Unconditional Clearance Levels for Releasing Radioactive Materials Contaminated with Major Radionuclides from Regulatory Control

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Abstract

Unconditional clearance levels were derived for fifteen short-lived radionuclides. Due to the uncertainty of long-term radiological impact analysis, alpha emitting nuclides and nuclides with half-lives longer than 30 years (except for C-14) were excluded from the scope of this study. The candidate waste streams are solid wastes and waste oil generated from nuclear power reactors. The clearance levels were derived by generic assessment for enveloping scenarios, along with specific assessment for each detailed scenario such as landfill, incineration and recycling. The derived values lie in the range from 0.01 to 100 Bq/g.

Key words : Unconditional Clearance, Short-Lived Radionuclides, Regulatory Control

1. Introduction

Clearance is a process to remove radioactive materials within authorized regulatory control from further regulatory control. The concept of clearance has been partly implemented in Korean Atomic Energy Act and relevant regulations in terms of "Self-Disposition" along with the dose criteria of 0.01 mSv/y and 1 person·Sv/y. Although Notice No. 2001-30 of the Minister of Science and Technology provides a single clearance level for thirty short-lived beta/gamma emitting nuclides as 100 Bq/g, clearance levels for other major nuclides (e.g. Cs-137, Co-60, etc.) have not been determined yet. Accordingly, a case-by-case safety review has been done for each application of clearance of waste containing nuclides not listed explicitly in the Notice. This approach requires large amount of regulatory resources and applicants' works, therefore the need of deriving unconditional clearance levels for major radionuclides generated from large-scale nuclear installations has been raised by industries. The ultimate objective of this study is to develop unconditional clearance levels for the waste contaminated with radionuclides which have not been covered by present domestic regulations.

2. Assumptions and Methodology

2.1 Basic Assumptions

According to the Notice No. 2001-30, the maximum radiation dose posed by the cleared materials to any individuals shall not exceed 0.01 mS/y. In order to derive clearance levels based on the above dose criterion, a series of scenario-specific assessment should be performed. Otherwise, more generic approach, in which a set of comprehensive simple scenarios enveloping detailed ones are modeled, can be taken into consideration. In this study, both methodologies of "Specific Assessment" and "Generic Assessment" were adopted. As for the specific scenarios, landfill, incineration and recycling options were considered.

The total amount of waste cleared per year was determined to be 1,000 ton. The waste streams to be cleared were limited to solid waste and waste oil, and the target nuclides were selected as follows: H-3, C-14, Mn-54, Fe-55, Co-58, Fe-59, Co-60, Ni-63, Zn-65, Sr-89, Sr-90, Sb-125, Cs-134, Cs-137, and Ce-144. Above conditions envelop most of domestic regulatory experiences on clearance for the last 10 years. In addition, it was also conservatively assumed that the waste would not be further diluted with clean materials after clearance.

2.2 Generic Assessment

In the generic assessment, a series of representative scenarios enveloping a variety of detailed ones was conservatively assumed. As a result, inhalation, ingestion, and direct exposure pathways were chosen. The inhalation scenario simulates the situation in which workers inhale contaminated dust originated from cleared waste both in workplace and environment. In the ingestion scenario, it was assumed that workers might inadvertently swallow radioactive materials by hand-to-mouth pathway in dusty workplace (secondary ingestion) and pica children might ingest soil-like materials cleared from regulatory control. In addition, direct exposure to truck drivers and landfill workers handling cleared materials were taken into consideration. The generic assessment was performed by spread sheet embodied macros of numerical models similar to the European Commission models [1].

In the generic assessment, the maximum individual worker dose was calculated as follows:

$$ED_W = D_{INH-W} + D_{ING-W} + \max\ (D_{EXT-1W}, D_{EXT-2W}, D_{EXT-3W}), \quad (1)$$

where, ED_W = worker's total annual exposure, D_s = worker's annual dose from a single scenario. On the other hand, the maximum dose to the individual member of the public was calculated according to the following equation:

$$ED_P = D_{INH-P} + D_{ING-P} + \max\ (D_{EXT-1P}, D_{EXT-2P}, D_{EXT-3P}), \quad (2)$$

where, ED_P = total annual exposure to a member of general public, D_s = the general public's annual dose from a single scenario. More detailed assumptions and parameters for each scenario were explained in Ref. [4].

2.3 Landfill Scenario Assessment

Landfill is one of the most widely used options to release materials from regulatory control. The following pathways were chosen: (1) direct exposure from buried materials, (2) inhalation of resuspended airborne dust, and (3) ingestion of contaminated water and foods.

The critical groups are (1) workers at landfill, and (2) on-site residents after closure of the burial site. Numerical calculations were performed by RESRAD [2]. In order to calculate effective dose, however, dose conversion factors (DCFs) for intake (ingestion and inhalation) were adjusted to reflect IAEA Safety Series No. 115. Taking into account of potential radiological impacts to all age groups, the standard DCFs for intake were set to the DCF values for adult multiplied by a factor of "2".

The workers working at the landfill during its operational period handle with "fresh" waste, and are to be exposed by three major pathways such as direct external exposure and internal exposures from inhalation of dust and secondary ingestion. After the landfill capacity is exhausted, the site should be closed. The closed site is expected to be under the institutional control for a few years, and released to the public thereafter. Members of the public may inhabit on the closed landfill after institutional control period is over. The onsite inhabitants can be exposed to the cleared waste by direct external radiation and by ingestion of contaminated agricultural or livestock products and ground and/or surface water.

Fig. 1 shows the geometrical assumptions on the landfill in which candidate waste is buried. In order to model the geometry of the landfill site, the total mass of buried waste (M) and average height (h), and one of the following parameters of the buried layer such as ρ (density of the waste), r and D (radius and diameter, respectively), and A (area) should be known. The characteristic parameters can be obtained by the following equations:

$$R = \sqrt{\frac{M}{\pi \cdot \rho \cdot h}},\ D = 2 \cdot \sqrt{\frac{M}{\pi \cdot \rho \cdot h}},\ V = \frac{M}{\rho} \text{ and } A = \pi \cdot R^2 = \frac{M}{\rho \cdot h}. \quad (3)$$

Other specific parameters for landfill scenario assessment are listed in Ref. [4].

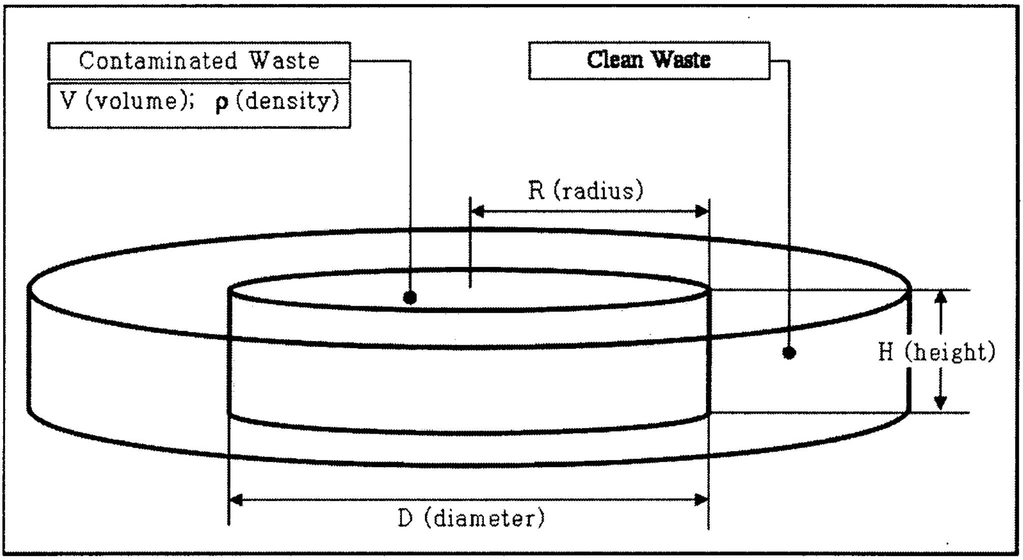

Fig. 1. Geometry of hypothetical industrial waste landfill at which cleared materials are to be buried

2.4 Incineration Scenario Assessment

Incineration of combustible solid waste and waste oil has been partly done as an option for clearance in Korea. But some issues on re-concentration of radioactivity in the by-product (e.g. ash) have been brought up in the process of regulatory assessment. In this regard, a series of constraints were established prior to the assessment of the incineration scenario as follows: (1) Off-site incineration is allowed for waste oil contaminated only with H-3 and/or C-14.; and (2) On-site incineration can be used for all waste streams, provided the area is specified as "controlled area" and ash is controlled.

It is assumed that all radionuclides existing in particulate form are still remained in the ash, but only 10% of initial radioactivity of H-3 and C-14 is remained in the ash after incineration. On the other hand, the fractions of radioactivity released to the atmosphere for H-3, C-14, and other particulate nuclides were conservatively set to 100%, 95%, and 10%, respectively. The radiological impacts due to the atmospheric dispersion of radioactive plume from the incinerator stack were calculated by INDAC within the area of radius 10 km [4].

2.5 Recycling Scenario Assessment

In this recycling scenario, it is assumed that the steel scrap can be directly reused or melted in industrial smelter or refiner and then fabricated into consumer/public products. The radionuclides in the steel scrap may redistribute into metal product, slag, and dust filter. Accordingly, the phenomena of mass partitioning and elemental partitioning in the melting process were mathematically modeled.

In general, the radiological characteristics of the steel scraps are not changed before they are put into the smelter. It is also expected that the steel scraps are mixed with ordinary (i.e. non-radioactive) metal scraps in the yard of smelting plants and their radioactivity concentration is to be decreased. For ensuring conservatism, however, it was assumed that all cleared steel scraps generated in a year to be melted in a single smelter without mixing with other clean metals. In the melting process, the radioactivity and mass present in the cleared steel scraps are to be redistributed into three immediate products such as ingot, slag, and dust. In addition, a part of dusts leaves the off-gas treatment system and then releases to the atmosphere. A few investigators have simulated the redistribution phenomena in the melting process by introducing mass partitioning factor (MPF) and elemental partitioning factor (EPF). In this study, higher portioning factors obtained from literature survey were chosen. The mass of each product i generated from melting process can be simply estimated from the initial mass of steel scraps and mass partitioning factors as:

$$M_i = M_0 \cdot MPF_i , \tag{4}$$

where, i = product identification number (1 = ingot, 2 = dust in bag house filter, 3 = slag), Mi = mass of product i, M_0 = initial mass of steel scraps, and MPF_i = mass partitioning factor for product I.

On the other hand, the radioactivity concentration of each product can be calculated from elemental portioning factors and initial activity concentration of steel scraps as follows:

$$C_i = \frac{C_0 \cdot RPF_i \cdot M_0}{M_0 \cdot MPF_i} = \frac{C_0 \cdot RPF_i}{MPF_i} , \tag{5}$$

where, C_i = radioactivity concentration of product i, M_0 = initial radioactivity concentration of steel scrap, and EPF_i = elemental partitioning factor for product i.

Critical groups in the whole recycling scenario are (1) workers for collecting and transporting scraps, (2) workers at melting and fabrication plants, (3) workers for handling and transporting products, and (4) consumers using recycled products. The above scenario was numerically calculated by RESRAD-RECYCLE [5]. However, relevant DCFs for intake were also adjusted according to the same approach as the landfill scenario assessment.

3. Calculation Results and Derivation of Clearance Levels

3.1 Clearance Levels for Each Scenario

Expected dose per unit radioactivity concentration of each radionuclide (i.e., mSv/y perBq/g) was calculated for each scenario as discussed in Section 2. The above values were divided by 0.01mSv/y of dose criterion and then the clearance levels for each scenario were obtained as listed in Table 1. The clearance levels in Table 1 have been derived from the un-rounded values by assigning the nearest power of 10, according to the European Commission's approach [1].

It turns out that the recycling scenario is critical to H-3 and Fe-55, and the incineration scenario is dominant for C-14, Ni-63, Sr-89 and Ce-144. In addition, the clearance levels for Co-58, Sr-90 and Cs-137 were determined by landfill scenario and those for Mn-54, Fe-59, Co-60, Zn-65, Sb-125 and Cs-134 by generic assessment.

Table 1. Radioactivity concentration equivalent to 0.01mSv/y for each scenario and clearance level

Nuclide	Generic Assessment [Bq/g]	Landfill Scenario [Bq/g]	Incineration Scenario [Bq/g]	Recycling Scenario [Bq/g]	Minimum Value [Bq/g]	Critical Scenario -	Clearance Level [Bq/g]
H-3	7.06E+02	1.32E+02	6.76E+01	6.02E+01	6.02E+01	Recycling	1E+2
C-14	3.32E+01	3.10E+00	2.72E-01	4.24E+00	2.72E-01	Incineration	1E-1
Mn-54	1.90E-01	4.13E-01	2.23E+00	3.31E-01	1.90E-01	Generic	1E-1
Fe-55	1.58E+02	6.67E+02	1.60E+01	8.55E+00	8.55E+00	Recycling	1E+1
Co-58	2.48E-01	1.59E-01	4.20E+00	1.51E+00	1.59E-01	Landfill	1E-1
Fe-59	1.92E-01	9.43E-01	2.81E+00	1.01E+00	1.92E-01	Generic	1E-1
Co-60	3.64E-02	7.60E-02	1.33E-01	1.76E-01	3.64E-02	Generic	1E-1
Ni-63	1.46E+02	7.19E+00	3.76E+00	1.66E+01	3.76E+00	Incineration	1E+1
Zn-65	2.45E-01	8.78E-01	1.03E+00	6.76E-01	2.45E-01	Generic	1E-1
Sr-89	2.05E+01	2.03E+03	3.12E+00	4.81E+00	3.12E+00	Incineration	1E+1
Sr-90	1.14E+00	1.16E-02	5.18E-02	8.93E-02	1.16E-02	Landfill	1E-2
Sb-125	2.96E-01	1.43E+00	1.03E+00	1.05E+00	2.96E-01	Generic	1E-1
Cs-134	7.97E-02	2.00E-01	1.85E-01	1.19E-01	7.97E-02	Generic	1E-1
Cs-137	1.89E-01	1.06E-01	3.19E-01	1.68E-01	1.06E-01	Landfill	1E-1
Ce-144	2.14E+00	7.91E+00	5.88E-01	6.85E-01	5.88E-01	Incineration	1E+0

3.2 Comparison with Reference Values

Fig. 2 shows the clearance levels derived in this study, and clearance levels and exemptions levels listed in three different documents published by the IAEA [6-8]. The clearance levels proposed in this study are quite comparable to the values listed in the IAEA Safety Guide and generally lower than other reference values. The relative conservatism of the final results of this study can be mainly attributed to the additional consideration of incineration scenario and other conservative basic assumptions such as excluding dilution effect.

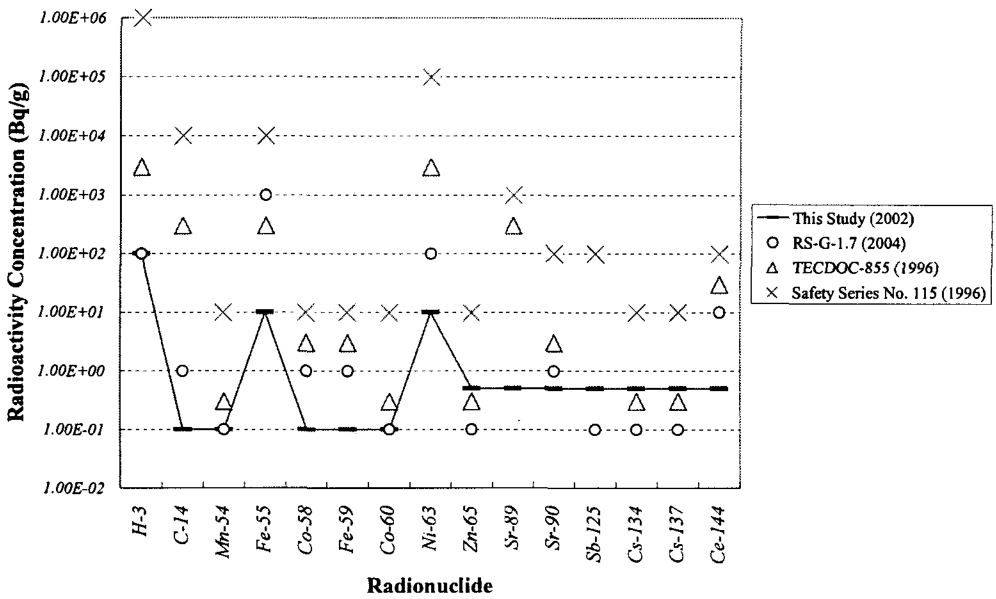

Fig. 2. Comparison of derived clearance levels with other reference values

4. Concluding Remarks

Clearance concentration criteria were derived for selected fifteen major radionuclides by use of generic assessment methodology and specific assessment methodology for three scenarios (i.e., landfill, incineration, and recycling of steel scraps). In general, the results of this study are more conservative than those proposed by some foreign investigators or comparable to them. It turned out that the conservatism resulted from a series of assumptions adopted in this study such as additional consideration of incineration as a scenario and excluding the possibility of dilution with clean wastes after clearance.

Korea is now planning to revise its clearance-related regulations, and therefore recently initiated a feasibility study for adopting basic principles along with values of activity concentration in the IAEA Safety Guide. In the rule-making process, the assumptions, scenarios, methodologies and results of this study may provide a clue to improve regulatory effectiveness on unconditional clearance.

Acknowledgements

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