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Prediction of Decontamination Factor Change by Adjustment of Decontamination Scope

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1. Introduction

In the early stages of decommissioning a nuclear power plant (NPP), pre-decommissioning system decontamination can be considered. System decontamination is the process of removing metallic radioactive deposits (CRUD) in the primary system of a nuclear power plant by using redox reactions. The effectiveness of this process varies across a number of elements in the primary system, including physical structure, oxidizer concentration, and deposit thickness. Therefore, even within a single decontamination cycle, the decontamination efficiency of each element in the system can vary. The decontamination efficiency is expressed as the decontamination factor (DF), which is the ratio of the activity before and after decontamination. The overall DF is calculated by comparing the activity before and after decontamination within the overall range. In order to maximize the overall DF, adjustments to the decontamination range can be considered, such as excluding elements with low contributions to the overall DF. This study examines the case of excluding the steam generator (SG) of Gori Unit 1 using data from Obrigheim NPP and Barsebäck Unit 2.

2. Methods and Results

In this study, an expected total DF can be calculated by certain formulas. These formulas are derived from several assumptions. The expected total DF by each decontamination scenario can be calculated by decontamination scope in each scenario, initial activity in each element before decontamination, and partial DF of each element in each cycle of decontamination. To calculate the partial DF of each element in each cycle, whole scope DF data from Barsebäck Unit 2 and partial DF with all-cycle-decontamination in Obrigheim are collaborated with target DF of Kori Unit 1 decontamination.

2.1 Formula Development

In the transformation of Barsebäck Unit 2 data, the relationship among DF by cycles can be expressed with assumed formula with constant m are applied. By defining DF_n is the partial DF of n-th cycle decontamination,

$$DF_{n+1} = (DF_n)^{k_n}, \qquad (1)$$

$$k_n = 1 + \frac{k_1 - 1}{n^m}. \qquad (2)$$

With k_n values, partial DF by each cycle in whole scope can be calculated from all-cycle-DF value. From the formula (1) and definition of DF,

$$DF = \frac{Radioactive\ Inventory\ before\ 1st\ cycle}{Radioactive\ Inventory\ after\ n\text{–}th\ cycle}, \qquad (3)$$

The below formula can be derived,

$$DF_{total}^{1\sim n\ cycle} = (DF_1)^{1+k_1+k_1k_2+\cdots+k_1k_2\cdots k_n}. \qquad (4)$$

2.2 Application of Formula for DF Cycles

From the activity output shown in Table I in Barsebäck Unit 2 decontamination result with overall DF 93 after all 3 cycles of decontamination [1], partial DFs of each cycle in Barsebäck Unit 2 decontamination can be calculated.

Table I: Activity Output of Barsebäck Unit 2

Cycle	Activity Output
1	$1.56 \times 10^{12}\ Bq$
2	$0.48 \times 10^{12}\ Bq$
3	$0.10 \times 10^{12}\ Bq$

From the partial DFs of each cycle shown in Table II, k_1 and k_2 is calculated as 1.243554 and 1.0500513, and constant m is obtained to be 2.282766.

Table II: DF of Barsebäck Unit 2

Cycle	DF
1	3.59
2	4.89
3	5.30

With this m value, k_3 to k_4 values are derived and shown in Table III.

Table III: k values

k_1	k_2	k_3	k_4
1.243554	1.0500513	1.019835	1.010286

2.3 Application of DF by Scope

For the partial DF of element, the data from Obrigheim NPP was imported and processed. Figure 1 shows the dose rate and DF by element in the decontamination of Obrigheim NPP [2]. The elements divided from whole system of Obrigheim, and adjusted to that of Kori Unit 1 were pressurizer (PZR), PZR surge line, reactor cooling system (RCS) hot leg A, RCS hot leg B, RCS cold leg A, RCS cold leg B, reactor cooling pump (RCP) crossover (CX) leg A, RCP CX leg B, SG chamber A, SG chamber B, SG U-tube A, SG U-tube B, CVCS, and RHRS. For the same type of elements, A is connected to the line with PZR, and B is connected to the line without it.

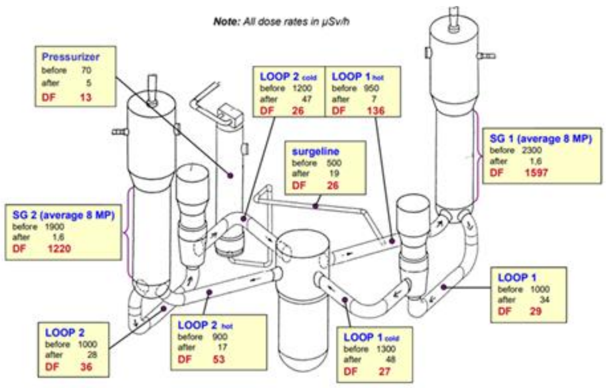

Fig. 1. Dose rate and DF by element in Obrigheim NPP.

The DFs of Chemical and Volume Control System (CVCS) and Residual Heat Removal System (RHRS) were obtained from the DF of auxiliary system of Obrigheim, 29, which was calculated from radioactivity inventory change of it before and after decontamination [3]. With the ratio of initial radioactive inventory of CVCS and that of RHRS in Kori Unit 1, approximately 5.27, the partial DF of CVCS and RHRS were obtained as 40 and 12. Table IV shows the partial DFs by elements in Obrigheim, and calculated DFs by each cycle from equation (1), equation (4), and Table III.

Table IV: DF by element and cycle in Obrigheim NPP

Name	Total DF	DF_1	DF_2	DF_3	DF_4
PZR	13	1.69	1.92	1.99	2.01
PZR surge line	26	1.95	2.29	2.39	2.43
RCS hot leg A	136	2.74	3.50	3.72	3.82
RCS hot leg B	53	2.26	2.75	2.89	2.95
RCS cold leg A	27	1.96	2.32	2.42	2.46
RCS cold leg B	26	1.95	2.29	2.39	2.43
RCP CX leg A	29	1.99	2.36	2.46	2.51
RCP CX leg B	36	2.08	2.49	2.61	2.66
SG chamber A	60	2.31	2.84	2.99	3.06
SG chamber B	60	2.31	2.84	2.99	3.06
SG U-tube A	1597	4.53	6.55	7.19	7.48
SG U-tube B	1220	4.29	6.11	6.69	6.95
CVCS	40	2.13	2.56	2.68	2.73
RHRS	12	1.65	1.86	1.92	1.95

2.4 Shaping Amplifier Model

The DF values by elements and cycle in Obrigheim NPP was used in the Kori Unit 1 decommissioning scenarios. The scenarios consist of a total of 8, distinguished by the number of decontamination cycles including that of full system decontamination (FSD), and partial system decontaminations without SG A or SG B. Table V shows the scenarios and their descriptions. Abbreviation of scenarios were set arbitrarily.

Table V: Decontamination scenarios

Scenario	Description
F	3 cycles FSD
N1	2 cycles FSD + 1 cycle without all SGs
N2	2 cycles FSD + 2 cycles without all SGs
A1	2 cycles FSD + 1 cycle with only SG A
A2	2 cycles FSD + 2 cycles with only SG A
B1	2 cycles FSD + 1 cycle with only SG B
B2	2 cycles FSD + 2 cycles with only SG B

2.5 Results

The overall DF by Scenarios are shown in Table VI.

Table VI: DF of Barsebäck Unit 2

Scenario	Overall DF
F	43
N1	19
N2	23

A1	26
A2	36
B1	27
B2	39

Comparing the total-3-cycle scenarios, overall DF is lowest in N1 scenario, as 19, and highest in F scenario, 43. In single SG exclusion cases, A1 shows lower overall DF compared to B1, but the difference is only 1 as 26 and 27. Comparing the total-4-cycle scenarios, the difference between A2 and B2 becomes 3 as 36 and 39. Comparing the F and B2, which shows highest overall DF in total-4-cycle scenarios, the difference is 4, as 43 and 39. Comparing the total-3-cycle scenarios and total-4-cycle scenarios with excluding same SG(s), the differences are 4 in N scenarios, 10 in A scenarios, and 12 in B scenarios.

3. Conclusions

From the result, excluding SG and add 1 more cycle of decontamination shows lower overall DF. This means increasing the number of decontamination cycles instead of excluding the element(s) in decontamination scope is not effective, considering that adding cycle increase the amount of secondary radioactive waste. Nevertheless, if one of SGs is excluded, excluding SG A, which is connected to the line with PZR is slightly more effective.

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