# RECOMMENDATIONS FOR THE DISPOSAL OF CARBON-14 WASTES

**Handbook 53**



**U. S. Department of Commerce**
**National Bureau of Standards**

U. S. Department of Commerce Sinclair Weeks, Secretary
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 $\mu$C 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 $\mu$C per gram of carbon. (In animal carcasses, this requirement would usually be met by an *average* concentration not exceeding 0.2 $\mu$C/g of tissue.) Sufficient fuel should be employed to make sure there is not more than 5 $\mu$C 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 $\mu$C/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 $\mu$C/lb of garbage available to the disposer within his own institution.

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

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



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## 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 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 $\mu$C/kg in an adult is made in three parts. (The calculation assumes that all components of the 10 $\mu$C 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 $D_{\beta 3}$. $D_\beta$ 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 $\mu$C/kg, or a total of the

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

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

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

[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 $\mu C$ 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 $\mu C$ when fat is considered as the critical organ and 1,500 $\mu C$ when bone is considered as the critical organ.

(a) Considering fat as the critical organ:

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

(b) Considering bone as the critical organ:

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

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 $1 \mu C/10$ 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 $(1\ \mu C/10\ g) \times 0.20$ (fraction of solids) $\times 0.45$ (fraction of carbon in solids) $\times 454\ g/lb = 4.10\ \mu C$.

[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, $3\times10^{-3}$ $\mu$C/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 $\mu$C/g of material may be incinerated if mixed with natural fuel so that there is not more than 5 $\mu$C/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\times80=12{,}800$ ft$^3$/yd$^3$ of garbage.
$1.28\times10^{4}\times2.832\times10^{4}=3.63\times10^{8}$ cm$^3$ of air/yd$^3$ of garbage.

The initial concentration that will not exceed tolerance at top of the stack is $3.63\times10^{8}\times10^{-6}=363$ $\mu$C/yd$^3$.[6] This is equivalent to 2.3 $\mu$C/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 $\mu$C/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 $\mu$C 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 $\mu$C/g of carbon (0.2 $\mu$C/g of tissue).

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

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

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

[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-$\mu$-diameter particle,
$V = \frac{1}{6}\pi d^3 = 0.524\times10^{-9}$ cm$^3$,
$V_d$=volume of an 80-$\mu$-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-$\mu$-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 $2.68\times10^{-7}$ g, the energy dose of beta radiation will average $7.0/(2.68\times10^{-7})=2.60\times10^7$ Mev/g/hr.

Since $5.8\times10^7$ 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 $\mu$C/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 $\mu$C/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$^3$:

$$2\times4 \text{ (face area in ft}^2) \times 50 \text{ (face velocity in ft/min)} \times 60 \text{ (min)} \times 2.832\times10^4 \text{ (cm}^3/\text{ft}^3) \times 10^{-6} (\mu\text{C/cm}^3) = 679.7\ \mu\text{C/hr.}$$

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 $\mu$C/lb of garbage available to the disposer within his own institution.

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

1 $\mu$C/lb of garbage=20 $\mu$C per 10-gal garbage can (allowing for 50 percent voids),
800 $\mu$C/yd$^3$ of garbage, or
0.5 $\mu$C/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 $\mu$C 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 $\mu$C per 4-oz is $(250/0.25)\times7=$ 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 $\mu$C/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 | $\mu$C/lb | Pounds | $\mu$C/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 $\mu$C/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 $\mu$C/g): 200 g.
Other materials (at 10 mC/ft$^3$ of soil): 10 lb of soil.

## IV. References


[1] E. C. Anderson, W. F. Libby, S. Weinhouse, A. F. Reid, A. D. Kirshenbaum, and A. V. Grosse, Natural radiocarbon from cosmic radiation, Phys. Rev. **72**, 931 (1947).

[2] A. M. Brues and D. L. Buchanan, Summary of conference on carbon-14 held at Argonne National Laboratory, Jan. 15–16, 1952. ANL–4787.[7]

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


Submitted for the National Committee on Radiation Protection.

LAURISTON S. TAYLOR, *Chairman*.

WASHINGTON, January, 1953.

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

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**Addendum to National Bureau of Standards Handbook 59, Permissible Dose from External Sources of Ionizing Radiations**
**(Extends and replaces insert of January 8, 1957)**

(This addendum will necessitate changes in the following NBS Handbooks: 42, 48, 49, 50, 51, 52, 53, 54, 55, 56, 58, 60, and 61.)

# Maximum Permissible Radiation Exposures to Man

## Introduction

On January 8, 1957, the National Committee on Radiation Protection and Measurements issued a Preliminary Statement setting forth its revised philosophy on Maximum Permissible Radiation Exposures to Man.[1] Since that time several of the NCRP subcommittees have been actively studying the necessary revisions of their respective handbooks. These studies have shown the need for (1) clarification of the earlier statement and (2) modification or extension of some of the concepts in that statement. Furthermore, the International Commission on Radiological Protection has made minor changes in their recommendations. Accordingly the NCRP has prepared a set of guides, given below, that will assure uniformity in the basic philosophy to be embodied in the various handbooks. Since many of the handbooks are followed closely in planning radiation operations in the United States, and since the modification of a handbook may require many months of effort, it seems wise to make the over-all guiding principles available in advance of the reissuance of the revised handbooks. These guides are not designed to take the place of any of the handbooks; the principles given below will be extensively treated later in appropriate places. In the meantime handbook revisions or supplementary statements will be issued as rapidly as possible.

Since the statement of an average per capita dose for the whole population does not directly influence the substance of the NCRP Handbooks, no further statements regarding such a number will be made at this time. In any discussion of the MPD it is impractical to take into consideration the dose from natural background and medical or dental procedures.

The changes in the accumulated MPD are not the result of positive evidence of damage due to use of the earlier permissible dose levels, but rather are based on the desire to bring the MPD into accord with the trends of scientific opinion; it is recognized that there are still many uncertainties in the available data and information. Consideration has also been given to the probability of a large future increase in radiation uses. In spite of the trends, it is believed that the risk

[1] NBS Tech. News Bul. **41**, 17 (Feb. 1957).

involved in delaying the activation of these recommendations is very small if not negligible. Conditions in existing installations should be modified to meet the new recommendations as soon as practicable, and the new MPD limits should be used in the design and planning of future apparatus and installations. Because of the impact of these changes and the time required to modify existing equipment and installations, it is recommended on the basis of present knowledge that a conversion period of not more than 5 years from January 1957 (see footnote 1) be adopted within which time all necessary modifications should be completed.

The basic rules and the operational guides outlined below are intended to be in general conformity with the philosophy expressed in the 1953 statements of the ICRP, as revised in April 1956 and March 1958.

## Guides for the Preparation of NCRP Recommendations

It is agreed that we should make clear distinction between basic MPD *rules* or requirements, and operational or administrative *guides* to be used according to the special requirements in any particular situation. Guides have the distinct value of retaining some reasonable degree of uniformity in the interpretation of the basic rules.

The risk to the individual is not precisely determinable but, however small, it is believed not to be zero. Even if the injury should prove to be proportional to the amount of radiation the individual receives, to the best of our present knowledge, the new permissible levels are thought not to constitute an unacceptable risk. Since the new rules are designed to limit the potential hazards to the individual and to the reproductive cells, it is therefore, necessary to control the radiation dose to the population as a whole, as well as to the individual. For this reason, maximum permissible doses are set for the small percentage of the whole population who may be occupationally exposed, in order that they not be involved in risks greater than are normally accepted in industry. Also radiation workers represent a somewhat selected group in that individuals presumably of the greatest susceptibility (i. e., infants and children) are not included. However, for the persons located immediately outside of controlled areas but who may be exposed to radiation originating in controlled areas, the permissible level is adjusted downward from that in the controlled area because the number of such persons may not be negligible. With this downward adjustment, the risk to the *individual* is negligible so that small transient deviations from the prescribed levels are unimportant.

Controls of radiation exposure should be adequate to provide reasonable assurance that recommended levels of maximum permissible dose shall not be exceeded. In addition, the NCRP reemphasizes its long-standing philosophy that radiation exposures from whatever sources should be as low as practical.



## Definitions

For the purposes of these guides, the following definitions are given:

*Controlled area.* A defined area in which the occupational exposure of personnel to radiation or to radioactive material is under the supervision of an individual in charge of radiation protection. (This implies that a controlled area is one that requires control of access, occupancy, and working conditions for radiation protection purposes.)

*Workload.* The output of a radiation machine or a radioactive source integrated over a suitable time and expressed in appropriate units.

*Occupancy factor.* The factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area in question.

*RBE dose.* RBE stands for relative biological effectiveness. An RBE dose is the dose measured in rems. (This is discussed in the report of the International Commission on Radiological Units and Measurements, 1956, NBS Handbook 62, p. 7.)

## Basic Rules

### 1. *Accumulated Dose (Radiation Workers).*

A. *External exposure to critical organs.*

*Whole body, head and trunk, active blood-forming organs, or gonads:* The maximum permissible dose (MPD), to the most critical organs, accumulated at any age, shall not exceed 5 rems multiplied by the number of years beyond age 18, and the dose in any 13 consecutive weeks shall not exceed 3 rems.[2]

Thus the accumulated MPD$=(N-18)\times 5$ rems, where $N$ is the age in years and is greater than 18.

> COMMENT: This applies to radiation of sufficient penetrating power to affect a significant fraction of the critical tissue (This will be enlarged upon in the revision of H59.)

B. *External exposure to other organs.*

*Skin of whole body:* MPD$=10$ (N–18) rems, and the dose in any 13 consecutive weeks shall not exceed 6 rems.[3]

> COMMENT: This rule applies to radiation of low penetrating power. See figure 2, H59.

*Lens of the eyes:* The dose to the lens of the eyes shall be limited by the dose to the head and trunk (A, above).

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[2] The quarterly limitation of 3 rems in 13 weeks is basically the same as in H59 except that it is no longer related to the old weekly dose limit. The yearly limitation is 12 rems instead of the 15 rems as given in the NCRP preliminary recommendtions of January 8, 1957.

[3] This is similar to the 1954 (H59) recommendations in that the permissible skin dose is double the whole-body dose. H59 made no statement regarding a 13-week limitation.

*Hands and forearms, feet and ankles:* MPD=75 rems/year, and the dose in any 13 consecutive weeks shall not exceed 25 rems.[4]

C. *Internal exposures.*

The permissible levels from internal emitters will be consistent as far as possible with the age-proration principles above. Control of the internal dose will be achieved by limiting the body burden of radioisotopes. This will generally be accomplished by control of the average concentration of radioactive materials in the air, water, or food taken into the body. Since it would be impractical to set different MPC values for air, water, and food for radiation workers as a function of age, the MPC values are selected in such a manner that they conform to the above-stated limits when applied to the most restrictive case, viz., they are set to be applicable to radiation workers of age 18. Thus, the values are conservative and are applicable to radiation workers of any age (assuming there is no occupational exposure to radiation permitted at age less than 18). The factors entering into the calculations will be dealt with in detail in the forthcoming revision of Handbook 52.

The maximum permissible average concentrations of radionuclides in air and water are determined from biological data whenever such data are available, or are calculated on the basis of an averaged annual dose of 15 rems for most individual organs of the body,[5] 30 rems when the critical organ is the thyroid or skin, and 5 rems when the gonads or the whole body is the critical organ. For bone seekers the maximum permissible limit is based on the distribution of the deposit, the RBE, and a comparison of the energy release in the bone with the energy release delivered by a maximum permissible body burden of 0.1 $\mu g\ Ra^{226}$ plus daughters.

**2. *Emergency Dose (Radiation Workers).***

An accidental or emergency dose of 25 rems to the whole body or a major portion thereof, occuring only once in the lifetime of the person, need not be included in the determination of the radiation exposure status of that person (see p. 69, H59).[6]

**3. *Medical Dose (Radiation Workers).***

Radiation exposures resulting from necessary medical and dental procedures need not be included in the determination of the radiation exposure status of the person concerned.[6]

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[4] This is basically the same as the 1954 (H59) recommendations except for the 13-week limitation.

[5] This is basically the same as the 1953 (H52) recommendations.

[6] This is the same as the 1954 (H59) recommendations.



**4. *Dose to Persons Outside of Controlled Areas.***

The radiation or radioactive material outside a controlled area, attributable to normal operations within the controlled area, shall be such that it is improbable that any individual will receive a dose of more than 0.5 rem in any 1 year from external radiation.

The maximum permissible average body burden of radionuclides in persons outside of the controlled area and attributable to the operations within the controlled area shall not exceed one-tenth of that for radiation workers.[7] This will normally entail control of the average concentrations in air or water at the point of intake, or rate of intake to the body in foodstuffs, to levels not exceeding one-tenth of the maximum permissible concentrations allowed in air, water, and foodstuffs for occupational exposure. The body burden and concentrations of radionuclides may be averaged over periods up to 1 year.

The maximum permissible dose and the maximum permissible concentrations of radionuclides as recommended above are primarily for the purpose of keeping the average dose to the whole population as low as reasonably possible, and not because of specific injury to the individual.

COMMENT: Occupancy-factor guides will be needed by several of the subcommittees. It will be important that these do not differ markedly between different handbooks. The Executive Committee will endeavor to establish a set of uniform occupancy-factor guides.

## Operational and Administrative Guides

**5.** The maximum dose of 12 rems in any 1 year as governed by the 13 week limitation, should be allowed only when adequate past and current exposure records exist. The allowance of a dose of 12 rems in any 1 year should not be encouraged as a part of routine operations; it should be regarded as an allowable but unusual condition. The records of previous exposures must show that the addition of such a dose will not cause the individual to exceed his age-prorated allowance.

**6.** The full 3-rem dose should not be allowed to be taken within a short time interval under routine or ordinary circumstances (however, see paragraph 2 on Emergency Dose above.) Desirably, it should be distributed in time as uniformly as possible and in any case *the dose* should not be greater than 3 rems in any 13 consecutive weeks. When the individual is not personally monitored and/or personal exposure records are not maintained, the exposure of 12 rems in a year should not be allowed; the yearly allowance under these circumstances should be 5 rems, provided area surveys indicate an adequate margin of safety.

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[7] This is basically the same as the recommendations of January 8, 1957.

7. When any person accepts employment in radiation work, it shall be assumed that he has received his age-prorated dose up to that time unless (1) satisfactory records from prior radiation employment show the contrary, or (2) it can be satisfactorily demonstrated that he has not been employed in radiation work. This is not to imply that such an individual should be expected to routinely accept exposures at radiation levels approaching the yearly maximum of 12 rems up to the time he reaches his age-prorated limit. Application of these principles will serve to minimize abuse.

8. The new MPD standards stated above are not intended to be applied retroactively to individuals exposed under previously accepted standards.

9. It is implicit in the establishment of the basic protection rules that at present it is neither possible nor prudent to administer a suitably safe radiation protection plan on the basis of yearly monitoring only. It is also implicit that at the low permissible dose levels now being recommended, there is fairly wide latitude in the rate of delivery of this dose to an individual so long as the dose remains within the age-prorated limits specified above. In spite of a lack of clear evidence of harm due to irradiation at dose rates in excess of some specified level, it is prudent to set some reasonable upper limit to the rate at which an occupational exposure may be delivered. Therefore, it has been agreed that the dose to a radiation worker should not exceed 3 rems in any 13 consecutive weeks.

10. The latitude that may appropriately be applied in the operational and administrative control of occupational exposure will be dictated by two major factors (a) the type of risk involved and the likelihood of the occurrence of over-exposures and (b) the monitoring methods, equipment, and the dose recording procedures available to the radiation users. Where the hazards are minimal and not likely to change from day to day or where there are auxiliary controls to insure that the 13-week limitation will not be exceeded, the integration may be carried out over periods up to 3 months. Where the hazards are significant and where the exposure experience indicates unpredictability as to exposure levels, the doses should be determined more frequently, such as weekly, daily, hourly, or oftener, as may be required to limit the exposure to permissible values.

11. For the vast majority of installations (medical and industrial), operation is more or less routine and reasonably predictable and it may be expected that their monitoring procedures will be minimal. For such installations the protection design should be adequate to insure that over-exposures will not occur—otherwise frequent sampling tests should be specified. Where film badges are used for monitoring, it is preferable that they be worn for 4 weeks or longer, since otherwise the inaccuracy of the readings may unduly prejudice the radiation history of the individual. Where operations are not routine or are subject to unpredictable variations that may be hazardous, self-reading pocket dosimeters, pocket chambers, or other such devices should also be worn and should be read daily or more often as circumstances dictate.



12. Except for planning, convenience of calculation, design, or administrative guides, the NCRP will discontinue the use of a weekly MPD or MPC.[8]

13. The Committee has deliberately omitted the discussion of future exposure forfeiture for exposures exceeding the MPD on the grounds that any such statements might lend encouragement to the unnecessary use of forfeiture provisions.

[8] This represents a minor change from the NCRP recommendations of January 8, 1957, but no change in the basic MPD.

April 15, 1958.

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