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Requirement of LILW Disposal Facility for the PEACER Final Waste

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Abstract

A pyrochemical process has been conceptually designed so that the transmutation of spent PWR fuel in PEACER (Proliferation-resistant Environmental-friendly Accident-tolerant Continuable and Economical Reactor) can produce mainly low and intermediate level waste for near surface disposal. Major radioactive nuclides from PEACER pyroprocessing are composed of TRU and LLFP. In this study, the Concentration limit (CL) for the final waste from PEACER is evaluated based on the methodology for establishment of acceptance criteria. Also, sensitivity analysis for several input parameters is conducted in order to determine acceptable decontamination factor (DF) and LLFP removal efficiency and to find out input parameter that extremely have an effect on CL. As a result of the study, LLFP removal efficiency, especially Sr-90 and Tc-99, is proved to be a major nuclide which contributes to annual dose by human intrusion scenario rather than TRU DF. More than 98.5% of LLFP have to be removed to meet below dose constraint within the DF more than 5.0E+03. Besides, because of the relative short half-life of Sr-90, the increasing of the institutional control period is recommended for most important input parameter to determine CL.

1. INTRODUCTION

The spent nuclear fuel of current nuclear reactor is one of challenging issues for the continuous utilization of nuclear power. In order to solve this problem, geological disposal has been suggested and studied for decades. But, because of difficulty in finding its highly qualified sites, the partitioning and transmutation (P&T) technology have been made an alternative idea. P&T method of radioactive waste from spent fuel is more attractive because of highly concerning on the protection and the difficulty in radioactive waste disposal site selection in Korea. In the previous works, Seoul National University (SNU) proposed a new transmutation concept designated as PEACER to convert all the final waste into the class of low level waste (LLW).

In order to dispose the final waste from PEACER, The Establishment of Waste Acceptance Criteria for the LLW facility has to be considered first. According to NRC, the human intrusion scenarios establish volumetric concentration limit. On the other hand, the radionuclide migration scenarios imposed limit on the total inventory of a radionuclide disposed at the site by means of site specific analysis. The Methodology NRC worked backward from the dose limit using the human intrusion scenario to find concentration limit.[1]

PEACER final waste has several distinctive characteristics in establishing concentration limit. It consisted of TRU and LLFP and the mass ratio of each nuclide has been fixed by pyrochemical process. The previous study for waste from PEACER has focused on the feasibility of converting waste into LLW based on pyroprocess technology and Practical range of decontamination factor (DF) to meet the concentration limit for class C waste of U.S. NRC. Moreover, for the establishment of waste concentration limits, the radionuclide by neutron activation is mainly considered.

For this reason, the concentration limit for the final waste from PEACER is evaluated based on the methodology for establishment of waste acceptance criteria in this paper. And, DF and LLFP removal efficiency for satisfaction of derived concentration limit also are suggested. Lastly, the most important input parameter which has an effect on determination of concentration limit is presented by sensitivity analysis. Because the mass ratio of each nuclide is fixed and final waste from PEACER is homogenous, annual dose by most hazardous scenario is presented in this study rather than concentration limit in sensitivity analysis.

2. CHARACTERISTICS AND GENERATION OF RADIOACTIVE WASTE FROM PEACER

In the back end fuel cycle in PEACER, about 99% of uranium in the LWR spent fuel is recovered for the future utilization and all TRU are recycled during the pyroprocess to convert all the final waste into the LLW. Tc-99 and I-129 also are separated from waste stream and transmuted to stable nuclide because of their high solubility in water with 95% removal efficiency. In the prrochemical process, decontamination factor of TRU is introduced for indication of process performance. Overall DF in pyorchemical process is defined as the ratio of mass of TRU load into the process to TRU lost into waste stream expressed as follows;

$$DF = \frac{\text{The loaded TRU into pyrochemical process}}{\text{The lost TRU into waste stream}}$$

In the early study, PEACER pyroprocessing system that has 10^5 of DF was conceptually designed[2] and 2.3E+05 of DF was suggested considering several requirements to be satisfied by NRC Class C limit with disposal facility volume 1.6E+05m^3. Figure 1 shows the flow sheet of back end fuel cycle in PEACER.

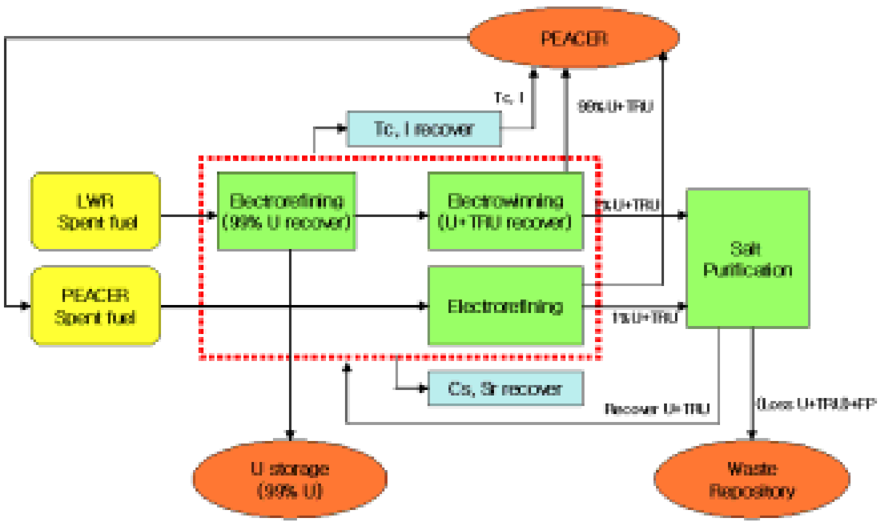

Figure 1. Flow sheet of back end fuel cycle in PEACER

In order to evaluate the produced total wastes from pyroprocessing, we assumed that 20 LWR has 1 GWe capacity, 40years lifetime with spent fuel discharged at 33,000MWD/MTU burnup with 30years cooling time and 12 PEACER has 60years lifetime. The nuclide inventory by LWR was obtained by ORIGEN2 code. And the actinide mass in case of PEACER is analyzed in equilibrium state by REBUS code conducted by Kyoung-hui University, considering the time interval between each process in pyroprocessing. Sr-90, Cs-135, Cs-137 and Sm-151 were recovered with 95% removal efficiency during process to satisfy regulation about heat load and volume of disposal facility because of its highest activity and decay heat than other LLFP's. Table 1 and Table 2 show total TRU and LLFP waste production, respectively, from pyroprocessing when the value of DF=2.3E+05 and 95% LLFP removal efficiency was applied.

Table 1. Total produced TRU waste from pyropocessing with DF=2.3E+05

Nuclide	Initial Inventory(g)			DF	Waste Mass(g)		
	PEACER	LWR	Total		PEACER	LWR	Total
CM244	8.10E+01	2.09E+05	2.93E+07	2.3E+05	1.27E+02	9.09E-01	1.27E+02
PU240	2.20E-01	5.29E+07	5.11E+08	2.3E+05	1.99E+03	2.30E+02	2.22E+03
U236	6.47E-05	1.06E+06	1.11E+07	2.3E+05	4.35E+01	4.61E+00	4.81E+01
PU238	1.71E+01	3.61E+06	4.71E+07	2.3E+05	1.89E+02	1.57E+01	2.05E+02
PU242	3.90E-03	1.34E+07	1.40E+08	2.3E+05	5.52E+02	5.83E+01	6.10E+02
U234	6.25E-03	1.37E+04	9.23E+06	2.3E+05	4.01E+01	5.96E-02	4.01E+01
U238	3.36E-07	2.02E+08	2.34E+09	2.3E+05	9.30E+03	8.78E+02	1.02E+04
PU241	1.01E+02	4.85E+06	1.04E+08	2.3E+05	4.33E+02	2.11E+01	4.54E+02
AM241	3.43E+00	2.85E+07	3.03E+07	2.3E+05	7.70E+00	1.24E+02	1.32E+02
NP237	7.06E-04	1.39E+07	5.28E+07	2.3E+05	1.69E+02	6.04E+01	2.30E+02
U233	9.69E-03	1.81E+00	4.63E+02	2.3E+05	2.00E-03	7.87E-06	2.01E-03
AM243	1.92E-01	2.85E+06	3.75E+07	2.3E+05	1.50E+02	1.24E+01	1.63E+02
PU239	6.13E-02	1.22E+08	5.51E+08	2.3E+05	1.87E+03	5.30E+02	2.40E+03
U235	2.16E-06	1.84E+06	5.90E+06	2.3E+05	1.77E+01	8.00E+00	2.57E+01

Table 2. Total waste production generated from LLFP with 95% removal efficiency

Nuclide	Initial Inventory(g)			1 - Removal Efficiency	Waste Mass(g)		
	PEACER	LWR	Total		PEACER	LWR	Total
SE79	2.93E+04	1.55E+05	1.84E+05	1.00E+00	2.93E+04	1.55E+05	1.84E+05
SR90	1.50E+06	5.34E+06	6.84E+06	5.00E-02	7.50E+04	2.67E+05	3.42E+05
ZR93	2.78E+06	1.89E+07	2.17E+07	1.00E+00	2.78E+06	1.89E+07	2.17E+07
TC99	3.97E+06	1.99E+07	2.39E+07	5.00E-02	1.99E+05	9.95E+05	1.19E+06
PD107	2.52E+06	5.91E+06	8.43E+06	1.00E+00	2.52E+06	5.91E+06	8.43E+06
SN126	2.84E+05	7.23E+05	1.01E+06	1.00E+00	2.84E+05	7.23E+05	1.01E+06
I129	1.25E+06	4.72E+05	1.72E+06	5.00E-02	6.25E+04	2.36E+04	8.61E+04
CS135	8.01E+06	9.22E+06	1.72E+07	5.00E-02	4.01E+05	4.61E+05	8.62E+05
CS137	6.77E+06	1.24E+07	1.92E+07	5.00E-02	3.39E+05	6.20E+05	9.59E+05
SM151	5.52E+05	2.64E+05	8.16E+05	5.00E-02	2.76E+04	1.32E+04	4.08E+04

3. REQURIEMENT OF LILW DISPOSAL FACILITY FOR THE PEACER FINAL WASTE

3.1 Performance assessment

For the assessment of human intrusion scenarios, LILW disposal facility has been based on the conceptual design study of the near surface disposal facility in Korea.[3] The disposal facility represented in Figure 2 is reconstructed from conceptual design of reference and is composed of radioactive drum. This facility is excavated into the ground, lined with about 0.5m concrete and cover with thickness of 6m. The approximate dimensions of the disposal facility are 200m by 400m, and the depth of facility is assumed to be 8m. The total volume of disposal facility is 6.4E+05m^3. During the institutional control period, it is assumed that upper cover system of 2m thickness can be removed by erosion processes.[4]

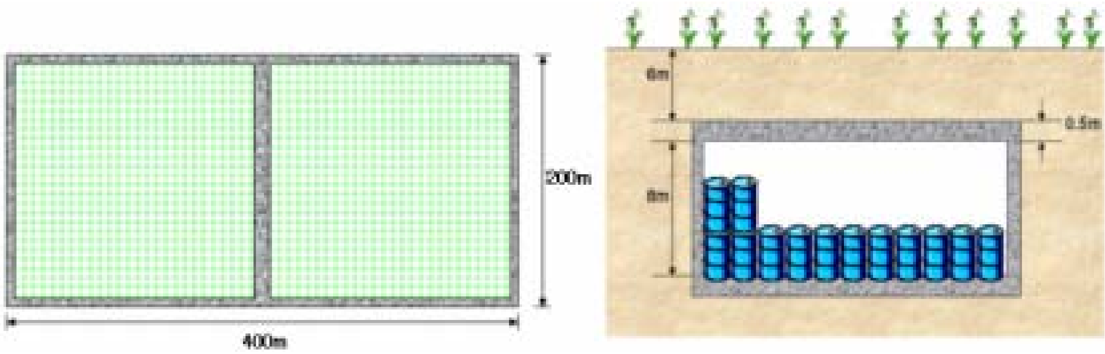

Figure 2. The scale of the conceptually designed disposal facility

Reference intruder scenarios are identified based on the review of well-established ones considered in other countries and/or organizations for near surface disposal. Six kinds of scenarios as potential intruder events-well drilling, post-well drilling, road construction, post-construction, housing and gardening, and farming scenarios- were selected as applicable for the facility. Well drilling scenario is that the intruder drills a well at the top of the facility. In this scenario, it is assumed that drilling is to penetrate the disposal facility. Road construction scenario assumes that the intruder constructs a road directly over a waste disposal site. Waste Packages and engineered barriers are assumed to be completely degraded and mixed together during the construction work time. Post-well drilling and post-construction scenarios are the extension of well drilling and house construction scenario, though hose construction scenario is ruled out in the main scenario categories due to small scale of construction comparing with road construction scenario. Housing and gardening scenario is considered as equivalent as residential scenario. Farming scenario is similar to gardening scenario except that the former has longer intruder occupancy time and larger contaminated area than the latter and contained dose by ingestion of meat and animal products.[5]

The radiological impact on the intruder directly depends on the institutional control period. In the base case assessment, human intrusion into the disposal facility is assumed to occur at time after loss of institutional control of 300years.[5] Also, 5mSv/yr as a dose constraint for the disposal facility was applied.

The GENII computer code is used to evaluate annual dose by exposure pathways. Table 3 presents input parameter for GENII code.[6] Concentration limit for each radioactive nuclide are calculated by backward method from the dose limit using the human intrusion scenario.[1]

Table 3. Input parameter for GENII code

	Drilling	Road Con	Post Drilling	Post Con	H & Gardening	Farming	Input Parameter
Near Field Parameter	300, 00	300, 00	300, 00	300, 00	300, 00	300, 00	Inventory disposed n years prior to the beginning of the intake period(yr)
	0	0	1	1	0, 99	0, 99	Fraction of roots in upper soil (top 15cm)
	0	0	0	0	0, 01	0, 01	Fraction of roots in deep soil
	5, 70E-03	0, 00E+00	2, 30E-04	0	0	0	Manual redistribution : deep soil/surface soil dilution factor
	100	2500	2500	2500	2500	20000	Source area for external dose modification factor (m2)
Waste Form Availablity	0	0	0	0	0	0	Waste form / package half life (yr)
	8	8	8	8	8	8	Waste thickness (m)
	4, 5	4, 5	4, 5	4, 5	4, 5	4, 5	Depth of soil overburden (m)
External Exporsure	1	90	3245	3245	3245	5825	Plume (hr)
	40	90	3245	3245	3245	5825	Soil contmination (hr)
Inhalation	1	90	4390	4390	4390	6570	Hours of exposure to contamination per year
	1, 00E-04	1, 00E-03	1, 00E-04	1, 00E-04	1, 00E-04	1, 00E-04	Mass loading factor (g/m3)

Food Ingestion	Food	Grow time (day)	Irrigation Rate(in/yr)	Irrigation Time(mo/yr)	Yield (kg/m2)	Production (kg/yr)	Consumption hold up(day)	Consumption Rate(kg/yr)	Scenario
	leaf	60	10, 6	0	4, 5	0	1	31, 7	Post drilling, Post Con, H & G, Farming
	Root	90	19, 3	0	4, 5	0	14	24, 5	Post drilling, Post Con, H & G, Farming
	Fruit	155	34, 1	0	1, 1	0	14	16, 6	Post drilling, Post Con, H & G, Farming
	Grain	150	60	0	0, 4	0	14	47, 1	Farming

Animal Product Ingestion	Product	Consumption Rate (kg/yr)	Consumption holdup (day)	Stored Feed Diet Fraction	Stored Feed Grow Time (day)	Stored Feed Irrigation Rate(in/yr)	Stored Feed Irrigation Time(mo/yr)	Stored Feed Yield (kg/m3)	Stored Feed Stroage (day)	Scenario
	Beef	33, 1	7	0, 83	180	60	5, 5	2, 4	22, 4	Farming
	Poultry	22	3	1	180	60	5, 5	0, 42	2, 4	
	Milk	63	1	0, 83	180	60	5, 5	3, 2	23, 9	
	Egg	8	3	1	180	60	5, 5	0, 42	8	
	Fresh Forage									
	Beef			0, 17	90	14, 4	3	4	0	
	Milk			0, 17	90	14, 4	3	3, 48	0	

3.2 Result and discussion

The dose evaluation for the human intrusion scenarios that has concentration of $1Ci/m^3$ is performed. And in order to derive concentration limit for each nuclide, the result is converted into a dose limit of 5mSv/yr using the relation between dose and concentration of nuclides. The concentration limit for nuclide from PEACER shows that post-construction scenario and farming scenario result in the most limiting radionuclide concentration in the Table 4.

Table 4. Concentration limit for human intrusion scenario (Ci/m^3)

Nuclide	Drilling	Road Con	Post-Drill	Post-Con	H & G	Farming	CL
SE79	8.77E+05	1.02E+20	9.62E+00	2.78E+18	1.47E+00	1.39E-01	1.39E-01
SR90	1.92E+07	5.00E+13	2.38E+02	1.35E+12	3.57E+01	3.33E+01	3.33E+01
ZR93	6.25E+05	-	5.21E+02	-	9.43E+01	5.49E+01	0.00E+00
TC99	2.08E+05	3.57E+14	1.00E+00	9.43E+12	6.94E-02	3.85E-02	3.85E-02
PD107	1.52E+07	-	8.77E+02	-	1.39E+02	1.14E+02	1.14E+02
SN126	9.26E+01	1.04E+16	8.77E+00	2.78E+14	3.13E+00	2.63E+00	2.63E+00
I129	1.92E+03	8.93E+19	8.93E-01	2.38E+18	6.17E-02	2.50E-02	2.50E-02
CS135	3.33E+05	3.13E+17	2.78E+02	8.47E+15	4.55E+01	2.00E+01	2.00E+01
CS137	2.63E+03	4.55E+07	4.17E+02	1.25E+06	6.33E+03	2.78E+03	4.17E+02
SM151	1.85E+07	-	7.81E+04	-	1.56E+04	1.32E+04	1.32E+04
CM244	7.69E+07	-	2.78E+05	-	1.43E+05	1.28E+05	1.28E+05
PU240	5.00E+02	-	2.38E+00	-	4.55E+00	4.17E+00	2.38E+00
U236	1.52E+03	1.09E+26	7.14E+00	2.94E+24	5.68E+00	5.43E+00	5.43E+00
PU238	5.49E+03	-	2.63E+01	-	5.10E+01	5.00E+01	2.63E+01
PU242	5.00E+02	-	2.38E+00	-	4.55E+00	4.17E+00	2.38E+00
U234	1.43E+03	2.08E+15	6.76E+00	5.62E+13	5.43E+00	5.21E+00	5.21E+00
U238	1.67E+03	1.32E+26	7.58E+00	3.57E+24	5.95E+00	5.68E+00	5.68E+00
PU241	4.55E+10	-	2.17E+08	-	4.17E+08	3.85E+08	2.17E+08
AM241	2.94E+02	1.04E+26	2.50E+00	2.94E+24	1.32E+00	1.25E+00	1.25E+00
NP237	1.09E+02	6.76E+10	7.58E-03	1.85E+09	1.16E-03	1.09E-03	1.09E-03
U233	1.28E+03	4.55E+14	6.67E+00	1.22E+13	5.32E+00	5.10E+00	5.10E+00
AM243	7.81E+01	1.22E+14	1.56E+00	3.33E+12	8.62E-01	8.06E-01	8.06E-01
NP239	1.22E+01	1.47E+07	2.00E+00	4.17E+05	9.43E+00	9.43E+00	2.00E+00
PU239	4.55E+02	1.72E+15	2.27E+00	4.55E+13	4.17E+00	4.17E+00	2.27E+00
U235	2.00E+01	1.85E+09	2.27E+00	5.10E+07	5.75E+00	5.49E+00	2.27E+00

Consequently, the radionuclide of the final waste from PEACER can be disposed within the Table 4 concentration limit. For disposal of waste that contains a mixture of radionuclide, it is necessary to apply to the sum of fractions by dividing each radionuclide concentration by the above concentration limit and adding the resulting values. The sum of the fractions for the column must be less than 1.0 by NRC 10CFR61.55.[7] The total inventory and the component ratio of radionuclide is determined in according to the TRU DF value and LLFP removal efficiency. Therefore, DF and removal efficiency have to be selected to satisfy the sum of fraction rule within the sum of dose by each radioactive nuclide not exceed 5mSv/yr. The farming scenario shows the highest dose among the six human intrusion scenarios in Figure 3. It means that farming scenario is the necessary and sufficient condition that satisfies the other scenarios. The possible DF value in the pyroprocessing examined by literature survey conducted by SNU is about U=1.43E+04, Np=1.43E+05, Pu=1.67E+05, Am=2.94E+04 and Cm=2.94E+04, respectively. And it was assumed that the removal efficiency of LLFP is 95%.

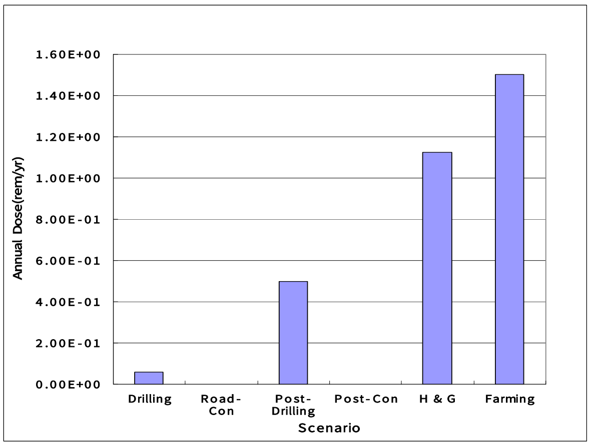

Figure 3. Dose by each human intrusion scenario

Figure 4 shows a change in the annual dose by TRU DF and LLFP removal efficiency in the case of human intrusion that happens after institutional control period 300years. The change of annual dose by DF value more than 5.0E+03 is so small that annual dose is affected by LLFP removal efficiency. In order to satisfy dose constraint, at least LLFP has to be removed by efficiency more than 98.5%. The radionuclides affecting dose in the LLFP are showed in Figure 5. As expected in previous study, Sr-90 and Tc-99 occupies overwhelming majority in the annual dose.[8]

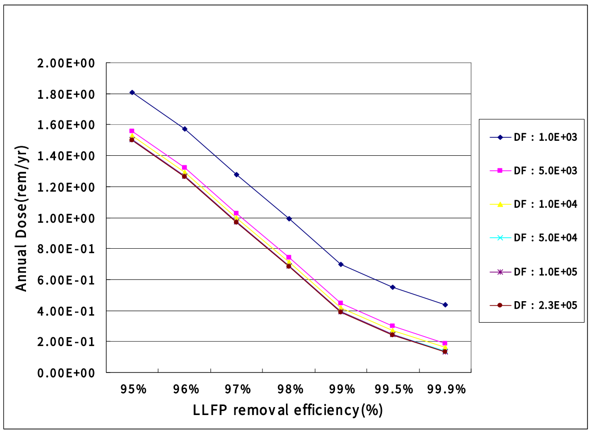

Figure 4. Dose by DF and LLFP removal efficiency

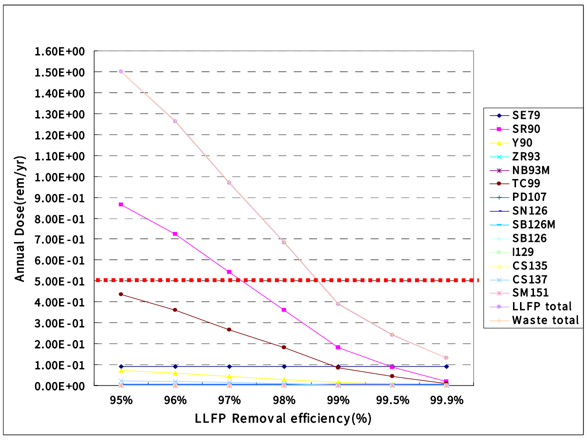

Figure 5. Dose by major LLFP radioactive efficiency

3.3 Sensitivity analysis for important parameter

The parameters in this study have a relatively uncertainty. The evaluation for the uncertainty of input parameter shows new application in establishing concentration limit for disposal of PEACER final waste. The dose by uncertainty of Institutional Control Period (ICP) and depth of soil overburden is evaluated and although the volume of disposal facility is not direct input parameter to derive CL, it is considered as an important parameter in this study.

Figure 6 shows the dose by change of ICP. The dose by short-lived radionuclide including Sr-90 and its daughter nuclide Y-90 decreases exponentially along with increasing ICP. Especially, Sr-90, one of the most hazardous radionuclide in human intrusion scenarios, has largely an effect of ICP with relative short half-life of 28.1years. On the other hand, dose by Tc-99, on of the long-lived radionuclide, maintain uniformly regardless of ICP. Considering that the NRC fixed ICP with 500years for Class C waste, the ICP can be the most important parameter in establishing CL for PEACER waste.[9]

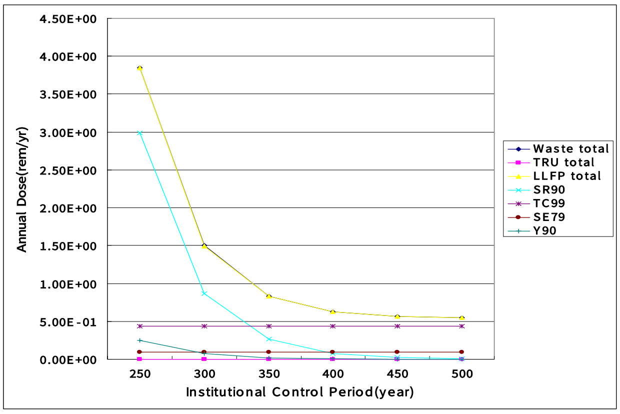

Figure 6. Dose by the institutional control period

The effect of depth of soil overburden has something to do with dose by external exposure and the fraction of roots in deep soil. The external exposure can be ignored because the dose due to external exposure is relatively small comparing with that of ingestion through crop. Due to the shortage of quantitative data between the depth and fraction of root, Figure 7 only shows relation between the fraction of roots in deep soil and dose. And, it must be considered that the change in depth of soil overburden is a matter connected with scenario selection.

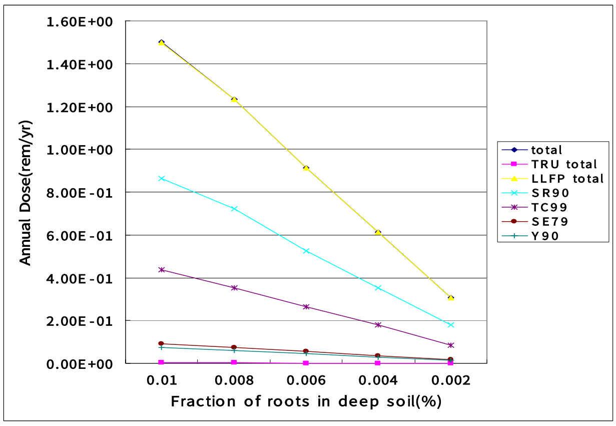

Figure 7. Dose by fraction of roots in deep soil (Depth of soil overburden)

The volume of disposal facility connecting with GENII input parameter to calculate dose, namely disposed concentration for each nuclide is directly in inverse proportion to dose. It is considered that volume of disposal facility is subject to restriction to make it large infinitely in reality. It is showed in Figure 8.

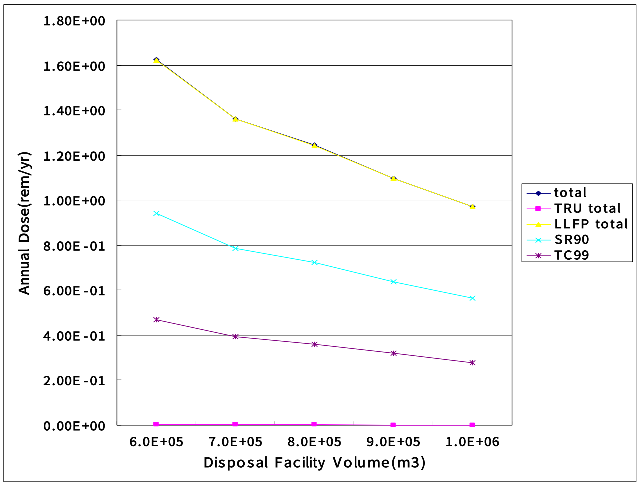

Figure 8. Dose by the volume of disposal facility

4. CONCLUSION

The concentration limits for PEACER final waste to dispose it into LILW disposal facility are derived by the existing methodology and input parameters. In order to satisfy these concentration limits, TRU DF value and LLFP removal efficiency have to be maintained more than 5.0+03 and 98.5%, respectively. The intruder in the human intrusion scenarios is exposed to annual dose by not TRU but LLFP in the range of more than TRU DF 5.0E+03. Especially, a dose by Sr-90 and Tc-99 mark the highest level.

The sensitivity analysis about ICP shows that the dose by Sr-90, a short-lived radionuclide can be reduced effectively with increasing ICP. Therefore, The ICP acts on one of the most important input parameter in establishing the CL to dispose waste into LILW disposal facility.

ACKNOWLEDGMENTS

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