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Human Radiation Dose Assessment of the ACP Experimentation

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The Advanced spent fuel Conditioning Process(ACP) is under development for the effective management of spent fuels which have been generated in nuclear plants. The ACP needs a hot cell where most of the operations will be performed. To give priority to environmental safety, radiation dose evaluation for the radioactive nuclides was preliminarily performed with the basic concept design report, the meteorological data and the recent site specific data. According to the production and release rate of the nuclides, dose evaluations for residents around the facility were performed. Evaluation results compared with the regulation limits presented a very good safety level, but the elimination efficiency for several important nuclides has to be highly maintained.

KEYWORDS: gasdos, radiation evaluation, hot cell, dose

I. Introduction

Although a lot of nuclear power plants tend to operate in high burnup nowadays, the proportion of nuclear power for electricity supply is getting higher and the amount of spent fuels has increased accordingly. On the contrary, the storage capacity of spent fuels is expected to be saturated before long because there is still no permanent disposal site in Korea. To solve this kind of problem, ACP (Advanced spent fuel Conditioning Process) was proposed as the main concept to convert oxide spent fuel to metallic uranium in a LiCl solution at a high temperature and therefore, to reduce the quantity of spent fuel by 1/4, radioactivity by 1/4 and the necessary disposal area by 1/2. Such a proceeding is expected to improve the disposal safety & economical savings and also to help choose a storage site more easily.

For demonstration and a hot test of the ACP, α-γ hot cells will be located in the base floor of the IMEF (Irradiated Material Examination Facility) in KAERI (Korea Atomic Energy Research Institute). According to the facilities new site data, this study performed the evaluation with the GASDOS program which has been developed by USNRC and revised by KINS(Korea Institute of Nuclear Safety) afterwards because all nuclear facilities should be investigated for radiation doses to the operators and the environment.

II. Radiation Source Determination

Because ACP is a dry process[1), 2)], there is no liquid source. To determine how much nuclear materials and radioactivities are treated during the process, this study set up the source specifications as follows;

- Spent fuel quantity in a year :
  100kg-HM(20kg/batch, 5 batches/y)
- Initial enrichment : 3.5 wt%
- Assembly average burnup : 43,000 MWD/MTU
- Cooling time : 10 years

ORIGEN-2 program calculated the mass and radioactivity for each nuclide by considering the source specifications above, for all the proceeding steps and the process operating concept. As a result, **Table 1** shows the total radioactivity treated during a normal operation in a year as 1.38E+15 Bq.

Table 1. The Amount of Radioactivity Treatment in Hot Cell

Radioactive Source Terms	Radioactivity (Bq)
Spent Fuel (20 kg-HM) – 1 batch	3.67E+14
Metal Uranium 4 batches	5.45E+14 (1.36E+14 × 4)
Volatile Fission Products (H, Kr) 4 batches	2.01E+13 (5.02E+12 × 4)
Molten Salts 2 batches	4.52E+14 (2.26E+14 × 2)
Total	1.38E+15

Fission gases which include H-3, I, Kr, Xe and so on would vaporize and be exhausted through the ventilation duct according to each procedure condition, but almost all the fission gases tend to be discharged during the vol-oxidation step and the rest would come out during the metallization or smelting procedure. Cesium in a Cs_2O_3 form is expected to flow out when the metallization procedure is operated at 650°C and the remaining Cs, Sr and Ru in a chemical compound form would be exhausted entirely during the smelting & casting procedure operated at 1400°C.

To treat the radioactive gases mentioned above, an off-gas clean-up system is required and has to consist of TGT(Thermal Gradient Tube) for semi-volatile gas, Metal Wool for minute particles, SIZ(Silver Impregnated Zeolite) for iodine, Molecular Sieve 5A for tritium and a HEPA(High Efficiency Particulate Air) filter for the not yet disposed gases. Exhaust gases go through the off-gas clean-up system

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and pass the hot cell exhaust equipments and finally go out of the building through HANARO (Korean Multipurpose Research Reactor (KMRR) stack. To determine the radioactive gas release amounts, it is necessary to examine the off-gas clean-up system and perform an efficiency test. In **Table 2**, the produced rate in the first column means how much of each nuclide is released from the examination equipment and the middle columns display the off-gas removal efficiency for each trap unit and the last column sums up. Every nuclide release quantity which was generated during the ACP will be calculated with the last column data as a radioactive source.

Table 2. Produced rate and removal efficiency in each trap for important nuclides in the off-gas

Nuclide	Produced Rate (Bq/y)	Removal Efficiency(%)			Released Rate (Bq/y)
		HEPA1	HEPA2	Charcoal	
H-3	2.13E+12				2.13E+12
C-14	6.44E+07				6.44E+07
Kr-85	2.30E+13				2.30E+13
Mo-93	1.00E+05	99.97	99.97		9.03E-03
Ru-106	2.86E+12	99.97	99.97		2.58E+05
Cd-109	2.35E+07	99.97	99.97		2.11E+00
Sb-125	5.55E+12	99.97	99.97		5.00E+05
I-129	1.52E+08			99.75	3.81E+05
Cs-134	7.84E+11	99.97	99.97		7.07E+04
Cs-137	9.21E+12	99.97	99.97		8.29E+05

III. Determination of atmospheric Dispersion Factor

The method of radiation dose assessment for the human body has two categories, which are external and internal dose. The basic route of the external dose includes deposition on the ground and radioactive clouds which contain radioactive minute particles floating in the air. For the Internal dose, there is inhalation by breathing and ingestion by eating vegetables and meats. Dispersion factor of the evaluation referred to the models of the US NRC Regulatory Guide 1.111[3].

Dispersion type of ACP corresponds to a high-altitude dispersion because the meteorological observation tower measures data at a 67meter height. Meteorological data is collected from 160 mesh zones which have a center in the concerned facility and consist of 16 directions and 10 distance steps. **Figure 1** shows these mesh zones around the facility. Data at the site boundary (about 800m) usually indicates the maximum values and the evaluation takes this data for a conservative consideration. The code also needs milk, meat, vegetable production and population data for each mesh zone and this data have to be updated every 5 years. Because new data acquisition is in progress this year, data for 1996 and 1997 was introduced into this research. For another conservatism, this study did not consider radioactive decay and deposition of the meteorological dispersion factor.

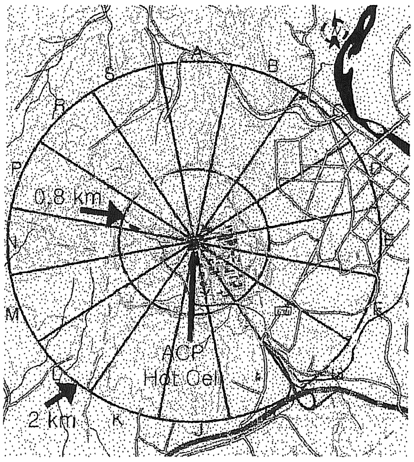

Figure 1. Mesh zones for meteorological dispersion factor calculation.

Table 3 shows the dose assessment study cases[4-7] of the facilities related to the HANARO building for the past several years (HANARO building consists of IMEF, RIPF(Radioactive Isotope Production Facility) and itself).

Table 3. Atmospheric Dispersion Factor Comparison

Year	Document	Dispersion Factor [s/m^3]
1986	HANARO Safety Analysis Report	7.37×10^{-6}
1994	IMEF Safety Analysis Report	1.26×10^{-6}
2002	Facility Operation Annual Report	1.31×10^{-4}

Having a focus on the meteorological dispersion value, there is a significant difference between the middle and the latter half of the 1990's. The reason is assumed to be that the recent advances of meteorological data analysis helps get more precise values and for that reason, a further more accurate calculation is needed. KAERI Annual Report[7] gives recent data for atmospheric dispersion factors and deposition factors and this study used them.

IV. Radiation Dose Evaluation

Dose limit for residents around the nuclear facilities should be maintained lower than the regulation limits proposed by USNRC and MOST(Ministry of Science & Technology, Korea) notification No. 2002-23(Standard for Radiation Protection)[3), 8)]. The GASPAR code based its main concept on the USNRC regulation notification 1.109

and has been used for evaluation of gaseous radioactive effluents. KINS revised GASPAR with the Korean geographical features data and took the ICRP-60 recommendations for new dose conversion factors into account. The effective dose conversion coefficients are based on the new tissue weighting factors for external exposure from the radionuclides deposited on the ground surface. In the external dose case, this study applied the dose factor proposed by IAEA safety Series 115 for exposure doses from radioactive clouds. Inhalation and skin exposure dose factors by NRC Regulatory Guide 1.109 were applied, too.

ICRP(International Commission on Radiological Protection) and IAEA recommend six age groups for people instead of the original four age groups, but there are slight differences between two age groups and therefore this study considered only the child age group which is the most sensitive one. Since the most important standards of dose assessment are Effective Dose and Organ Equivalent Dose, this study concentrates on these two categories.

V. Evaluation at Accident

Safety analysis of a nuclear facility must be performed for not only normal operation but also operation in accident cases. For an accident analysis, accident types and conditions should be assumed and radioactivity release rate should be calculated from them. The atmospheric dispersion data for an accident refers to the NRC Regulatory Guide 1.145 and it is assumed to be that all radioactive gases and particles would escape the examination facility in 2 hours. The following accidents could happen during the normal operation of Hot Cells.

- Fission gas release due to the duct system failure
- Fire in a Hot Cell (including uranium powder ignition by careless treatment)
- Treatment failure of the fission gas decay heat

Among the accident cases above, radioactivity release by a fire would be the most dangerous accident.

VI. Results & Discussion

Table 4 below shows the radiation dose for residents and the data compared with the regulations. Krypton-85, Carbon-14 and Tritium were considered to be released totally because there is no way to control and remove them clearly. Therefore, it dominates the effective dose(10%,0.7% and 64% for each), but the result value is slight.

Thyroid is known as the most sensitive organ to radiation, and for that reason, it is representatively selected for the radiation dose evaluation of human organs. In this study, I-129 dominates the Organ Equivalent Dose, especially for the thyroid. But, its effect does not seem to be a big problem because the iodine trap installation like the other studies was considered and the trap efficiency was highly applied at 1%[6]. For each case of effective dose and thyroid, the results of evaluation during a normal operation satisfy the regulation limit and design limit.

Table 4. Comparison of this evaluation result with regulation.

Item	Regulation (Bq/y)	Result (Bq/y)	Percent (%)	Remark
Effective Dose	1.85E+09	2.26E+07	0.1	
Organ Equivalent Dose	5.55E+09	2.38E+08	4.3	Child, thyroid

Evaluation results for the assumed accident case(Fire in Hotcell) are shown in **Table 5**.

Table 5. Evaluation result for Accident Case(Fire in Hotcell)

Item		Effective Dose (Bq/y)		Equivalent Dose (Bq/y)
		External	Internal	Thyroid
Standard for Dose	Regulation	9.25E+9	9.25E+9	1.11E+11
	Facility Standard	9.25E+7	9.25E+7	1.11E+09
Fire Accident		1.41E+6	1.78E+7	6.29E+07

According to **Table 4** and **Table 5**, it is concluded that the radiation dose assessment evaluation of ACP drove an acceptable result for safety. As a conclusion, metallization of uranium oxides with above-mentioned conditions in the α-γ type hotcell could affect the environment by inevitable radioactive particles and gases release. But this study shows that radiation effect around facility is insignificant and helps uranium metallization research for spent fuel treatment to develop with environmental safety.

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