Journal of the Korean Nuclear Society
Volume 35, Number 5, pp.387 ~ 398, October, 2003

Statistical Approach for Derivation of Quantitative Acceptance Criteria for Radioactive Wastes to Near Surface Disposal Facility

Jin Beak Park, Joo Wan Park, Eun Yong Lee, and Chang Lak Kim
Korea Hydro & Nuclear Power Co., Ltd.
150 Dukjin-dong Yuseung-gu, Daejeon 305-353, Korea
clkim@khnp.co.kr

(Received December 24, 2002)

Abstract

For reference human intrusion scenarios constructed in previous study, a probabilistic safety assessment to derive the radionuclide concentration limits for the low- and intermediate- level radioactive waste disposal facility is conducted. Statistical approach by the Latin Hypercube Sampling method is introduced and new assumptions about the disposal facility system are examined and discussed. In our previous study of deterministic approach, the post construction scenarios appeared as most limiting scenario to derive the radionuclide concentration limits. Whereas, in this statistical approach, the post drilling and the post construction scenarios are mutually competing for the scenario selection according to which radionuclides are more important in safety assessment context. Introduction of new assumption shows that the post drilling scenario can play an important role as the limiting scenario instead of the post-construction scenario. When we compare the concentration limits between the previous and this study, concentrations of radionuclides such as Nb-94, Cs-137 and alpha-emitting radionuclides show elevated values than the case of the previous study. Remaining radionuclides such as Sr-90, Tc-99 I-129, Ni-59 and Ni-63 show lower values than the case of the previous study.

Key Words : radwaste disposal, concentration limit, near-surface disposal facility, latin hypercube sampling, human Intrusion,

1. Introduction

Radioactive wastes need to be safely managed in a regulated manner, compatible with the internationally agreed principles and standards. The disposal method chosen for the low and intermediate-level waste (LILW) should be commensurate with the hazard and longevity of the waste. Near surface disposal is an option used by many countries for the disposal of radioactive waste containing short-lived radionuclides and low concentrations of long-lived radionuclides. The term 'near surface disposal' encompasses a wide range of options, including the disposal in engineered structure at ground level, disposal in simple trenches a few meters deep, disposal in engineered concrete vaults, and disposal in rock caverns several tens of meters below the surface.

In 1995, the International Atomic Energy Agency (IAEA) published the Principles of Radioactive Waste Management [1]. This document states that the objective of radioactive waste management is '*to deal with radioactive waste in a manner that protects the human health and the environment now and in the future without imposing undue burdens on future generations*'. Thus the application of the near surface disposal option requires the implementation of measure that will provide the protection of human health and environment since improperly managed radioactive waste would result in adverse effects to human health and environment now and in the future. By these means, international attentions to the concentration limit for specific radionuclides in the near surface disposal option has been emphasized. Performance assessment for the near-surface disposal option requires many phenomenological and physico-chemical parameters, which can be derived from the facility design process, physical experiment in the lab or in the field. In general, these parameters have their own spatial distributions such as uniform, normal or log-normal distributions.

Individual performance assessment with deterministic approach selects most representative value from the each distribution and repeats the assessment process by choosing alternative values from the distribution. This deterministic approach does not show the effect of individual input parameters and the parametric uncertainty. As an alternative method to overcome this parametric uncertainty of deterministic performance assessment, statistical approach is essentially required and used in many nations. In the previous studies [2, 3], performance assessment with deterministic approach was conducted to derive the waste concentration limits for a near-surface radioactive disposal facility. Brief sensitivity analysis was conducted for the several important parameters such as institutional control period, soil dilution factor, food consumption rate and exposure time.

In this study, based on the Latin Hypercube Sampling (LHS) procedure, the statistical approach is introduced and conducted as an extension of our previous published work [2, 3] to accommodate the parametric uncertainty of previous deterministic approach. Due to the difficulties to deal with the uncertainty of multiple parameters of GENII [4], which is the dose assessment code developed by PNL, the statistical package program called GENII-LHS is developed and linked by the authors. GENII-LHS is programmed to be able to: 1) prepares the multiple input sets for GENII according to LHS process, 2) execute the GENII program by external procedures of GENII, 3) calculate the statistical properties of output variables of GENII and 3) organize the statistical results for the result representation.

2. Approaches To Derive Quantitative Acceptance Criteria

A number of approaches could be used to derive the quantitative acceptance criteria for the disposal of radioactive waste to near surface facilities. It is important that the chosen approach should be (1) relevant, (2) adequate, (3) understandable and (4) credible. [5]

In the previous studies [6, 7], which is taken to derive the limit values of radionuclide concentrations, the safety assessment approach has been found to be most useful. The Safety Guide on Safety Assessment for Near Surface Disposal [8] notes that the '*results of safety assessment are an important means for determining the inventory and/or concentration limit for specific radionuclides in the waste and provide one way for developing the waste acceptance requirements for the near surface repository*'.

The safety assessment approach has been developed and applied in several ways for the assessment of near surface facilities [2,3,9-11]. IAEA Co-ordinated Research Program (CRP) on the Near-surface Radioactive Waste Disposal Safety Assessment Reliability Study (NSARS) in 1996 was focused on developing the confidence in the physical process models by conducting inter-comparison between approaches for specific test cases that represented typical assessment problems. Based on the experience of NSARS [9], it was decided that a new CRP should be implemented to built and place a special emphasis on the review and the enhancement of the post-closure safety assessment approaches and to recommend the tools for proposed and existing near-surface radioactive waste disposal facilities. Thus, ISAM [10, 11] programs provids a critical evaluation of the safety assessment approach and the key components of the safety assessment approach were also identified and synthesized. The synthetic procedure is developed in consistent with the international recommendations on the structure and the content of safety assessments by the authors [2, 3]. In our previous studies [2, 3], main four steps consisted of (1) assessment context, (2) scenario selection, (3) model formulation, and (4) assessment and determination are set up and considerations within each step are identified from the six human intrusion reference scenarios for the conceptually designed concrete vault type disposal facility.

3. Near-Surface Facility and Human Intrusion Scenarios

3.1 Near-Surface Disposal Facility

For the assessment of human intrusion scenarios, the hypothetical near-surface disposal facility has been conceptualized in Figure 1 based on the conceptual design study of the near-surface disposal facility for the LILW [12]. The disposal facility represented in Figure 1 is composed of radioactive waste drum, high-integrity engineered vaults, backfilling materials and multi-layered cover system with thickness of 6 meters.

This facility can accommodate the different types of vaults and locate into the ground lined with about 0.5m concrete and covered with cover materials. Therefore, this disposal facility has 6m thickness of cover system plus 0.5 m concrete barrier from the top surface to the waste matrix.

During the institutional control period, it is assumed that upper cover system of 2m thickness

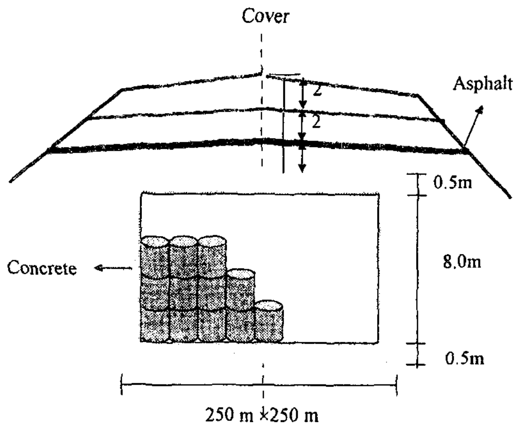

Fig. 1. Hypothetical Representation of Near-Surface Disposal Facility in This Study

can be removed by erosion processes. In the safety assessment, the remained thickness of cover system (4m) plus concrete vault system (0.5m) can act as a barrier of water infiltration from the top surface.

The approximate dimensions of the disposal facility are 250m by 250m and the height of vault is assumed to be 8m. The final disposal cover will be constructed after the disposal vaults in a disposal area of 400,000 drums capacity are completely filled.

3.2 Human Intrusion Scenarios

Human intrusion reference scenarios were identified based on the review of well-established scenarios for the near-surface disposal considered in other countries and/or organizations such as U.S. NRC [13], U.S. DOE [14], OECD/NEA[7], IAEA[5], Japan[15], France and Spain[16]. Six scenarios as potential intruder events, called in this paper as (1) (well) drilling, (2) post(-well) drilling, (3) road construction, (4) post-construction, (5)

Table 1 Characteristic Parameters of Selected Human Intrusion Scenarios[2,3]

Parameter					Scenario / parameter value					
					Drilling	Road construction	Post Drilling	Post Construction	Housing & gardening	Farming
Near-field parameter	Inventory disposed years prior to beginning of intake period (yr)				300	300	300	300	300	300
	LOIC occurred n years prior to beginning of intake period				0	0	0	0	0	0
	Fraction of roots in upper soil(top15cm)				0.00	0.00	1.00	1.00	0.99	0.99
	Fraction of roots in deep soil				0.00	0.00	0.00	0.00	0.01	0.01
	Manual redistribution (m^3/m^2)				5.7E-3	9.0E-2	2.3E-4	3.0E-2	0.0E+0	0.0E+0
	Source area for external dose modification factor (m^2)				100	1250	1250	1250	1250	1250
Waste form	Waste form/package half life				0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Thickness of buried waste (m)				8.00	8.00	8.00	8.00	8.00	8.00
	Depth of soil overburden (m)				4.50	4.50	4.50	4.50	4.50	4.50
External exposure	Hours of exposure to ground contamination				4.0E+01	9.0E+01	3.2E+03	3.2E+03	3.2E+03	5.8E+04
Inhalation	Hours of inhalation exposure per year				1.0E+00	9.0E+01	4.4E+03	4.4E+03	4.4E+03	6.6E+03
	Resuspension model 1-mass loading, 2- anapauugh				1	1	1	1	1	1
	Mass-loading factor (g/m^3)				1.00E-04	1.00E-03	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Plants ingestion	Food type	Grow time(d)	Yield (kg/m^2)	Holdup (d)	Consumption rate (kg/yr)					
	Leaf. Veg.	60	4.52	1	NA	NA	31.7	31.7	31.7	31.7
	oth. veg.	90	4.53	14			24.5	24.5	24.5	24.5
	Fruits	155	1.13	14			16.6	16.6	16.6	16.6
	Grains	150	0.36	14			NA	NA	NA	47.1
Animal food ingestion	Food type		Holdup (d)							
	Meat		7		NA	NA	NA	NA	NA	33.1
	Poultry		3							22
	Milk		1							63
	Eggs		3							8

Table 2. Derived Concentration Limit for Each Scenario from Previous Deterministic Study [2,3]

Nuclides (Bq/t)	Drilling Scenario	Road Construction Scenario	Post Drilling Scenario	Post Construction Scenario	House & Gardening Scenario	Farming Scenario
NI59	8.810E+14	1.326E+13	3.627E+13	4.253E+11	7.255E+12	5.139E+12
NI63	3.524E+18	8.810E+14	1.386E+14	1.602E+12	2.090E+13	1.504E+13
SR90	4.744E+17	1.814E+15	5.873E+12	6.491E+10	8.810E+11	8.222E+11
Y90	8.810E+15	1.298E+14	7.708E+13	8.810E+11	1.246E+13	1.121E+13
NB94	2.467E+10	3.737E+08	4.111E+09	4.744E+07	4.568E+11	3.854E+11
TC99	5.139E+15	4.111E+13	2.467E+10	2.803E+08	1.644E+09	9.487E+08
I129	4.744E+13	6.491E+11	2.202E+10	2.517E+08	1.468E+09	6.167E+08
CS137	6.491E+13	9.487E+11	1.028E+13	1.233E+11	1.523E+14	6.852E+13
PU238	1.355E+14	9.487E+09	6.491E+11	7.708E+09	1.233E+12	1.233E+12
U238	4.111E+13	3.008E+09	1.869E+11	2.164E+09	1.418E+11	1.402E+11
TH234	1.841E+12	2.803E+10	2.937E+11	3.426E+09	2.624E+12	2.418E+12
PU239	1.121E+13	8.222E+08	5.606E+10	6.491E+08	1.028E+11	1.028E+11
U235	4.933E+11	2.090E+09	5.606E+10	6.491E+08	1.370E+11	1.355E+11
TH231	8.222E+12	1.246E+11	1.341E+12	1.542E+10	2.741E+13	2.681E+13

housing and gardening, and finally (6) farming scenarios, were selected as applicable ones for the vault type disposal facility.

The (well) drilling scenario is that the intruder drills a well at the top of the facility. In this scenario, it is assumed that drilling process penetrates the waste vault and engineered barriers. The road construction scenario assumes that the intruder constructs a road directly over the waste disposal site. Waste packages and engineered barriers are assumed to be completely degraded and mixed together during the construction work time. The post(-well) drilling and the post-construction scenarios are the extension of the (well) drilling and the road construction scenario. The housing and gardening scenario is considered as equivalent as residential scenario. The farming scenario is similar to the housing and gardening scenario except that the former has longer intruder occupancy time and larger contaminated area than the latter.

The radiological impact on the intruder depends directly on the institutional control period. In the base case assessment work of Park [2, 3], human intrusion into the disposal facility is assumed to occur at time after loss of institutional control of 300 years, in other words, just after the end of the passive institutional control period. Also, we applied 1 mSv/yr as the safety objective in the base case [2, 3]. The exposure pathway parameters of each scenario have been defined based on extensive literature review [5, 7, 13-16]. The exposure pathway parameters of each scenario are summarized in Table 1. The up-to-date input parameters are used with the consideration of consumption habit for the Korean.

In the previous works of authors [2, 3], it was found that post-construction of human intrusion scenario results in most limiting radionuclide concentration, and the major contributing radionuclides to the resulting dose are Nb-94, Tc-99 and I-129. Results from previous deterministic study [2, 3] are listed in Table 2. As an effort to dealing with the uncertainty, the effects of significant data and parameters are briefly investigated by calculating the different cases for the same scenarios. In this parametric sensitivity study, the difference of concentration limits would be small - in most cases within an order of magnitude, even through the effects of variations of soil dilution factors and average dust loadings are more significant than those of consumption rate and exposure time. This deterministic work [2, 3] shows the interim results for the waste concentration limits of individual radionuclides, pending the conclusions from more comprehensive (e.g. statistical approach) and iterative safety assessments with up-to-date information and new assumptions.

4. Statistical Approach of Safety Assessment

4.1 Latin Hypercube Sampling Method

Latin Hypercube Sampling (LHS) was developed as an alternative approach of the Monte Carlo sampling scheme and developed by McKay, Conover and Beckman [17]. The LHS selects n different values from each of k variables X_1, $\cdots$, X_k in the following manner. The range of each variable is divided into n non-overlapping intervals on the basis of equal probability. One value from each interval is selected at random with respect to the probability density in the interval. The n values thus obtained for X_1 are paired in a random manner (equally likely combinations) with the n values of X_2. These n pairs are combined in a random manner with the n values of X_3 to form n triplets, and so on, until nk-tuplets are formed. These nk-tuplets are the same as the nk-dimensional input vectors. This is the Latin Hypercube Sample. It is convenient to think of this sample (or any random sample of size n) as forming a $(n \times k)$ matrix of input where the i^{th} row contains specific values of each of the k input variables to be used on the i^{th} run of the computer model.

4.2 Manual Redistribution Factors

Transport of radionuclides from the deep soil or the contaminated waste compartment to the surface soils may occur through the human intrusion of a site after the institutional control period. This can be modeled simply using a manual redistribution factor in this study. The manual redistribution factors relate the resultant surface soil concentration, in Bq/m^2, to the initial subsurface concentration, in Bq/m^3 by definition [18]. According to the Table 1, which was used in our previous work [2, 3], manual redistributions are allocated for drilling related scenarios, including (well) drilling and the post-drilling scenario, and construction related scenarios, including the road construction and the post-construction scenario. Table 2 shows that the post-construction scenario resulted in most limiting radionuclide concentration due to the highest values of manual distribution factor such as 0.03 (m^3/m^2) in Table 1.

As for vault type disposal facilities, it is generally reported that the excavated depth during the road construction and/or post construction is less than 3 m [5, 14-15]. As discussed for the near-surface disposal facility (See Figure 1), the thickness of cover system (4m) plus concrete vault (0.5m) is approximately 4.5 m. At this point, we would like to take alternate assumption for the new safety assessment. Both in the road construction and in the post-construction scenario, the intruder cannot

Table 3. Random Input Variables and Distribution Type for the Human Intrusion Scenarios

Scenario	Description of Random Variables	Type of Distributi on	Mean Mean	Standard Deviation	Min.	Max.
Drilling Scemario	Manual Redistribution	Log N	0.0057	0.002	-	-
	Depth of soil overburden, m	Uniform	4.5	-	4.0	5.0
	Exposure time: Plume (hr)	Normal	1.0	0.3	-	-
	Exposure time: Soil Contamination (hr)	Normal	40.0	12.0	-	-
	Mass loading factor (g/m3)	Log N	0.0004	0.0002	-	-
Road Construction Scenario	Manual Redistribution	Log N	0.09	0.045	-	-
		Const.*	~ 0.0 *	-	-	-
	Depth of soil overburden, m	Uniform	4.5	-	4.0	5.0
	Exposure time: Plume (hr)	Normal	90.0	30.0	-	-
	Exposure time: Soil Contamination (hr)	Normal	90.0	30.0	-	-
	Mass loading factor (g/m3)	Log N	0.001	0.0005	-	-
Post-Drilling Scenario	Manual Redistribution	Log N	0.00023	0.00012	-	-
	Depth of soil overburden, m	Uniform	4.5	-	4.0	5.0
	Exposure time: Plume (hr)	Normal	3200.0	1000.0	-	-
	Exposure time: Soil Contamination (hr)	Normal	3200.0	1000.0	-	-
	Mass loading factor (g/m3)	Log N	0.0001	0.00005	-	-
	Consumption rate: Leaf Vegetable (kg/yr)	Normal	32.0	16.0	-	-
	Consumption rate: Root Vegetable (kg/yr)	Normal	24.5	12.5	-	-
	Consumption rate: Fruit (kg/yr)	Normal	16.6	8.5	-	-
	Consumption rate: Grain (kg/yr)	Normal	0.0	0.0	-	-
Post-Construction Scenario	Manual Redistribution	Log N	0.03	0.015	-	-
		Const. *	~ 0.0 *	-	-	-
	Depth of soil overburden, m	Uniform	4.5	-	4.0	5.0
	Exposure time: Plume (hr)	Normal	3200.0	1000.0	-	-
	Exposure time: Soil Contamination (hr)	Normal	3200.0	1000.0	-	-
	Mass loading factor (g/m3)	Log N	0.0001	0.00005	-	-
	Consumption rate: Leaf Vegetable (kg/yr)	Normal	31.7	16.0	-	-
	Consumption rate: Root Vegetable (kg/yr)	Normal	24.5	12.5	-	-
	Consumption rate: Fruit (kg/yr)	Normal	16.6	8.5	-	-
	Consumption rate: Grain (kg/yr)	Normal	0.0	0.0	-	-

* As for alternate assumption described in section 4.2

intrude directly the disposal site because that disposal site is located below the depth where construction program can excavate. Therefore, the waste package and the concrete vault are assumed to be remained intact during the construction period of human intruders.

Based on this assumption of construction related scenarios, the post-construction scenario is anticipated that it cannot act as a leading and/or a limiting scenario furthermore to derive the concentration limit of the disposal facility among selected six human intrusion scenarios.

To accommodate this alternate assumption, manual redistribution factors are allocated only for drilling related scenario such as the drilling and the post drilling scenario.

4.3 Random Input Variables

As for four human intrusion scenarios which are related with drilling and construction process, random input variables are selected based on the result of our previous work [2, 3] and listed in Table 3. Table 3 shows the distribution type and the accompanying statistical properties such as mean, standard deviation, minimum and maximum values.

According to the assumption discussed in section 4.2, in Table 3, the manual distribution factors for both scenarios in the construction and in the post-construction are changed from the value used in our previous work[3] to nearly zero values.

4.4 Results and Discussions

When we consider the appropriate and/or limiting scenario, the lowest value of radionuclides concentration calculated from each intrusion scenario acts as an important role. In our previous study of deterministic approach [2, 3], the post-construction scenario appeared as most limiting scenario to derive the radionuclide concentration limits.

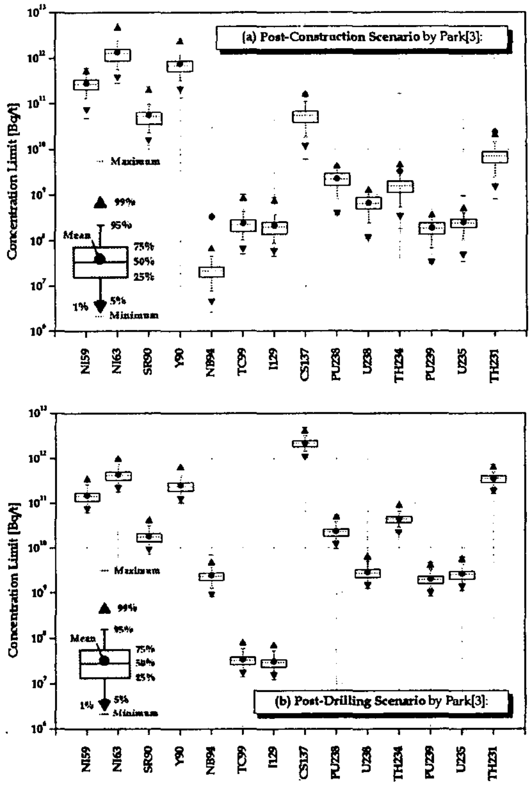

Fig. 2. Statistical Results of Concentration Limits of the Previous Work [3] : (a) Post-Construction Scenario and (b) Post-Drilling Scenario

Figure 2 shows the statistical results calculated with the data used in our previous work [2,3]. Although post construction shows the lowest value of concentration value for all radionuclides in Table 2, the statistical calculation shown in Figure 2 shows the interesting results.

In Figure 2 (a), Nb-94 shows the lowest concentration distributions of the post-construction scenario and in Figure 2 (b), Tc-99 and I-129 show the lowest concentration distribution of the post-drilling scenario. When it is compared between these two lowest distribution, minimum value of Nb-94 in post-construction scenario

Table 4 Comparison of Radionuclide Concentration Limits of the Foreign Regulations, the Previous Study and This Study

Radio-Nuclide	Japan[1]	France[1]	Spain[1]	US (ClassC)[2]	Previous Study[3]	This Study		
	Conc. Limit (Bq/t)	Conc. Limit (Bq/t)	Conc. Limit (Bq/t)	Conc. Limit (Bq/t)	Conc. Limit (Bq/t)	Conc. Limit [Min.] (Bq/t)	Conc. Limit [Mean] (Bq/t)	Conc. Limit [Max.] (Bq/t)
Ni-59	-	-	6.30E+10	-	8.51E+10	6.16e+10	1.50E+11	3.52E+11
Ni-63	1.11E+12	1.2E+13	1.2E+13	1.73E+13	3.21E+11	1.78E+11	4.34E+11	1.02E+12
Sr-90	7.40E+10	9.1E+10	9.1E+10	1.73E+14	1.30E+10	7.25E+9	1.80E+10	4.25E+10
Nb-94	-	1.2E+08	1.2E+08	-	9.50E+06	8.22E+8	2.43E+9	6.85E+9
Tc-99	-	1.0E+09	1.0E+09	7.43E+10	5.60E+07	1.40E+7	3.45E+7	8.22E+7
I-129	-	4.6E+07	4.6E+07	1.97E+09	5.03E+07	1.25E+7	3.08E+7	7.25E+7
Cs-137	1.11E+12	3.3E+11	3.3E+11	1.13E+14	2.47E+10	1.02E+12	2.17E+12	4.74E+12
Alpha	1.11E+09	-	3.70E+09	3.36E+9	1.30E+08	8.22E+8	1.97E+9	4.56E+9

1 Reference [16]: Concentration limits of Japan represent the upper limit values of nuclear regulatory organization. Disposal facility of Japan, France and Spain is engineered barrier near-surface system.

2 Reference [13]: Concentration limit of US is come from 10CFR61, which based on general radwaste classification.

3 Reference [2,3]

(Figure 2 (a)) is lower than the values of Tc-99 and I-129 in post-drilling scenario (Figure 2 (b)). When mean values are considered, Tc-99 and I-129 in post-drilling scenario (Figure 2 (b)) is lower than the value of Nb-94 in post-construction scenario (Figure 2 (a)).

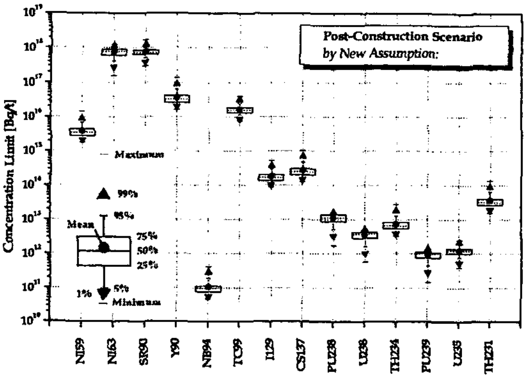

Fig. 3. Statistical Results of Concentration Limits by Introducing New Assumption: Post-Construction Scenarios

Therefore, in this statistical approach, the post-drilling and the post-construction scenario are mutually competitive in their concentration distributions for selection of limiting scenario according to which radionuclides are more representative in the safety assessment contexts.

As discussed in section 4.2, alternate assumption is introduced to check out further both the competing human intrusion scenarios, which are the post-drilling scenario and the post-construction scenario. Introduction of a new assumption and repeated assessments are the typical procedures of safety assessment to obtain the common assurance for the utmost results. In this sense, it is assumed that the human intruder cannot excavate the disposal site during the (road) construction program because that disposal location is situated below the construction area.

Figure 3 shows the result of concentration limits obtained by considering new assumption in post-construction scenario. In case Nb-94, the values are increased about 4~5 orders of magnitude in post construction scenario. Concentration limits of other remaining radionuclides are also increased same magnitude. As expected in section 4.2, introducing new assumption shows that the post construction scenario is no longer the limiting scenario to derive the concentration limits for low and intermediate-level radwaste disposal facility. Therefore, the post drilling scenario in Figure 2(b) can play an important role as the limiting scenario instead of the post-construction scenario.

In Table 4, the calculated radionuclide concentration limits of the post drilling scenario in Figure 2(b) are compared with those in the existing foreign regulations and/or the near-surface disposal facilities. The results of previous deterministic study [2,3] are also compared with those of this study. Density of radwaste matrix is used for unit conversion as 1,500 kg/m^3.

From the distributions of concentration limits in statistical calculation, the minimum concentration values for each distribution are selected as the limiting concentrations in this study (See Table 4). When we compare the concentration limits between the previous and this study, concentrations of radionuclides such as Nb-94, Cs-137 and alpha-emitting radionuclides show elevated values than the case of the previous study. Remaining radionuclides such as Sr-90, Tc-99 I-129, Ni-59 and Ni-63 show lower values than the case of the previous study.

Except for the values of Nb-94 and Cs-137, concentration values of this study show lower than the values of Japan, France and Spain.

5. Conclusion and Recommendations

The statistical approaches using the Latin Hypercube Sampling method is conducted to derive the radionuclide concentration limits for the low and intermediate radioactive waste disposal facility.

In our previous study of deterministic approach [3], the post construction appeared as most limiting scenario to derive the radionuclide concentrations. In this statistical approach, however, the post drilling and the post construction scenario are mutually competing for the scenario selection according to which radionuclides are more important in safety assessment context.

As a standard strategy of performance assessment, new assumption of the disposal facility is introduced. This assumption resulted in that, in case Nb-94, Tc-99 and I-129 which are the candidate radionuclides to determine the radionuclide concentration limits, concentration values are increased about 4~5 orders of magnitude in the post construction scenario. Concentration limits of other radionuclides are also increased same magnitude. Therefore, the post construction scenario is no longer the limiting scenario to derive the concentration limits of disposal facility when introducing new assumption. When we compare the concentration limits between the previous and this study, concentrations of radionuclides such as Nb-94, Cs-137 and alpha-emitting radionuclides show elevated values than the case of the previous study. Remaining radionuclides such as Sr-90, Tc-99 I-129, Ni-59 and Ni-63 show lower values than the case of the previous study. Except for the values of Nb-94 and Cs-137, concentration values of this study show lower than the values of Japan, France and Spain.

Results of this study are one possible case by introducing new assumption of safety assessment and further calculations and detailed considerations of the concentration limits should be continued. For example, dose conversion factors (DCF) reflecting ICRP-60 and/or food consumption rate of the Korean are applied in recent unpublished research report. In the near future, additional effort to refine the concentration limit for LILW disposal facility will be pursued.

Acknowledgements

This work has been carried out as a part of National Research Laboratory (NRL) program financially supported by the Ministry of Science and Technology (MOST), Korea.

References

(1) IAEA, *The Principles of Radioactive Waste Management*, Safety Series No. 111-F, IAEA (1995).

(2) C.L. Kim, *Development of Performance Assessment Methodology for Establishment of Quantitative Acceptance Criteria of near-Surface Radioactive Waste Disposal*, TM.01NC03.M2002.1, NETEC (2002).

(3) J.W. Park, S. Park, C. L. Kim, and C. Chung, "Development and Implementation of a Performance Assessment Approach to Determine Waste Concentration Limits for a Near-Surface Radioactive Waste Disposal Facility in KOREA," SPECTRUM 2002, Reno, Nevada (2002).

(4) B.A. Napier, D.L. Strenge, R.A. Peloquin, and J.V. Ramsdell, *GENII-The Hanford Environmental Radiation Dosimetry Software System Volume2: User's Manual*, PNL-6584 Vol.2 (1988).

(5) IAEA, *Derivation of Quantitative Acceptance Criteria For Disposal of Radioactive Waste To Near Surface Facilities: Development and Implementation of an Approach*, Draft Safety Report Version 3.0, IAEA (1999).

(6) R.H. Little, K.J. Clark, P.R. Maul, G.H. Smith, P.A. Towler, and B.M. Watkins, *Application of Procedures and Disposal Criteria Developed for Nuclear Waste Package to Cases Involving Chemical Toxicity*, EUR 16745 EN, European Commission (1996).

(7) NEA, *Shallow Land Disposal of Radioactive Waste: Reference Levels for the Acceptance of Long-Lived Radionuclides, Organization for Economic Co-operation and Development (1987).*

(8) IAEA, Safety Assessment for Near Surface Disposal of Radioactive Waste, Draft Safety Guide, NS 166, IAEA (1998).

(9) IAEA, "Planning and Operation of Low Level Waste Disposal Facilities," Proceedings of a Symposium, Vienna, 17-21 June (1997).

(10) IAEA, ISAM- *The International Programme for Improving Long Term Safety Assessment Methodologies for Near Surface Radioactive Waste Disposal Facilities: Objectives, Content and Work Programme*, IAEA (1997).

(11) IAEA, ISAM- *The International Programme for Improving Long Term Safety Assessment Methodologies for Near Surface Radioactive Waste Disposal Facilities: Vault Safety Case Report*, IAEA (2001).

(12) KEPCO-NETEC, *A Conceptual Design Report of LLW & ILW Near-Surface Disposal Facility*, 2000-1300-9 (2000).

(13) U.S. NRC, *Draft Environmental Impact Statement on 10CFR Part 61 License Requirements for Land Disposal of Radioactive Waste*, NUREG-0782, Vol. 1 (1981).

(14) R.L. Aaberg, *Definition of Intrusion Scenarios and Example Concentration Ranges for the Disposal of Near-Surface*

Waste at the Hanford Site, PNL-6312 (1990).

(15) T. Aoki, "The Radioactive Concentration Upper bounds for the Safety Regulations on the Shallow-Land Disposal of Low-Level Solid Radioactive Waste," Proc. the Specilaists' Meeting on Radioactive Waste Management, Kyoto, Nov. 29-30 (1993).

(16) KEPCO-NETEC, "NETEC Workshop on Shallow Land Disposal Technology," Daejeon, Oct. 20-21 (1997).

(17) M.D. McKay, R.J. Beckman, and W.J. Conover, "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code," *Technometrics*, 21[2], 239-245 (1979).

(18) B.A. Napier, D.L. Strenge, R.A. Peloquin, and J.V. Ramsdell, *GENII- The Hanford Environmental Radiation Dosimetry Software System Volume1: Conceptual Representation*, PNL-6584 Vol.1 (1988).