

A Critical Study on the IAEA Definition of High Level Radioactive Waste Unsuitable for Dumping at Sea

by

Yasuo Miyake

Geochemistry Research Association, Tokyo

and

Katsuko Saruhashi

Meteorological Research Institute, Tokyo

(Received May 31, 1976)

Abstract

The definition of high level radioactive waste and other high level radioactive matter not suitable for dumping at sea has been given by IAEA (1975). Since this definition is based on the report by WEBB and MORLEY (1973), a critical study is made on their report. The result of study shows that owing to the assumption of a very small value of the horizontal eddy diffusion coefficient ($10^4 \text{ cm}^2/\text{s}$) for the sake of safety for these nuclides, the limiting environmental capacity for such nuclides as ^{226}Ra and ^{239}Pu with longer half-lives is extremely overestimated. And due to a very small value of a daily intake of marine foods (6 g/d) and a larger value of the ratio of nuclidic concentrations between the top of the deep layer and the surface layer (100), the environmental capacity is also overestimated for every nuclide. It is proposed that the definition of high level radioactive waste should be reassessed carefully by experts in various countries.

1. Introduction

According to the definition which was asked by the resolution at the Inter-governmental Conference on the Dumping of Wastes at Sea, held in London in the fall in 1972, and has been recently adopted by the International Atomic Energy Agency (IAEA, 1975), high-level radioactive waste or other high-level radioactive matter unsuitable for dumping at sea means any waste or other matter with a concentration in curies per unit gross mass (in tons) exceeding (a) 10 Ci/t for α active waste of half-life greater than 50 years (in the case of ^{226}Ra , not more than 100 Ci/y may be dumped at any one site); (b) 10^3 Ci/t for β/γ -active waste (excluding tritium) but the limit for ^{90}Sr plus ^{137}Cs is 10^2 Ci/t; (c) 10^6 Ci/t for tritium.

ium.

The definition is based on the results of the United Kingdom evaluation (WEBB and MORLEY, 1973) which gave the limit of capacity of the environment in relation to dumping into the North East Atlantic. The evaluation was reassessed by the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD, 1973). Because of the great importance of the definition to future developments in peaceful uses of atomic energy in the world, and also to the health and safety of human beings, as well as to the conservation of marine environment, a critical study is done on the report published by WEBB and MORLEY on which the above definition is largely dependent.

2. A criticism and comments on the definition by IAEA

(1) In the case that 1 Ci of a certain radionuclide R is dumped on the deep sea floor annually, the amount of radionuclide m (Ci) finally reaches 1 Ci divided by a radioactive decay constant, Ci/λ , at a time when the rate of disposal becomes equal to the rate of radioactive decay. In a closed system, the mean concentration C_m (Ci/cm^3) is also proportional to a reciprocal of λ .

(2) The ocean is divided into two layers, *i. e.*, the surface layer with a thickness of 1,000 m and the deep layer with a thickness of 4,000 m. The highest concentration (Ci/cm^3) of a certain nuclide in the surface layer and just below the bottom of the layer are called respectively C_a and C_c at the steady state. As there is a pycnocline between the surface and the deep layer, the ratio C_c/C_a or β is usually, $\beta \geq 1$. In the eastern North Atlantic, WEBB and MORLEY gave a larger value of 100 to β . But, in most of other areas in the world oceans, β is generally somewhere between 1 and 10.

(3) The maximum permissible concentration in sea water in the surface layer $C_{a \max}$ is given by the equation

$$C_{a \max} = \frac{MPDI \cdot x}{f \cdot \gamma} \quad (1)$$

where MPDI is the maximum permissible daily intake of a certain radionuclide (Ci/d), or it is equal to MPC recommended by the International Commission on Radiological Protection (ICRP) in drinking water multiplied by 2,200 cm^3 , which is a mean daily amount of drinking water for a standard man (70 kg, mean weight). x is a safety factor, f is an amount of intake of marine foods per day per person (g/d), γ is a concentration factor of a radionuclide in marine foods. By using $C_{a \max}$ a value of maximum permissible annual rate of disposal ($L Ci/y$) of a radionuclide is calculated by the next equation,

$$\frac{C_{a \max}}{C_a} \times 1 Ci/y = L Ci/y \quad (2)$$

L is the same as a term which is called limiting environmental capacity by WEBB and MORLEY.

The total amount M (Ci) of a certain radionuclide in the ocean area, when the steady state is reached with the rate of disposal of $L Ci/y$, is expressed as follows,

$$M = \frac{L}{\lambda} Ci \quad (3)$$

Usually, a greater part of M is contained in the deep layer.

(4) The relation between a total amount of a certain radionuclide and a total amount of water in the deep layer W (cm^3) is

$$W = \frac{M}{C_{m \max}} \quad (4)$$

where $C_{m \max}$ is the maximum permissible mean concentration in the deep water. Since C_c is the highest equilibrium concentration of a radionuclide at the top of the deep layer when the rate of disposal is 1 Ci/y , the maximum permissible concentration $C_{c \max}$ at the same depth for the rate of disposal $L Ci/y$ is

$$C_{c \max} = L_0 C_c, \quad (5)$$

where L_0 is a ratio of $C_{a \max}$ to C_a .

(5) The mean of the highest concentration in each layer from the bottom to the top of the deep layer ($\bar{C}_{m \max}$) for the rate of disposal $L Ci/y$ is,

$$\bar{C}_{m \max} = \alpha C_{c \max} \quad (6)$$

where α is a constant which is usually larger than 1, and increases with the increase of λ and decreases with the decrease of λ , finally approaching 1.

On the other hand, as $\bar{C}_{m \max}$ is a mean of a highest concentration in each layer,

$$\bar{C}_{m \max} > C_{m \max} \quad (7)$$

or

$$C_{m \max} = \delta \bar{C}_{m \max} \quad (8)$$

where δ is smaller than 1, and it is probable to assume it to be about 0.1. Therefore, Eq. (4) can be rewritten as follows:

$$W = \frac{L}{\lambda L_0 \delta \alpha C_c} = \frac{1}{\lambda \delta \alpha C_c} cm^3 \quad (9)$$

(6) Since W is constant and common to every radionuclide in the same area, and δ may be regarded approximately as the same for different nuclides,

$$\lambda_1 \alpha_1 C_{c_1} = \lambda_2 \alpha_2 C_{c_2} = \dots \quad (10)$$

where, 1, 2, ... indicate nuclides R_1, R_2, \dots . Therefore, for two different nuclides R_1 and R_2 the ratio of each C_c is approximately,

$$\frac{C_{c_1}}{C_{c_2}} = \frac{\alpha_2 \lambda_2}{\alpha_1 \lambda_1} \quad (11)$$

(7) When each 1 Ci of ^{60}Co , ^3H , ^{90}Sr , ^{137}Cs , ^{226}Ra and ^{239}Pu is dumped annually on the ocean floor, the ratio of C_c of each nuclide to that of ^{90}Sr ($C_{c\text{Sr}}$), at the steady state is calculated by assuming each probable value of α for each nuclide. The results of calculation are given in Table 1. The values of $C_c/C_{c\text{Sr}}$ which were given by WEBB and MORLEY and adopted by IAEA are also shown in the last column in Table 1.

As seen in Table 1, the values of $C_c/C_{c\text{Sr}}$

Table 1. The ratio of $C_c/C_{c\text{Sr}}$.

Nuclide	λ, y^{-1}	α	$C_c/C_{c\text{Sr}}$	$C_c/C_{c\text{Sr}}$ (WEBB-MORLEY-IAEA)
^{60}Co	0.14	100	0.018	0.005
^3H	0.056	20	0.2	0.2
^{90}Sr	0.025	10	1	1
^{137}Cs	0.023	10	1	1
^{226}Ra	4×10^{-4}	3	200	7
^{239}Pu	2.8×10^{-5}	1	10,000	7

of ^{226}Ra and ^{239}Pu given by WEBB-MORLEY-IAEA are very much smaller than those calculated by the present authors. Especially, the $C_c/C_{c\text{Sr}}$ value of ^{239}Pu is extremely smaller by a factor of 10^{-3} . When we consider that at the steady state, a ratio of a mean concentration of a radionuclide is proportional to a reciprocal of λ , it is evident that such smaller values of $C_c/C_{c\text{Sr}}$ for ^{226}Ra and ^{239}Pu are improbable. In other words, the limiting environmental capacities for ^{226}Ra and ^{239}Pu given by WEBB and MORLEY are extraordinary overestimations.

(8) Concerning the safety factor x in Eq. (1), WEBB and MORLEY and IAEA gave, respectively values of 0.1 and 10^{-5} . According to the present authors' view, x consists of the following five factors:

$$x = A \cdot B \cdot C \cdot D \cdot E$$

A is a factor concerning on allotment to the marine-origin radiation dose in the radiation dose limit for an individual in the public, 0.1; B is a factor concerning the effect of radioactive waste disposal at other sites, 0.1; C is a factor concerning combined pollution with various kinds of radionuclides

0.1; D is a factor to reduce the radiation dose limit for an individual in the public to the level of 5 mr/y, 10^{-3} ; E is a factor concerning the effects of other sources of radioactive pollution such as coastal effluence and dumping of waste from nuclear powered ships, 1/3. As a whole, the value of x will be 3.3×10^{-7} .

(9) The selection of the value of f in Eq. (1) or an amount of daily intake of marine foods, is important for nations that depend largely on marine foods in their daily diets. Nevertheless, WEBB and MORLEY and IAEA employed a very small value of only 6 g/d for f in their calculations of $C_{c\text{max}}$. Usually, f is considered to be 100 g/d or more. The present authors assume that f is 100 g/d.

(10) WEBB and MORLEY, and IAEA assumed a very high value of 100 for the ratio β or C_c/C_a in the eastern North Atlantic. But, as mentioned above, β is generally 1 to 10. The present authors adopt a value of 10 for β .

With respect to γ , a concentration factor of a certain radionuclide in marine foods, the values adopted by WEBB and MORLEY

are used here, though there are some questions. Thus, the relation between L and x , f and β is expressed as follows:

$$\frac{L_1}{L_2} = \frac{x_1 f_2 \beta_1}{x_2 f_1 \beta_2} \quad (12)$$

where L_1 and L_2 are the values of the maximum permissible annual rates of disposal (Ci/y) of a certain radionuclide calculated by Eq. (1) respectively by using different factors (x_1, f_1, β_1) and (x_2, f_2, β_2). In Table

2 are the values of x , f and β used by WEBB and MORLEY, and IAEA compared with those adopted by the present authors. In Table 2, the relative values of L obtained by different values of x , f and β are also given in the last column.

Table 2 shows that the ratio of L value given by IAEA to that by the present authors is as high as 5×10^3 for the same value of C_a .

Table 2. The comparisons of x , f , β and L .

	x	f (g/d)	β	Ratio of L
WEBB and MORLEY	0.1	6	100	5×10^7
IAEA	10^{-5}	6	100	5×10^3
The present authors	3.3×10^{-7}	100	10	1

Table 3. Recalculated values of L (Ci/y) given by IAEA.

Nuclide	IAEA original $x=10^{-5}$ $f=6$ g/d $\beta=100$	IAEA recal. I $x=10^{-5}$ $f=6$ g/d $\beta=100$	IAEA recal. II $x=10^{-5}$ $f=100$ g/d $\beta=10$
^{60}Co	2×10^9	3×10^8	1.8×10^6
^3H	3×10^{11}	3×10^{11}	1.8×10^9
^{90}Sr	3×10^7	3×10^7	1.8×10^5
^{137}Cs	1×10^7	1×10^7	6×10^4
^{226}Ra	1×10^2	3	1.8×10^{-2}
^{239}Pu	1×10^6	700	4

(11) The recalculation of L values for different nuclides given by IAEA is done by using corrected values of ratios of concentration of each nuclide to ^{90}Sr concentration. The results of calculation are given in the column of (IAEA recal. I) in Table 3. In Table 3 is also given the result of recalculation of L values of IAEA by employing more probable values of f and β (IAEA recal. II).

When a revised definition of high level radioactive waste is given on the basis of (IAEA recal. II) in Table 3, a new definition will be expressed as follows: "high level radioactive waste or other high level radioactive matter unsuitable for dumping at sea means any waste or other matter

with a concentration in curies per ton exceeding

- (a) 10 Ci/t for β/γ active waste (excluding tritium) but the limit for ^{90}Sr plus ^{137}Cs 1 Ci/t.
- (b) 10^4 Ci/t for tritium.
- (c) α active waste of longer half-lives, such as ^{226}Ra and ^{239}Pu may not be dumped at any site.

Incidentally, the above revised definition is in good agreement with that given by SUGIURA, SARUHASHI and MIYAKE (1976) on the basis of the diffusion model. It is also in good agreement with that given by the present authors, although the idea and the model of the ocean are quite different from those by WEBB and MORLEY. A report

including the new definition by the present authors will soon be published (an abstract of a part of the study was published by MIYAKE and SARUHASHI, 1976).

(12) From the model of the ocean proposed by WEBB and MORLEY, the total volume of water W is calculated by Eq. (9) in which δ is assumed to be 0.1 and the same values of α are used as given in Table 1.

In a closed system the total amount of water must be constant and common to every radionuclide. As shown in Table 4, W seems to be nearly constant and common to ^{60}Co , ^3H , ^{90}Sr and ^{137}Cs , but it is much

Table 4. The calculation of the total volume of water in the model by WEBB and MORLEY.

Nuclide	W cm ³ (calc.)
^{60}Co	5×10^{20}
^3H	2×10^{20}
^{90}Sr	2×10^{20}
^{137}Cs	2×10^{20}
^{226}Ra	6×10^{21}
^{239}Pu	2.5×10^{23}

different for ^{226}Ra and ^{239}Pu . W value for ^{239}Pu is close to the total volume of the entire Atlantic Ocean (3.4×10^{23} cm³), while those for ^3H , ^{90}Sr and ^{137}Cs are only 2×10^{20} cm³ which is equal to a small body of water with a surface area of 200 km square with a depth of 5,000 m. The reason for such contradictory results involved in the calculations by WEBB and MORLEY may be the inadequacy in the assumption for the sake of safety of a very small diffusion coefficient on the horizontal direction, *i. e.*, 10^4 cm²/s. As a result, such radionuclides as ^{60}Co , ^3H , ^{90}Sr and ^{137}Cs with half-lives from 5 to 30 years are, so to say, confined and accumulated in a very small volume of water, while radionuclides with longer half-lives, such as ^{226}Ra and ^{239}Pu , spread throughout a large body of water. This will be discussed in

more detail in an article in the present number by SUGIURA, SARUHASHI and MIYAKE (1976).

In considering a model of the ocean, not only radioactive contaminations of sea water in a small area above or near a disposal site, but also contaminations in a wide area due to nuclides with longer half-lives must be taken into account. Otherwise, overestimations on the maximum permissible annual rate of disposal of radionuclides with longer half-lives are inevitable, as was done by WEBB and MORLEY for ^{226}Ra and ^{239}Pu .

(13) In conclusion, the model of the ocean as a receptacle of solid radioactive wastes proposed by WEBB and MORLEY and adopted by OECD and IAEA, has not only many questionable points, but also seems unrealistic. The definition of high-level radioactive waste and other high-level radioactive matter unsuitable for dumping at sea is so important that it should be reexamined extensively and carefully under the international cooperation by experts on these problems in the whole world.

References

- IAEA, 1975: Convention on the prevention of marine pollution by dumping of waste and other matter. Information Circular, INFCIRC/205/Add, 1, 10 Jan. 1975.
- MIYAKE, Y. and K. SARUHASHI, 1976: Disposal of radioactive waste into deep seas. *J. Radiat. Res.*, 17, 42-43.
- OECD-NEA, 1973: Radioactive waste disposal into the Atlantic. SEN/SAN (73), 10, 21st May 1973. Solid radioactive waste disposal into the sea. SEN/SAN (73), 30th May 1973.
- SUGIURA, Y., K. SARUHASHI and Y. MIYAKE, 1976: The evaluation on the disposal of radioactive wastes into the North Pacific. *Pap. Met. Geophys.*, 27, 81-87.
- WEBB, G. A. M. and F. MORLEY, 1973: A model for the evaluation of the deep ocean disposal of radioactive waste. NRPE-R 14, published by National Radiological Protection Board, UK.

海洋処分に不適当な高レベル放射性廃棄物に関する 国際原子力機関の定義についての批判的研究

三宅泰雄・猿橋勝子

海洋処分に不適当な高レベル放射性廃棄物と他の放射性物質の定義が、国際原子力機関によって与えられている (1975)。

この定義は WEBB と MORLEY (1973) の報告に基くが、多くの問題点があるので、彼らの報告について批判的研究を行った。

研究の結果、彼らは安全のために水平方向のうず拡散係数の値を、非常に小さく ($10^4 \text{ cm}^2/\text{s}$) 仮定したために、 ^{226}Ra や ^{239}Pu のような半減期の長い核種については、環境容量限度が非常に過大評価されていることが分つた。

さらに水産食品の摂取量を非常に少なくし (6g/d)、また深層水の上部と表層水中の放射性核種の濃度比の値を非常に大きく (100) としたために、環境容量限度が各核種に対して、過大評価されている。

高レベル放射性廃棄物の定義は、関係する各国の専門家によって、慎重に再検討されることを提唱する。