INCINERATION OF RADIOACTIVE WASTES CONTAINING ONLY C-14 AND H-3

Corazon M. Garcia
Philippine Nuclear Research Institute
Philippines

ABSTRACT

C-14 and H-3 are popularly used in chemical and biological research institutions in the Philippines. Most of the solid radioactive wastes generated by these institutions consist of combustible materials such as paper and accumulated environmental samples. Liquid wastes usually contain organic substances. The method proposed for managing C-14 and H-3 wastes is incineration which is expected to provide an acceptable means of disposal for C-14 and H-3 and their hazardous organic constituent.

In the incineration process, the radioactively contaminated waste will be mixed with non-radioactive combustible wastes to lower the activity concentration and to improve the efficiency of combustion which will be carried out in a locally fabricated drum incinerator.

The calculations presented determines the concentration limit for the incinerable wastes and the restriction on specific activity of the particles of the incinerable wastes containing C- 14 or H-3 on the basis of the accepted air concentration and on the annual dose limit for an average radiation worker in the country.

In the calculations for C-14, considerations were taken on the exposure received from the deposition of radioactive particles in the lungs containing unoxidized carbon.

Calculations for H-3, however, is based on the assumption that the concentration of the radionuclide in the body water is the same as that in the environment.

GENERAL CONSIDERATIONS

Incineration is a method that can be applied for the disposal of wastes containing C-14 or H-3. The method is considered conservative as far as minimizing the hazards of releasing C-14 and H-3 to the environment is concerned. It can also be considered practical and economical with respect to the needs of the users because it provides a simple means of destroying hazardous organic and biological components of the radioactive wastes.

Carbon-14 is one of the most commonly encountered elements in living matter, being a component of all food we eat and also present in the air we breath. Both C-14 and H-3 undergo rapid dispersion in the atmosphere together with their stable element counterparts in nature. In its transformation, C-14 is reduced to CO_2 which becomes fixed in vegetation through photosynthesis. The only way it reaches man is through the ingestion pathway.

The uptake of H-3 results in the incorporation of the radionuclide in the organic molecules of the body tissue and its mixing with the body water.

Since carbon and hydrogen are components of plants and animals, C-14 and H-3 are popular and becoming very useful in most biological and chemical researches in the Philippines.

BASES FOR RECOMMENDATION

The majority of the C-14 and H-3 solid wastes generated in the Philippines consist of combustible materials such as paper and accumulated environmental and biological samples. Liquid wastes generally contain organic substances. Users of the radionuclides segregated waste materials generated according to radionuclide following licensing requirements on radiation safety program.

Calculation concerning incineration of C-14 and H-3 wastes are presented in the succeeding sections. The calculations are based generally on accepted maximum permissible concentration in air and annual dose limit for radiation workers in the Philippines.

In the calculation for C-14, no considerations were taken on the fact that exposure can only be occasional and that additional dilution occur as stack gases are released to the atmosphere.

In the absence of available data on the heating value of mixture of combustible waste materials, the heating value for garbage provided in Ref. 5 is used.

Since combustion results in the reduction of biological and organic C-14 to CO_2, restriction in the specific activity of the wastes materials is established because incineration may result to the release of dust and smokes which may contain unoxidized particles of carbon. These particles may be inhaled and fixed in the lungs causing long-term radiation exposure.

In the calculation for H-3, it is assumed that the concentration of H-3 in the body tissue is equal to that in the environment. Values and assumptions used concerning average radiation worker are taken from data for a reference man provided in Ref. 2.

CALCULATIONS

For H-3

The calculations for H-3 are based on the following assumptions:

a) The average relative humidity of air is 70%.

b) Air Temperature is 25°C.

c) The permissible concentration of H-3 in air is the derived air concentration (DAC) which is 8×10^5 Bq/m^3 as provided in Ref. 1.

d) Vapor pressure of H_2O @ 25°C is 101353 pascals.

e) Average energy for H-3 is 0.005 MeV

g) Weight of an average radiation worker 70 Kg with body containing 7 kg of hydrogen, approximately 4.8 kg of which is in body water and 2.2 kg in organic molecules (4).

h) Annual exposure limit is 5 rems.

i) The heating value of combustible material is 4440 calories per Kg. (5). The corresponding theoretical volume of dry air required in m^3 per Kg combustible materials is 4.55. (Table I)

Restriction on Specific Activity

The body burden corresponding to the limiting annual dose rate will be calculated as follows:

$$\frac{5 Rems}{year} \times \frac{100\ ergs/g}{1\ Rem} \times \frac{1 MeV}{1.6 \times 10^{-6}\ ergs} \times \frac{dis}{0.006\ MeV} \times \frac{1\ year}{3.2 \times 10^{7}\ sec} \times \frac{1\ Bq-sec}{1\ dis.} \times \frac{7 \times 10^{4}\ g}{1\ ave.\ worker} = \frac{1.14 \times 10^{8}\ Bg}{ave.\ worker}$$

The resulting limiting activity will be obtained from the following:

$$\frac{1.14 \times 10^{8}\ Bg}{1\ ave.\ worker} \times \frac{1\ ave.\ worker}{7\ Kg\ H} \times \frac{2\ Kg\ H}{18\ Kg\ H_20} \times \frac{1\ Kg\ H_20}{1000\ ml} \times \frac{7\ Kg\ H}{[4.8\ Kg + 0.85(2.2\ Kg)]} = 1898 \frac{Bg}{ml}$$

Concentration Limit for Incineration

The molar density of dry air can be calculated can be obtained as follows:

$$1\ m^3 \times \frac{273}{298} \times \frac{454\ g-mole}{10.052\ m^3} = 41.4\ \frac{mole}{m^3}$$

The resulting ratio between the amount of water vapor per unit volume of air will be as follows:

$$\frac{moles\ H_20}{m^3\ dry\ air} = 0.7287$$

The ratio between the volume of moist air to the volume of dry air will be:

$$\frac{m^3\ wet\ air}{m^3\ dry\ air} = 1.006$$

The maximum concentration of H-3 in the incinerable wastes will be:

$$\frac{8 \times 10^{5}\ Bg}{m^3\ wet\ air} \times \frac{1.006\ m^3\ wet\ air}{m^3\ dry\ air} \times \frac{4.55\ m^3\ dry\ air}{Kg.\ combustibles} = 3.66 \times 10^{6} \frac{Bg}{Kg\ combustibles}$$

TABLE I

Theoretical Volume Of Dry Air Required For Some Selected Combustible Substances

Combustible Substance	Heating Value Calories/g	Theoretical Air Volume Cu. m/Kg
Amorphous C	8075.25	9.63
Carbon Monoxide (CO)	2413.14	2.06
Methane (CH_4)	13296.07	14.45
Benzene (C_6H_6)	10082.13	11.11

The theoretical volume of dry air required per Kg of combustible materials for each substance considered was calculated on the assumption that Air Temperature is 25°C

The following relationship was developed using Linear Regression:

V = 0.0011HV - 0.3368 Eq. (1)

where:

V = Volume of dry air in cubic meter per Kg. of combustible materials

HV = Heating Value in calories per gram of substance

CALCULATIONS FOR C-14

The calculations for C-14 are based on the following assumptions:

a) The largest particle that can penetrate the lungs and become fixed has a diameter of 10 μ.

b) Beta ray from the 10 μ particle will be distributed in the tissue within a sphere of 40 μ.

c) Specific gravity of tissue is 1.0 (6).

d) The specific gravity of the Carbon particle is assumed to be identical to graphite which is 2.25.

e) Annual dose limit for the lungs of an adult workers is 500 mSv (50 rems) (1)

f) Average Energy of C-14 is 0.049 MeV

g) The permissible concentration in air is the derived air concentration (DAC) which is 3 x 10^6 Bq/m^3 (1).

h) The theoretical volume of dry air in m^3 needed in 1 Kg of combustible materials is 4.55 following instruction in Table I using *heating value of garbage* provided in Ref. 5.

i) Air temperature is 25°C.

Restriction on Specific Activity

The volume occupied by a 10 μ particle is:

$$\frac{4}{3} \times 3.1416 \times [5\ m\mu \times 10^{-4}\ {}^{cm}/\mu]^{3}$$

$= 5.24 \times 10^{-10} cm^3$

The volume of a 40 μ spherical tissue that will be exposed to Beta ray will be determined as follows:

$\frac{4}{3} \times 3.1416$

$\times [20 \mu \times 10^{-4}\ ^{cm}/u]^3$

$= 3.35 \times 10^8 cm^3$

The average energy released by C-14 will be:

$\frac{0.049\ MeV}{dis} \times \frac{2.22 \times 10^{12}\ dis/min}{1\ Ci}$

$\times \frac{60\ min}{1\ hr} = 6.5268 \times 10^{12} \frac{MeV}{Ci-hr}$

The energy emitted by the 10 μ particle will be:

$6.5266 \times 10^{12} \frac{MeV}{Ci-hr} \times 2.25 \frac{g}{cm^3}$

$\times 5.24 \times 10^{-10} cm^3$

$= 7695 \frac{MeV-g}{Ci-hr}$

The approximate mass of tissue which will be exposed will be:

$3.35 \times 10^{-8} cm^3 \times \frac{1 q}{cm^3}$

$= 3.35 \times 10^{-8} g$

The dose that will be received by the tissue from beta radiation will be:

$\frac{7694.86\ ^{MeV-g}/_{Ci-hr}}{3.35 \times 10^{-8}\ g\ tissue}$

$= 2.3 \times 10^{11} \frac{MeV}{Ci-hr}$

The energy of material corresponding to the annual dose limit will be:

$\frac{50\ Rads}{year} \times \frac{1\ year}{365\ days} \times \frac{1\ day}{24\ hours}$

$\times 6.242 \times 10^7 \frac{MeV}{g}$

$= 3.56 \times 10^5 \frac{MeV}{g-hr}$

The limiting specific activity of the incinerable radioactive waste must be:

$3.56 \times 10^5 \frac{MeV}{g-hr} \times \frac{1\ Ci-hr}{2.3 \times 10^{11}\ MeV}$

$\times \frac{3.7 \times 10^{10}\ Bg}{1\ Ci}$

$= 5.73 \times 10^4 \frac{Bg}{g}$

Concentration Limit for Incineration

The concentration limit for the incinerable materials will be:

$3 \times 10^6 \frac{Bg}{m^3} \times \frac{4.55\ m^3\ dry\ air}{Kg.\ combustibles}$

$\times \frac{1.006\ m^3\ wet\ air}{m^3\ dry\ air}$

$= \frac{1.37 \times 10^7\ Bg}{Kg.\ combustibles}$

RECOMMENDATIONS

Combustible wastes containing C-14 or H-3 may be incinerated in concentration that do not exceed 1.37×10^7 Bq/Kg of combustible materials for C-14 or 3.66×10^6 Bq/Kg of combustible materials for H-3. Since non-radioactive combustible wastes are usually incinerated, the calculations presented made use of data concerning combustible garbage. The combustion, however, should be supported by auxiliary fuel.

Restrictions on specific activity of H-3 or C-14 are determined because of the possibility of formation of radioactive particles. Incineration of C-14 may produce dusts or smokes containing unoxidized Carbon which when inhaled may be deposited in the lungs. Incineration of H-3 may cause contamination of the water vapor in air which when taken in by inhalation will be distributed in the body fluid.

In view of the above, it is recommended that materials C-14 wastes to be burned in an ordinary incinerator must contain C-14 of activity 5.73×10^4 Bq/g of Carbon in the region of highest C-14 concentration. On the other hand, materials containing H-3 must have a specific activity of 1898 Bq/ml of water in the region of highest concentration.

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