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Estimation of Radioactive Inventory for a major component of Reactor in Decommissioning

해체시 원자로 주요 구성품에 대한 방사능 재고량 평가

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Abstract

DORT and ORIGEN2 code were used for calculation of neutron flux and inventory in reactor pressure vessel(RPV) of Kori unit-1. To calculate neutron flux using DORT code, the reactor was divided into 94 mesh from the center of core to RPV and from 0 to 45 degree along the azimuth. The cross-sections of main nuclides were recalculated using neutron flux in the RPV region. The results showed that 95 % of the total activity in RPV came from the nuclides of ^{55}Fe, ^{60}Co, ^{59}Ni and ^{63}Ni. And the total activity with cooling of more than 50 years after decommissioning was no more than 0.2 % of at the time of shutdown. Considering the weight of RPV is 210 tons, the initial total activity of RPV reached 5.25×10^6 GBq. To verify results of ORIGEN2 calculation, comparison between calculated and measured value at RPV of Kori unit-1 was performed. The comparison results showed a good agreement.

Key words : Decommissioning, DORT, ORIGEN2, Activation Products Inventory

요약

고리 1호기 원자로압력용기의 중성자속과 방사화생성물 재고량을 계산하기 위하여 DORT 코드와 ORIGEN2 코드를 사용하였다. DORT 코드를 이용해 중성자속을 계산하기 위하여 노심을 중앙부터 원자로압력용기까지 방위각 방향으로 94 mesh로 분할하였다. 원자로압력용기 영역의 중성자속을 이용하여 주요 핵종의 단면적을 재계산하였다. 원자로압력용기의 경우, ^{55}Fe, ^{60}Co, ^{59}Ni 및 ^{63}Ni의 핵종이 총 방사능의 약 95%를 차지하였으며, 해

체 후 50년 이상 냉각후의 총 방사능은 정지시점과 비교하여 약 0.2% 이하로 감소하는 것으로 평가되었다. 총 중량이 210 ton인 원자로압력용기의 총 방사능은 5.25×10^6 GBq이었다. ORIGEN2 계산 결과를 검증하기 위하여 고리 1호기 원자로압력용기의 계산값과 실측값에 대한 비교 검증을 수행하였으며, 그 결과는 서로 일치함을 확인할 수 있었다.

중심단어 : 해체, DORT, ORIGEN2, 방사화생성물재고량

I. INTRODUCTION

The purpose of activation product inventory evaluation is to provide information on radiological environment during decommissioning of nuclear power plant and to assist establishment of decommissioning plan. Especially, the evaluation of inventory is a guidance to determine decommissioning technologies, estimate radiation dose of workers and public, select the decontamination technologies and determine requirements for disposal and transportation of radioactive material. As the time of decommissioning of Kori unit-1 approaches, we have performed the study on methodology for evaluation of activation product inventory in RPV. The spectrum of neutron energy varied with space. Therefore, it is not easy to calculate the activity due to activation products generated at region away from core. In order to evaluate the neutron flux and the activation product inventory at the adjacent regions of reactor core in this study, the 2-dimensional code DORT[1] and ORIGEN2[2] codes were applied. One of the codes most frequently used to perform the activation calculations is ORIGEN2, which is an extremely useful tool because of its capability to track a large number of isotopes through specified irradiation and decay times. This code has a cross-section library with neutron spectrum of core region in which fuel assembly was loaded. A reactor pressure vessel structure is far away from core, then its neutron flux becomes quite different from that of core region. Also, there are no neutrons generated from fission in this region and most of the fast neutrons coming in this region are thermalized. Therefore, the one group cross-section at the structures far away from core region should be recalculated. In this study, the neutron spectrum at region of reactor pressure vessel structure was calculated using DORT code. The cross-section of nuclides such as ^{54}Fe, ^{56}Fe, ^{58}Fe, ^{58}Ni, ^{55}Mn were recalculated with the neutron spectrum obtained from DORT code.

II. CALCULATION OF NEUTRON FLUX

DORT code is primarily intended to solve neutron and photon transport problems on a wide variety of computer types using the method of discrete ordinates. This code has generally been used to determine neutron flux or the fluence of particles throughout one-or two-dimensional geometric systems due to sources either generated as a result of particle interaction with the medium or incident upon the system from extraneous source, i.e., "fixed-source" problems. In this study, the neutron flux from core to RPV was calculated using DORT code. The multigroup cross-section library used in DORT code was BUGLE-96 which is intended for use in light water reactor(LWR) shielding and pressure vessel dosimetry applications. BUGLE-96 contains 120 nuclides which have been processed as infinitely dilute and collapsed using an LWR concrete shield spectrum. Additionally, it contains 105 nuclides which have been energy self-shield and collapsed using LWR-specific material compositions and flux spectra. The library of DORT code consisted of 47 neutron group [3].

The geometric model considered in DORT code is shown in Figure 1 and described as baffle, barrel, bypass, thermal shield, downcomer and RPV from the center of core region.

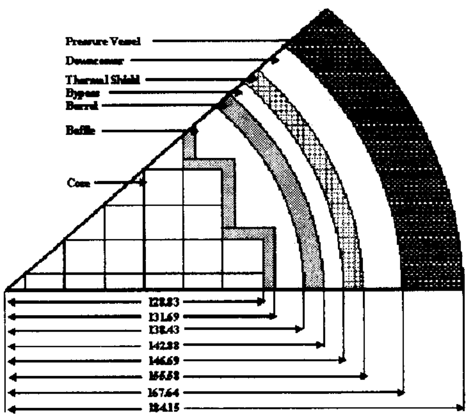

Fig. 1 DORT geometric calculation model of Kori unit-1

It was assumed that the coolant temperature was 571.7 °F, pressure was 2,250 psia and boron concentration in coolant was the average boron concentration of 546 ppm, And then, the core was assumed as a homogeneous region. We calculated chemical compositions and atomic density of materials for each structure of Kori unit-1 and adopted them in DORT code. The materials of baffle, barrel and thermal shield are stainless steel types 304 and RPV is ASME SA508 carbon steel[4]. Table 1 shows the chemical composition and atomic density of component materials.

III. CALCULATION OF ACTIVITY INVENTORY

Kori unit-1 is designed to produce 1,723.5 MW thermal core power and 587 MW gross electrical power. The reactor is a closed cycle moderated and cooled by pressurized light water and uses slightly enriched uranium oxide fuel. This plant has begun commercial operation since 1978.

The operation cycle of Kori unit-1 has been changed to 15 month since 1989(The operation cycle was 12 month till then.) to improve an availability.

It is necessary for nuclear design reports in each cycle to calculate activation product inventory, but we used the nuclear design report of Cycle 19 representatively and obtained ORIGEN2 input data from it. The burnup of Cycle 19, Kori unit-1 was 14,160 MWD/MTU[5][6]. Also, total operation time was considered 11,269 day based on 27 operation cycle from commercial operation to permanent shut down, The materials of baffle, barrel and thermal shield are stainless steel types 304 and RPV is ASME SA508 carbon steel. The weight of composition atoms in each material was calculated and shown in Table 2.

Table 1. Chemical composition and atomic density of component materials by zone(#/barn-cm)

Nuclide	Fuel and Coolant	Type 304 Stainless Steel	Pressure Vessel Steel	Bypass Down-comer	Nuclide	Fuel and Coolant	Type 304 Stainless Steel	Pressure Vessel Steel	Bypass Down-comer
^{235}U	1.152×10^{-4}	-	-	-	^{54}Fe	3.604×10^{-6}	3.443×10^{-3}	4.357×10^{-3}	-
^{238}U	6.644×10^{-3}	-	-	-	^{56}Fe	5.602×10^{-5}	5.352×10^{-2}	7.550×10^{-2}	-
^{239}Pu	3.695×10^{-5}	-	-	-	^{57}Fe	1.283×10^{-6}	1.225×10^{-3}	1.729×10^{-3}	-
^{240}Pu	8.857×10^{-6}	-	-	-	^{58}Fe	1.710×10^{-7}	1.634×10^{-4}	2.305×10^{-4}	-
^{241}Pu	3.568×10^{-6}	-	-	-	Fe-total	6.108×10^{-5}	5.835×10^{-2}	8.232×10^{-2}	-
H	2.764×10^{-2}	-	-	4.828×10^{-2}	^{58}Ni	9.910×10^{-5}	5.103×10^{-3}	4.007×10^{-4}	-
O	2.682×10^{-2}	-	-	2.414×10^{-2}	^{60}Ni	3.081×10^{-5}	1.966×10^{-3}	1.544×10^{-4}	-
^{10}B	2.303×10^{-6}	-	-	4.305×10^{-6}	^{61}Ni	1.660×10^{-6}	8.545×10^{-5}	6.710×10^{-6}	-
^{11}B	-	-	-	1.766×10^{-5}	^{62}Ni	5.517×10^{-6}	2.724×10^{-4}	2.139×10^{-5}	-
Al	1.126×10^{-6}	-	-	-	^{64}Ni	1.348×10^{-6}	6.941×10^{-5}	5.450×10^{-6}	-
C	3.568×10^{-6}	3.169×10^{-4}	8.670×10^{-4}	-	Ni-total	1.458×10^{-4}	7.496×10^{-3}	5.886×10^{-4}	-
^{50}Cr	5.509×10^{-7}	7.556×10^{-4}	1.266×10^{-5}	-	Mo	-	-	2.812×10^{-4}	-
^{52}Cr	1.062×10^{-5}	1.457×10^{-2}	2.441×10^{-4}	-	Zr	4.518×10^{-3}	-	-	-
^{53}Cr	1.205×10^{-7}	1.652×10^{-3}	2.767×10^{-5}	-	Mn	2.156×10^{-6}	1.732×10^{-3}	5.428×10^{-6}	-
^{54}Cr	2.999×10^{-7}	4.113×10^{-4}	6.889×10^{-6}	-	Si	-	1.694×10^{-4}	4.382×10^{-4}	-
Cr-total	1.258×10^{-5}	1.739×10^{-2}	2.913×10^{-4}	-		-	-	-	-

Table 2. Weight of composition atoms in each materials [g/ton]

Nuclide	Stainless Steel	Carbon Steel	Nuclide	Stainless Steel	Carbon Steel
H			^{54}Fe	3.92×10^{4}	5.54×10^{4}
C	3.95×10^{3}	1.08×10^{4}	^{56}Fe	6.32×10^{5}	8.92×10^{5}
O			^{57}Fe	1.48×10^{4}	2.08×10^{4}
Na			^{58}Fe	2.03×10^{3}	2.87×10^{3}
Mg			^{58}Ni	5.52×10^{4}	4.34×10^{3}
Al			^{60}Ni	2.20×10^{4}	1.73×10^{3}
Si	3.38×10^{4}	8.75×10^{3}	^{61}Ni	9.73×10^{2}	7.64×10^{1}
S			^{62}Ni	3.15×10^{3}	2.47×10^{2}
K			^{64}Ni	8.29×10^{2}	6.51×10^{1}
Ca			^{92}Mo	5.24×10^{2}	5.24×10^{2}
^{50}Cr	8.73×10^{3}	1.46×10^{2}	^{94}Mo	5.77×10^{2}	5.77×10^{2}
^{52}Cr	1.75×10^{5}	2.93×10^{3}	^{95}Mo	2.33×10^{2}	2.33×10^{2}
^{53}Cr	2.02×10^{4}	3.39×10^{2}	^{96}Mo	5.39×10^{2}	5.39×10^{2}
^{54}Cr	5.13×10^{3}	8.59×10^{1}	^{97}Mo	5.79×10^{2}	5.79×10^{2}
Mn	2.13×10^{4}	6.65×10^{3}	^{98}Mo	1.45×10^{3}	1.45×10^{3}
			^{100}Mo	4.81×10^{2}	4.81×10^{2}

ORIGEN2 code uses one group cross-section library and dose not describe the geometry of reactor because ORIGEN2 code assumes reactor as a point. ORIGEN2 code was developed in order to calculate source term and to predict the amount of fission product in core. To calculate cross-section library, ^{56}Fe, ^{54}Fe, ^{58}Ni, ^{59}Mn and etc., were selected as main nuclides.

One group cross-section library of ORIGEN2 was calculated using neutron flux obtained from DORT code and ENDF/VI-B Library[7]. Calculated cross-section of main nuclides in RPV was compared with cross- section in ORIGEN2. Table 3 shows the comparison results.

IV. RESULTS AND ESTIMATION

The total neutron flux calculated by DORT code from core to RPV is shown in Figure 2 and the regional total neutron flux distribution with azimuthal direction is shown in Figure 3.

It shows that neutron flux in core does not vary while the neutron flux decreases rapidly in baffle, barrel, thermal shield and RPV. Figures 4 and 5 show the activation product inventory in RPV of Kori unit-1 calculated by ORIGEN2.

Table 3. Comparison between original and calculated value for library of main nuclides

Main Nuclides	ORIGEN2 [barn]	Calculation Value [barn]	Main Nuclides	ORIGEN2 [barn]	Calculation Value [barn]
^{54}Fe	2.026×10^{-2}	8.079×10^{-3}	^{58}Ni	2.097×10^{-2}	1.116×10^{-2}
^{56}Fe	1.670×10^{-3}	2.401×10^{-4}	^{55}Mn	3.698×10^{-4}	1.007×10^{-4}

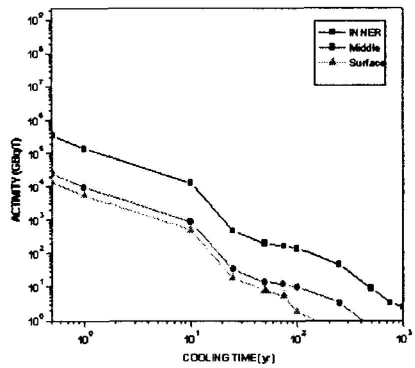

Fig.2. Radial distribution of total neutron flux by DORT

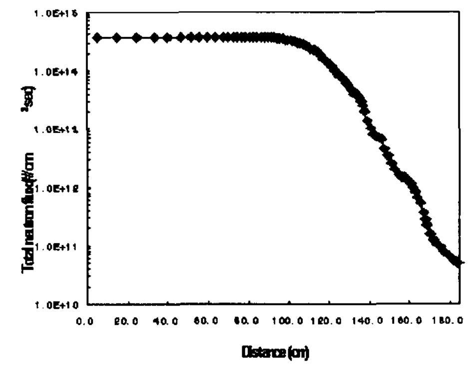

Fig. 3. Total neutron flux of cycle 19 with azimuthal direction

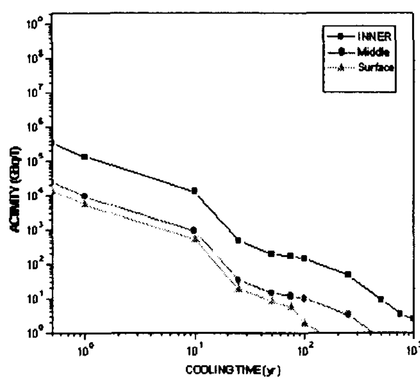

Fig. 4. Activity in the RPV steel

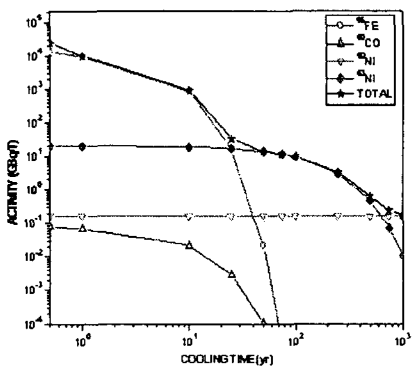

Fig. 5. Activity of nuclides in the RPV(middle)

To verify results of ORIGEN2 calculation, comparison between calculated and measured value at RPV of Kori unit-1 was performed. Measured values used in this study were obtained from "the 3rd surveillance testing results of Kori unit-1 reactor pressure vessel" by KAERI in 1985 and "Development of an equipment for measurement for neutron exposure on reactor ex-vessel" by NETEC in 2001.[8][9] The comparison between calculated and measured value was done by selecting 2 nuclides contained in specimen.

Table 4 shows the results. The results show that calculated values are slightly different from the measured values. It comes from the difference of neutron flux between sixth cycle and nineteenth cycle in case of surveillance specimen. In case of ex-vessel specimen, it occurred from the angular dependence and shielding material (about 2 mm thickness) of specimen.

Table 4. Comparison between measured and calculated values

	Nuclide	Measured (Bq/g)	Calculated (Bq/g)	Ratio
Surveillance sample	^{58}Ni (n,p)^{58}Co	4.991×10^{7}	4.732×10^{7}	0.9
	^{54}Fe (n,p) ^{54}Mn	3.368×10^{6}	2.571×10^{6}	0.8
Ex-vessel sample	Nuclide	Measured (Bq/g)	Calculated (Bq/g)	Ratio
	^{58}Ni (n,p)^{58}Co	3.025×10^{6}	3.606×10^{6}	1.19
	^{54}Fe (n,p) ^{54}Mn	1.709×10^{5}	1.281×10^{5}	0.75

V. CONCLUSION

The results show that activation product inventory decreases from core to RPV because of the decrease of neutron flux. In RPV, it was evaluated that 95 % of the total activity come from the nuclides of ^{55}Fe, ^{59}Ni and ^{63}Ni. The activity of ^{55}Fe is dominant of the whole activity about 10 years from shutdown, while ^{59}Ni and ^{63}Ni are dominant after 30 years. Total activity after cooled for more than 50 years remains about 0.2 % of total activity at the time of shutdown. Also we could predict that total activity of RPV at shutdown would be 5.25×10^{6} GBq considering the weight of pressure vessel is 210 tons. After selecting two nuclides contained in RPV material, comparison between measured and calculated values was performed. The comparison results showed a good agreement.

VI. ACKNOWLEDGEMENT

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VII. REFERENCE

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