that never exceeds 1 μC of C^{14} for every 10 g of stable carbon.

2. Sewers

Carbon-14 may be discharged to sewers in amounts that do not exceed 1 mC/100 gal of sewage based on the sewage flow available to the disposer within his own institution.

3. Incineration

Combustible material containing C^{14} may be incinerated if the *maximum* concentration does not exceed 5 μC per gram of carbon. (In animal carcasses, this requirement would usually be met by an *average* concentration not exceeding 0.2 μC/g of tissue.) Sufficient fuel should be employed to make sure there is not more than 5 μC of C^{14} per pound of total combustible material.

4. Atmospheric Dilution

$C^{14}O_2$ from carbonates may be discharged in the exhaust system of a standard chemical laboratory hood that has a lineal air flow of at least 50 ft/min, at a rate not to exceed 100 μC/hr/ft^2 of air intake area in the face of the hood as operated.

5. Garbage

Carbon-14 may be disposed of with garbage in amounts that do not exceed 1 μC/lb of garbage available to the disposer within his own institution.

Approximate equivalents of the above requirement are stated below for convenience.

1 μC/lb of garbage = 20 μC per 10-gal garbage can (allowing for 50 percent voids), 800 μC/yd^3 of garbage, or 0.5 μC/day per person contributing garbage.

6. Burial

Carbon-14-containing material may be buried provided it is covered with at least 4 ft of well compacted earth and does not exceed the following limits.

(a) The maximum permissible concentration of C^{14} in biological material (plant or animal) for burial shall not exceed 5 μC/g.

(b) The maximum permissible amount of C^{14} in chemical compounds mixed with 1 ft^3 of soil shall not exceed 10 mC.

II. General Considerations

1. Introductory Remarks

The considerations involved in the disposal of radioactive wastes from the use of C^{14} in research are, for several reasons, somewhat different from those encountered with other commonly used isotopes. In the first place, the long half-life (approximately 5,400 years) precludes significant loss by decay either during experimentation or in subsequent feasible storage periods. Secondly, carbon is one of the most commonly encountered elements in living matter, being a major constituent of all food we eat and present in all air we breathe. Thirdly, radiocarbon (C^{14}) occurs widely in nature, the amount being estimated at some 22 metric tons or 110 million curies [1].[1] (In spite of the large total, the concentration at any point is negligibly small.)

Since carbon is so intimately concerned with virtually all living processes of plants and animals, it follows that the radioactive isotopes of the element are popular and useful in biological and chemical research. The comparatively short half-life of C^{11} (20.35 min) precludes its wide usage whereas the long half-life of C^{14} enhances its usefulness in many respects.

Records of shipments of isotopes from the U. S. Atomic Energy Commission, Oak Ridge, Tennessee, show C^{14} to rank third up to 1952, being exceeded in number of shipments by iodine-131 and phosporus-32. The summary in table 1 presents information on the shipments made and indicates the magnitude of the problem.

A review of C^{14} shipments during the past five years shows that about 60 percent of the shipments were used for research in animal physiology, about 6 percent in chemistry, about 2 percent in physics, 8 percent in plant physiology, 2 percent in industrial research, and the remaining 22 percent in miscellaneous activities. The use of C^{14} by commercial companies in the synthesis of radioactive organic compounds suitable for research purposes is increasing. This program, proceeding under contract agreements between the U. S. Atomic Energy Commission and laboratories outside its facilities, will undoubtedly result in increased availability of such compounds.

TABLE 1. *Carbon-14 shipped from Atomic Energy Commission facilities*

Year	Number of shipments	Millicuries
[a]1946	47	45
1947	108	298
1948	124	426
1949	192	1,548
1950	259	2,216
1951	342	4,428
[b]1952	163	2,665
Totals	1,235	11,626

[a] 5 months.
[b] 6 months.

[1] Figures in brackets indicate the literature references at the end of this report.

2. Permissible Dose in Relation to Carbon-14 Disposal

In deciding upon the concentration of C^{14} that can be allowed in disposable material, attention must be paid to the manner in which various carbon compounds are eliminated from, or retained by, the living organism, particularly in man.

Most of the published work on uptake and elimination of C^{14} has been based on experiments with animals, and it was obviously necessary to rely on this for the first approach to work with man. However, data based on several studies with adult humans were presented at a conference on C^{14} held at the Argonne National Laboratory [2] in January 1952. This experimental work offers a basis for determining permissible levels. The data are summarized in table 2 and are in reasonably good agreement with previously published data from animal experiments.

All of the studies listed in table 2 are based on intravenous injection of the carbon compound. When $C^{14}O_2$ is inhaled, that reaching the alveoli is reported to be almost completely in exchange with the blood bicarbonate. At cessation of inhalation, that retained should be handled in the same manner as injected bicarbonate. C^{14}-labeled material that is ingested is partially eliminated through the gastrointestinal tract, and the remainder, having been absorbed into the blood, follows the same pattern as other blood-borne materials. Therefore, recommendations based upon the data of table 2 should be adequate for all cases *except* for solid carbon particles deposited in the lungs and not expelled.

A study of the data of table 2 indicates that acetate, glycine, and methionine are retained longer than the other substances tested. They appear to show an important component with an effective half-life[2] of about 1 day, and

TABLE 2. *Retention of C^{14}-labeled compounds in human beings, following intravenous injection [2]*

Compound	Percent of dose retained at various time intervals						Investigator
	1 hr	1 day	1 wk	1 mo	3 mo	500 days	
Acetate	-------	50	20	5	-------	-------	Hellman.
Acetate	83	35	-------	-------	-------	-------	Shreeve.
Bicarbonate	25	-------	-------	-------	-------	-------	Buchanan.
Bicarbonate	-------	<10	-------	-------	-------	-------	Hellman.
Glycine	100	45	20	9	6	1–2	Berlin.
Glycine	-------	50	20	5	-------	-------	Hellman.
Methionine	-------	65	20	-------	-------	-------	Hellman.
Urea	-------	<5	-------	-------	-------	-------	Hellman.

[2] Effective half-life is the half-life of a . dioactive isotope in a biological organism, resulting from the combination of radioactive decay and biological elimination.

another with an effective half-life of about a week. In addition, Dr. Berlin's patients with radioactive glycine (see table 2) retained about 1 to 2 percent at 500 days, and this component apparently has a half-life of about 2 years. These three components may be assumed as follows: 65 percent of injected material has an effective half-life of 1 day; 30 percent, 1 week; and 5 percent, 2 years (use 700 days).

On this basis, calculation of radiation exposure from, for example, a completely absorbed dose of 10 μC/kg in an adult is made in three parts. (The calculation assumes that all components of the 10 μC of C^{14} are distributed throughout the same 1 kg of tissue.) According to the following formula the total dose from a beta emitter uniformly distributed in tissue and remaining there for decay is

$$D=79\,\overline{E}_\beta TC \text{ rep},$$ [3]

where $\overline{E}_\beta$ is average beta energy in Mev (0.05 for C^{14}), T is effective half-life in days, and C is concentration in microcuries per gram of tissue. For the first component, T is one day and C is 0.0065.

$$D_{\beta 1}=79\times 0.05\times 1\times 0.0065=0.03 \text{ rep}.$$

Similarly,

$$D_{\beta 2}=79\times 0.05\times 7\times 0.003=0.08 \text{ rep},$$

and

$$D_{\beta 3}=79\times 0.05\times 700\times 0.0005=1.38 \text{ rep}.$$

The total dose for the first week will be obtained by determining the dose contributed by each component during this period. This will be all of $D_{\beta 1}$, one half of $D_{\beta 2}$, and a fraction of 1 percent of $D_{\beta 3}$. D_β first week$=0.03+0.04+0.01=0.08$. This is only a quarter of the maximum permissible dose of 0.03 rep per week.

Experiments with animals have given some evidence that the material that is retained for a long time is mainly in the skeleton. If it be assumed that the 5-percent long-term component concentrates in the skeleton, and that this is one-tenth of the body weight, then D (skeleton) from this is 13.8 reps total. This is approximately 0.1 rep the first week, and gradually diminishes.

Thus it appears that a dose of 10 μC/kg, or a total of the

[3] The unit of measurement of beta-ray dosage in common use in the rep, now defined as the absorption of 93 ergs energy per gram of tissue. The above formula is adapted from one given by Marinelli, Quimby, and Hine [3],

$$D=88\,\overline{E}_\beta TC \text{ equivalent roentgens},$$

where the equivalent roentgen is defined as "that amount of beta radiation which, under equilibrium conditions, releases in 1 g of air as much energy as 1 roentgen of gamma radiation."

order of 700 μC in a human adult, should be well within permissible limits. This agrees with the conclusion of the Argonne group, that there seems to be no serious reason to believe that glycine is unsafe in an adult human dose of 1 mC.

Levels for allowable concentrations in sewage and garbage are based on the evidence that 1 mC in a single dose to an adult human does not violate the accepted standards of maximum permissible dose.

III. Bases for Recommendations

Despite the long half-life of C^{14}, it is feasible to recommend various procedures for the disposal of this isotope as previously indicated. The amount available for disposal will not significantly affect the quantity of C^{14} already present in nature and the only concern is to prevent harmful localized concentrations of C^{14} due to waste disposal practices. If we consider 1 mC of C^{14} as the acceptable single permissible dose, it is inconceivable that harmful localized concentrations could result from the recommended disposal procedures.

Sample calculations concerning the various methods of disposal are presented in the following sections. Since it is impossible to arrive at exact values for disposal in the light of present knowledge, the examples cited are designed to show that the recommendations selected are reasonable and conservative. These illustrative examples are based generally on currently accepted maximum permissible concentrations in air and water for continuous use. They do not consider the improbability of these materials being accessible to humans after disposal, the fact that exposure will be occasional in nature, and the tremendous additional dilution that must occur after disposal by the methods recommended. While it would be difficult to quantify all of these factors, it is certain that in the average case they add up to a safety factor of not less than 100 and probably larger.

Two important cases are not covered adequately by these recommendations: (1) insoluble particles less than a few microns in size that contain carbon-14 and that may become lodged in the lower respiratory tract, and (2) wounds that may be contaminated with carbon-14 in the process of the disposal of radioactive material. Therefore, since an unknown radiation hazard may be represented by these cases, considerable effort should be made not to discharge insoluble particles containing carbon-14 into the air and to avoid the contamination of wounds with carbon-14, especially insoluble carbon-14.

1. Isotopic Dilution

Carbon-14 may be disposed of in any manner provided it is intimately mixed with stable carbon, *in the same chemical form*, in a ratio that never exceeds 1 mC of C^{14} for every 10 g of stable carbon.

It is possible to arrive at a value for dilution with stable isotopes, which if achieved should never permit hazardous conditions to occur. These calculations are based on data contained in the report [4] of the National Committee on Radiation Protection Subcommittee on Permissible Internal Dose, which states that the total body burden to give 0.3 rep/week is 250 μC when fat is considered as the critical organ and 1,500 μC when bone is considered as the critical organ.

(a) Considering fat as the critical organ:

$$\frac{250\ \mu\text{C (permissible body burden)} \times 0.6\ \text{(fraction in critical organ)}}{10^4\ \text{g (mass of organ)} \times 0.75\ \text{(fraction of carbon in organ)}} = 1\ \mu\text{C}/50\ \text{g of stable carbon.}$$

(b) Considering bone as the critical organ:

$$\frac{1{,}500\ \mu\text{C (permissible body burden)} \times 0.07\ \text{(fraction in critical organ)}}{7 \times 10^3\ g\ \text{(mass of organ)} \times 0.13\ \text{(fraction of carbon in organ)}} = 1\ \mu\text{C}/8.7\ \text{g of stable carbon.}$$

Since it is generally considered that the replacement of C^{14} in fat occurs very rapidly and that components of longer biological half-life are more likely to be found in bone, it would appear to be reasonable to use the value based on bone as the critical organ. On this basis, if the C^{14} content never exceeds the ratio of 1μC/10 g of stable metabolized carbon, one should never exceed the permissible total body burden irrespective of subsequent events. Of course, all of the safety factors previously mentioned also apply.

If this line of reasoning (isotopic dilution) is applied to the disposal of C^{14} in garbage, for example, the following value will result. The assumption will have to be made that the discharged C^{14} is sufficiently mixed with the garbage so that the average ratio of C^{14} to stable carbon is essentially constant. Then the permissible amount of C^{14} per pound of wet garbage [5] is (1 μC/10 g)$\times$0.20 (fraction of solids)$\times$0.45 (fraction of carbon in solids)$\times$454 g/lb=4.10 μC.

[4] National Bureau of Standards Handbook 52, Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water.
[5] Garbage as it normally occurs, i. e., fresh food waste.

2. Sewers

Carbon-14 may be discharged to sewers in amounts that do not exceed 1 mC/100 gal of sewage based on the sewage flow available to the disposer within his own institution.

If one assumes normal mixing, the problem of disposal of C^{14} in sewers becomes a straight dilution problem. On this basis and using the maximum permissible concentration for water, 3×10^{-3} μC/ml, the permissible amount of C^{14} that may be discharged per 100 gal of sewage may be calculated as follows:

$$(3\times10^{-3}\times10^{3}\times3.785\times10^{2})/10^{3}=1.14 \text{ mC}.$$

When one considers the improbability of the ingestion of sewage, all of the safety factors previously mentioned including the very large dilution in the main sewer, and the fact that even if ingested in the original dilution it would take 100 gal of sewage to furnish a single permissible dose, the essential conservativeness of this recommendation is apparent.

3. Incineration

Combustible material containing C^{14} in amounts that do not exceed 5 μC/g of material may be incinerated if mixed with natural fuel so that there is not more than 5 μC/lb of fuel burned.

Because garbage is frequently disposed of by incineration, the calculations concerning garbage incineration may be used to illustrate the combustion of wastes containing C^{14}. This is one of the most extreme cases, since normally garbage requires auxiliary fuel to support combustion and has a much lower stable-carbon content than other combustible materials. Any other common fuel should permit more liberal recommendations concerning C^{14} content than those permitted when garbage is incinerated.

If garbage containing C^{14} is incinerated, the permissible C^{14} content may be estimated on the basis of the dilution afforded by the air required for combustion. The following values are used in considering this problem.

(a) Theoretical volume of air required (in cubic feet) per unit of fuel-heating value (in BTU per unit)/100. (It is considered good practice to supply 50 to 200 percent of excess air.)

(b) Wet garbage is 20 percent solids.

(c) Wet garbage weighs 800 lb/yd^3.

(d) Dry-garbage solids contain 8,000 BTU/lb.

Using these values the following computation may be made.

1 yd^3 garbage = 800 lb.
= 160 lb dry solids.
Cubic feet air required per pound = 8,000/100 = 80.
Total air required = $160 \times 80 = 12{,}800$ ft^3/yd^3 of garbage.
$1.28 \times 10^4 \times 2.832 \times 10^4 = 3.63 \times 10^8$ cm^3 of air/yd^3 of garbage.

The initial concentration that will not exceed tolerance at top of the stack is $3.63 \times 10^8 \times 10^{-6} = 363$ $\mu C/yd^3$.[6] This is equivalent to 2.3 μC/lb of dry garbage. However, the value computed is conservative, because it ignores the dilution effects due to use of auxiliary fuel, excess air, and dilution of the waste gases after leaving the stack. Neither does it consider the fact that $C^{14}O_2$ exposure will seldom be continuous in nature. In view of the above estimates computed on the basis of a low carbon fuel, a recommendation of 5 μC/lb of fuel burned seems conservative.

Because of the possibility of the formation of radioactive particles, a restriction is placed on the specific activity of the material to be incinerated. This restriction was selected on the basis of the following line of reasoning. Incineration, as ordinarily practiced, may lead to the discharge into the outside air of dusts or smokes containing particles, some of which may be unoxidized carbon. Similar clouds of particles are often produced locally during ash-removal operations. Therefore, material to be burned in ordinary incinerators should not contain concentrations of C^{14} per gram of carbon great enough that such particles might constitute a radiation hazard if deposited in the lungs.

To avoid this hazard it is recommended that chemicals, animal carcasses, and other refuse and waste material not be disposed of through burning in ordinary incinerators if the C^{14} content exceeds 5 μC of C^{14} per gram of carbon in the region of highest C^{14} concentration. Ordinarily an individual animal carcass meets this requirement if the average C^{14} concentration does not exceed 1 μC/g of carbon (0.2 μC/g of tissue).

(a) *Assumptions on which this recommendation is based.* It is assumed that:

(1) Spherical carbon particles 10 μ in diameter are equivalent to the largest particles that will become fixed in the lung,

(2) The beta-ray dosage from a 10-μ particle fixed in the lung is distributed through a sphere of 40-μ radius and a specific gravity of 1.0,

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[6] The value 10^{-6} is the maximum permissible concentration in microcuries per milliliter of C^{14} in air for continuous exposure, according to table 3 of National Bureau of Standards Handbook 52 (see footnote 4), a report of the National Committee on Radiation Protection Subcommittee on Permissible Internal Dose.

(3) A carbon particle that will not give more than 0.3 rep/week radiation dosage averaged through such a sphere is acceptable in airborne waste, and

(4) The specific gravity of carbon is 2.

(b) *Calculations on which this recommendation is based.*

V=volume of a 10-μ-diameter particle,

$V = \frac{1}{6}\pi d^3 = 0.524\times10^{-9}$ cm^3,

V_d=volume of an 80-μ-diameter tissue-sphere in which dosage will be dissipated,

$V_d = \frac{1}{6}\pi (8\times10^{-3})^3 = 2.68\times10^{-7}$ cm^3.

Carbon-14 at a concentration of 1 mC/g of carbon will produce $2.22\times10^9\times60=1.33\times10^{11}$ beta rays/g/hr.

The average energy released by the beta rays from a gram of this material per hour will be $0.05\times1.33\times10^{11}=6.65\times10^9$ Mev/g/hr.

The energy emitted by a 10-μ-diameter spherical particle of this material per hour will be $6.65\times10^9\times0.524\times10^{-9}\times2=$ 7.0 Mev/hr.

Since this energy is assumed to be dissipated in a sphere of tissue weighing 2.68×10^{-7} g, the energy dose of beta radiation will average $7.0/(2.68\times10^{-7})=2.60\times10^7$ Mev/g/hr.

Since 5.8×10^7 Mev beta radiation dissipated per gram tissue is equal to 1 rep, this dosage rate corresponds to $(2.60\times10^7)/(5.8\times10^7)=0.45$ rep/hr or 75.6 rep/week.

The acceptable activity per gram of carbon on the above assumptions is therefore 0.3/75.6=approximately 0.004 mC/g or 4 μC/g.

4. Atmospheric Dilution

$C^{14}O_2$ from carbonates may be discharged in the exhaust system of a standard chemical laboratory hood that has a lineal air flow of at least 50 ft/min, at a rate not to exceed 100 μC/hr/ft^2 of air intake area in the face of the hood as operated.

In the case of carbonates containing C^{14}, it appears feasible to convert these materials to carbon dioxide and release them directly to the atmosphere. This operation should be carried out in a hood that is otherwise satisfactory for radiochemical work. In no case should the velocity of air flow be less than 50 lineal feet per minute. Conversion of carbonates to carbon dioxide for release could be accomplished by the slow addition of acid in a device similar to the alkalimeter that is used in the quantitative estimation of carbonates. The period of complete release would probably extend over a period of 15 to 30 min, tapering off with time.

The following example illustrates the situation in a hood with a face opening 2 by 4 ft, lineal air flow of 50 ft/min, and with the final C^{14} concentration not to exceed the maximum permissible concentration in air of 10^{-6} $\mu C/cm^3$:

$$2 \times 4 \text{ (face area in ft}^2) \times 50 \text{ (face velocity in ft/min)} \times 60 \text{ (min)} \times 2.832 \times 10^4 \text{ (cm}^3/\text{ft}^3) \times 10^{-6} (\mu C/cm^3) = 679.7\ \mu C/hr.$$

This illustrative example does not consider the dilutions that would occur if additional hoods exhausted into the same system and the atmospheric dilution after leaving the stack. Neither does it consider the fact that the tolerance value used is for continuous use 24 hours a day and consequently leads to a conservative figure for intermittent use.

It appears feasible to adopt arbitrarily a conservative, yet ample, recommendation for disposal by permitting release of C^{14} in this manner at a rate not to exceed 100 $\mu C/ft^2$ of face opening per hour when the lineal air flow is not less than 50 ft/min.

5. Garbage

Carbon-14 may be disposed of with garbage in amounts that do not exceed 1 μC/lb of garbage available to the disposer within his own institution.

Approximate equivalents of the above requirement are stated below for convenience.

1 μC/lb of garbage = 20 μC per 10-gal garbage can (allowing for 50 percent voids),
800 $\mu C/yd^3$ of garbage, or
0.5 μC/day per person contributing garbage.

The question of disposal of C^{14} contained in garbage has been considered previously under incineration. If garbage grinding followed by sewer disposal is practiced, the problem is similar to that of direct disposal in sewers. Since garbage may be used for hog feeding, some estimate of the problem may be made in the following manner.

Assume:

(1) All C^{14} intake is from garbage-fed pork,
(2) Hog weight=250 lb,
(3) A person eats one 4-oz serving per day,
(4) All C^{14} intake is evenly distributed in the hog,
(5) 7 μC per day is the permissible intake for humans as computed from the maximum permissible concentration in water,
(6) Biological half-life=35 days.

Then the total amount of C^{14} permissible in the hog that will not permit more than 7 μC per 4-oz is $(250/0.25) \times 7 = 7{,}000\ \mu C = 7$ mC.

The permissible daily intake for the hog that will not permit the hog to exceed 7 mC is 0.14 mC per day if calculated in the following manner.

$A=1.4\ RT\ (1-e^{-t/T})$, where A=quantity of activity at any time (t), R=rate of addition (curies per unit time), and T=half-life,

$A=RT$ is the equilibrium value,

$R=7/(1.4\times 35)=0.14$ mC/day.

This would mean that even if the sole diet of the animal consisted of 40 lb of garbage per day no harmful effects would occur if this garbage contained approximately 3.5 μC/lb.

If garbage reduction is employed, the situation will be the following:

Reduction processes can be applied economically only to large cities. Some experts are of the opinion that a population of 200,000 is required to furnish sufficient garbage. In 1943, there were eight full-scale municipal garbage reduction plants. The present number is undetermined, but it is probably true that this is a minor method of disposal.

The products of garbage reduction are as follows:

(1) *Grease.* This amounts to 1 to 3 percent by weight of the garbage. It is used for manufacturing red oil, glycerines, candles, and soaps.

(2) *Dry solids.* Known as tankage, this amounts to 8 to 13 percent by weight of the garbage. It is used as a fertilizer base and for stock feeding.

(3) *Waste materials.* Solids such as cans and other rubbish; liquids, floor washings, and tank-waste liquors, which go to sewers; and gases, which are absorbed in water sprays or, if combustible, passed through a fire.

By nature of the process, all of the garbage from a city will come to this central point and consequently, the C^{14} will be diluted very considerably by additional garbage.

If 10 mC/day were processed in the garbage for various size cities, the following conditions would probably occur if all of the C^{14} went into the salvagable products and was equally distributed according to weight:

Population	Pounds garbage per day	Grease		Tankage	
		Pounds	μC/lb	Pounds	μC/lb
200, 000	100, 000	2, 000	0. 8	10, 500	0. 8
500, 000	250, 000	5, 000	. 3	26, 250	. 3
1, 000, 000	500, 000	10, 000	. 2	52, 500	. 2

Garbage disposal in open dumps is not considered. The practice should be discouraged from a sanitation viewpoint, if no other. In any event, it would probably occur only in situations where one would not expect any large use of C^{14}. In the event that it did occur, the garbage would be decomposed completely in about 30 months and most of the C^{14} would have been released to the atmosphere.

If the garbage is disposed of in sanitary fills, it may be considered as a burial problem and the recommendations for burial should be followed. If buried, the garbage would decomposed slowly over a period of years and be converted to gases.

6. Burial

Carbon-14-containing material may be buried provided it is covered with at least 4 ft of well compacted earth and does not exceed the following limits:

(a) The maximum permissible concentration of C^{14} in biological material (plant or animal) for burial shall not exceed 5 μC/g.

(b) The maximum permissible amount of C^{14} in chemical compounds mixed with one cubic foot of soil shall not exceed 10 mC.

In general, one would consider the problem carefully before advocating burial of substantial quantities of radioactive material of long half-life. Carbon-14, however, deserves consideration as an exception to this rule because it possesses unusual potentialities for stable isotope dilution. It would appear, at first glance, that the greatest hazard from burial of C^{14} would be later incorporation in plant material. It is unlikely that this will occur to any great extent because (a) the feeding roots of annual plants are generally concentrated in the upper 12 in. of soil, and (b) very little carbon is taken in through the root system.

Burial shall be at least to a depth of 4 ft, with well compacted earth cover. Greater depths should constitute additional safeguards against subsequent access to buried materials. The burial should not be in sealed containers of permanent material (e. g., sealed glass bottles), which would prevent dispersion. In the burial of animal carcasses and other biological materials containing C^{14}, burial shall be done in accordance with the sanitary rules and precautions normally pertaining to burial of these materials. If the recommendations stated herein are followed, the health hazards from burial of C^{14} are not considered to be sufficiently great as to require marking of burial sites. In situations where a marked burial site is available, it is recommended that it be used for the burial of C^{14} wastes.

The differences allowed in the maximum permissible concentration of C^{14} in biological material as compared with the amount of C^{14} in chemical compounds is based on considerations of the dispersion of the C^{14} in the burial soil. The burial of C^{14} chemical compounds may result in higher specific activity since they cannot generally be dispersed in soil and it is less likely that a chemically similar stable material will be present. With inorganic C^{14} the soil carbonates may be available for isotopic dilution. It should be emphasized, however, that in the case of organic C^{14} bearing materials, decomposition will occur and that after a period of time these materials will be converted to methane, carbon dioxide, and water. These gaseous end products will be diluted isotopically and physically and will eventually be rendered innocuous through such dilution.

Since buried materials are in general inaccessible, the procedures recommended should not create a hazard. The worst case that one could visualize would be exhumation and ingestion of these materials. Although this is unlikely, if it did occur one would have to consume the following quantities of material to get the single permissible dose of 1 mc:

Biological material (at 5 μC/g): 200 g.
Other materials (at 10 mC/ft^3 of soil): 10 lb of soil.

IV. References

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LAURISTON S. TAYLOR, *Chairman.*

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[7] Obtainable from Office of Technical Services, Department of Commerce, Washington 25, D. C.

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