Journal of the Korean Nuclear Society
Volume 21, Number 3, September, 1989

Investigation of the Control Absorber Characteristics in the KMRR

Hark Rho Kim, Young Jin Kim, Jung-Do Kim and Ji Bok Lee
Korea Advanced Energy Research Institute
(Received January 10, 1989)

KMRR의 제어흡수체 특성에 관한 연구

김학노 · 김영진 · 김정도 · 이지복
한국에너지연구소
(1989. 1. 10 접수)

Abstract

Since in the KMRR the neutron spectrum is hardened in comparison with the conventional power reactors, and the absorber is in a tube-form which may contain the neutron multiplying media inside it, the reactor physics characteristics of the KMRR absorber are much different. The characteristics of the hafnium control absorber are studied under the several kinds of the environmental conditions. The environmental conditions include the inner materials inside the absorber shroud, the absorber thickness, the absorber burnout, and the fuel burnup. Investigated are nuclear characteristics such as the dependence of the spectral, regional, and isotopic contribution to the neutron absorption, and the dependence of the reactivity worth. Many important absorber characteristics are identified and presented from the analysis.

요 약

KMRR의 중성자 스펙트럼은 기존 상업로와는 달리 경화되어 있으며, 흡수체가 그 내부에 중성자 증배물질을 내포할 수 있는 원통형이기 때문에 KMRR 흡수체의 노물리 특성은 아주 다르다. 하프니움 제어흡수체의 특성을 여러가지 조건에 대하여 연구하였다. 흡수체 내부의 물질, 흡수체 두께, 흡수체 자체의 연소효과 및 주변 또는 내부의 핵연료 연소도 등을 고려하였다. 연구된 특성으로는 중성자 흡수에 대한 에너지별, 위치별 및 동위원소별 기여도와 반응도값이 있다. 중요한 흡수체 특성을 분석결과로부터 확인하였다.

I. Introduction

The design of a reactor control/shutdown system is determined by startup, shutdown, and safety requirements. In addition, the control system is used to shape the neutron flux in order to maintain the optimum power distribution in the core. Most of the power reactors use a rod-form or a blade type absorber as a part of the reactor control system and the follower type has long been adopted in the research reactors. The accurate prediction of the absorber characteristics is essential to safety considerations of the nuclear reactors. Many reactor physicists developed the methodologies for estimating the absorber neutronic properties more accurately[1-5]. The common features for these types of the absorbers lie in that there are no neutron multiplying media inside it and hence the major contributor to the neutron absorption in the absorber is the surface of the absorber facing the neutron multiplying media. The KMRR, however, uses a tube-type absorber and thus the major contributors to the neutron absorption become both the inner surface and the outer surface of the absorber tube. Moreover, there may be provided the fuel material inside the absorber shorud to enhance the total fuel loading when the absorber shroud is withdrawn from the core. This fuel loading makes the neutron flux distribution not well behaved within the control fuel bundle.

The neutron transport theory is common tool used for analyzing the neutron absorber characteristics. If there are no neutron multiplying media inside the neutron absorber, the neutron flux behaves simply and this makes comparatively easy to analyze the absorber properties. And the environments for the absorber of the conventional power or research reactors are the fuel enrichment, the fuel-to-moderator volume ratio, and the fuel/moderator temperatures. Saji analyzed the absorber characteristics in the HCPWR and found a correlation for the absorber reactivity worth as a function of the fuel-to-absorber diameter ratio[6]. However, in analyzing the KMRR absorber characteristics should be considered the environmental conditions forming the different neutron fields in the absorber site. The KMRR fuel management strategy revealed that the inner materials inside the absorber shroud would be different between the initial core and the succeeding cores, and the fuel burnup distribution is also different in-between. Also, the absorber is partly inserted into the core during normal operation and hence the isotopic density change of the absorber material should be taken into account.

In designing the lattice of the KMRR, the WIMS-KAERI[7] has been used after validation. The WIMS-KAERI is a modified version of the WIMSD4[8-9] and its cross section data were updated and augmented using the information contained in the published literature[10-12]. The calculation was carried out using the collision probability method and no neutron leakage was taken into account. The cross-section library of the WIMS-KAERI is constructed by 69–group structure and previous study has shown that 18 main transport calculation is near optimal for the KMRR lattice analysis. On the while, in the detail core calculation needed are 5–group structure cross-section sets, considering the computer requirement and the calculational accuracy. In the 5–group structure, the first group refers to the fast neutron with energy approximately higher than 1 MeV. The second group represents the neutron with energy between fast and resonance energy region. The third and the fourth group indicate higher and lower resonance separately treated in WIMS-KAERI. The cutoff energy of the thermal neutron is 0.625 eV. Table 1 shows the energy boundary used in this analysis.

II. Description of the KMRR

The KMRR(Korea Multi-purpose Research Reactor) is an open-tank-in-pool type reactor having benefits of free access at pool top and large inventory of ultimate heat sink. The reactor structure assembly consists of five components. These are the inlet plenum supporting the reactor tank and distributing inlet coolant, the lower and upper grid plates holding the fuel assemblies and the experimental facilities, the reactor tank, the outlet chimney mixing coolant passed individual flow tubes and the bypass flow, and the flow tube

Table 1. Energy Group Structure used in Transport Calculation and Reaction Ratio Edit

Energy Boundary		69-group Structure	Reaction Ratio Edit
Lower	Upper		
3.679	10.0 MeV	2	
0.821	3.679	5	1
0.06734	0.821	10	
0.009118	0.06734	14	2
5530.0	9118.0 eV	15	
48.052	5530.0	23	
27.7	48.052	24	
9.877	27.7	26	
4.0	9.877	27	3
1.071	4.0	36	
0.996	1.071	39	
0.625	0.996	45	4
0.350	0.625	48	
0.220	0.350	53	
0.100	0.220	56	
0.058	0.100	59	
0.030	0.058	63	
0.0	0.030	69	5

assembly. Fig. 1 illustrates the plan view of the KMRR. The reactor tank consists of the compact core and the bulky reflector. The hybrid-type core is composed of the compact, modular, H_2O cooled and moderated inner core and the D_2O moderated, H_2O cooled outer core.

Two types of fuel assemblies are required for the KMRR : 36-element and 18-element. The fuel elements of the 36-element driver fuel assembly are arranged in a hexagonal array at a 1.20cm element pitch, while those for the 18-element shim fuel assembly is located in two concentric annuli with 6 elements in the inner annulus and 12 in the outer one. The central position is occupied by the central tie rod.

The power regulation of the KMRR is accomplished by 4 tube-type natural hafnium absorber and the reactor scram is confirmed by dropping 4 shutoff absorber. The control absorber is basically

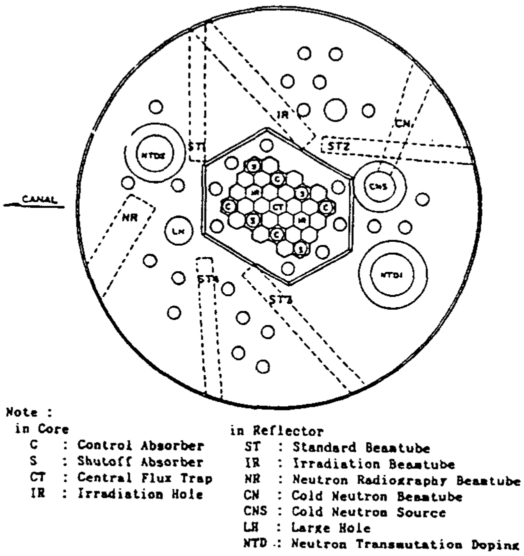

Fig. 1 Plan View of the KMRR

equivalent to the shutoff absorber except the signal actuating the absorber. In Fig.1, C refers the control absorber sites and S represents the shutoff absorber sites. The absorber material is the natural hafnium which consists of the naturally occurring isotopes such as $Hf^{174}(0.16)$, $Hf^{176}(5.2)$, $Hf^{177}(18.6)$, $Hf^{178}(27.1)$, $Hf^{179}(13.7)$ and $Hf^{180}(35.2)$ by weight percent. The control shroud is a bare form, i.e., has no cladding, since the hafnium has good compatibility to the water environment, and its physical dimension is 6.7cm I.D. and 7.6cm O.D.

III. Analyses Results and Discussions

For analyzing the nuclear characteristics of the KMRR absorber shroud, an ideal system was drawn under the assumption that using this system the KMRR absorber shroud can be well described. This system is constructed as shown in Fig.2. The center-point of the driver fuel assemblies surrounding the absorber site is taken as a boundary of this system where the zero-current condition is applied. So as to model this system using the WIMS-KAERI, the fuel element arrangement is modified into the circular cluster geometry as shown in Fig.2. Using this modified configuration, the absorber characteristics were investigated under the following environmental conditions :

- inner materials
- absorber thickness
- absorber burnout
- fuel burnup

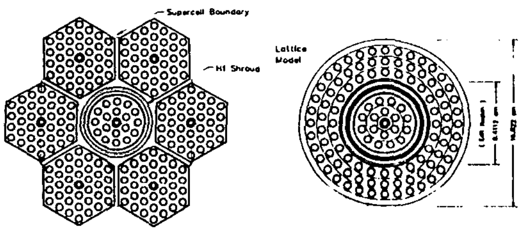

Fig. 2 Actual Layout and Analysis Model for Hafnium Absorber Shroud in KMRR

To investigate the spectral, regional and isotopic % contribution of the neutron absorption in the hafnium absorber, the total neutron absorption in the hafnium absorber is assumed to be 100 and the hafnium absorber is divided into 5-concentric segments with the same volume.

1. Inner Materials

The fuel management study[13] revealed that the control shroud is inserted into the core by 3/4 at the BOC(Beginning of Cycle) and then slowly withdrawn to compensate the reactivity loss due to the fuel burnup. Thus even though the 18-element shim assembly is loaded inside the flow tube in the control shroud site, the maximum linear heat rate in that shim assembly does not provoke the permitted linear heat rate. However, since the shutoff shroud is always withdrawn from the core under the normal operating conditions, the maximum linear heat rate of the 18-element shim assembly in the shutoff shroud site may exceed the permitted linear heat rate if the fresh shim assembly is loaded inside it. Therefore, the fuel management study decided the following strategy in the control/shutoff shroud site :

- The graphite block should be loaded in the shutoff shroud site of the initial core to achieve the permitted linear heat rate of the fuel assembly without loss of the excess reactivity,
- The shim assembly is loaded in the control shroud site in the initial core,
- The shim assembly burned once in the outer core site or in the control shroud site is transferred to the shutoff shroud site,
- The flow tube in the shutoff shroud site may be empty, i.e., H_2O coolant flows inside it under the assumption that the design flow rates are kept in the other fuel channels.

Thus the analysis of the neutronic characteristics of the KMRR hafnium absorber shroud considered the effect of the inner materials inside the absorber shroud such as H_2O, graphite block, and the 18–element shim assembly. In addition, the beryllium block, D_2O, and Moly target assembly[14] were included for the purpose of comparison.

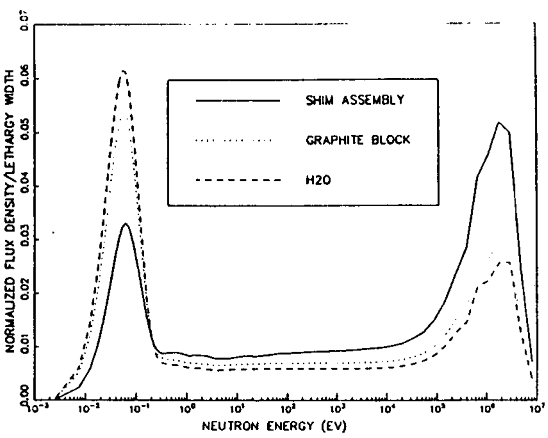

Fig. 3 Material-dependent Neutron Energy Spectra inside Flow Tube

The reactivity worth is a function of the energy-and-space dependent neutron flux densities. The environment condition produces the corresponding neutron flux distribution in the site where the absorber shroud occupies. Fig.3 compares the neutron flux spectra in the inner material inside the flow tube. WIMS-KAERI generates 69–group neutron spectra using the material volume specified by the spectrum options such as fuel(1), cladding(2), coolant(3), and moderator(4) by adopting the collision probability method. These spectra are used in condensing 69–group cross sections into the main transport groups. From those 4 types of the spectra, the representative neutron energy spectra for the region-of-interest was calculated by volume-averaging the respective spectra. For H_2O case, the neutron spectra is mostly thermalized in the inner material. Depending on the degree of the thermalization in the inner materials, the reactivity worth increases or decreases. Table 2 compares the reactivity worth of the control/shutoff shroud between the different materials inside the circular flow tube. For the cases of H_2O and Moly target fuel assembly, the reactivity worth of the absorber shroud increases by 11.06% and 3.14%, respectively, compared with that for the shim assembly case. For the other cases, the reactivity worth decreases by about 3%.

Table 2. Comparison of the Hafnium Absorber Shroud Reactivity Worth depending on the Inner Materials inside the Flow Tube

Inner Materials	K_{in}	K_{out}	Reactivity Worth(mk)[1]	Difference (%)[2]
Shim Assembly	1.064347	1.648201	332.8211	0.0
Graphite Block	1.072917	1.618199	314.0676	−5.63
H_2O	0.975252	1.524977	369.6282	11.06
Moly Target Fuel	1.045648	1.631163	343.2853	3.14
Beryllium Block	1.068246	1.628960	322.2254	−3.18
D_2O	1.068979	1.627724	321.1173	−3.51

Note : 1) The reactivity worth(mk) was calculated $(1/K_{in}-1/K_{out})\times 1000$ where K_{in} and K_{out} are the lattice infinite multiplication factor when the hafnium shroud is inserted and withdrawn, respectively.

2) The difference was calculated by comparing the reactivity worth of each case with the shim assembly case, i.e., $(\rho_{case}/\rho_{shim}-1)\times 100$.

Table 3. The Percent Contribution of the Neutron Absorption in the Hafnium Absorber Shroud Depending on the Inner Materials inside the Flow Tube

i) Spectral Contribution

Inner Material	Energy Group				
	1	2	3	4	5
Shim Assembly	0.4322	2.0631	46.3037	16.4499	34.7510
Graphite Block	0.4661	2.3221	48.4998	15.2528	33.4591
H_2O	0.3506	1.6567	40.1329	15.2897	42.5701
Moly Target Fuel	0.4200	2.0022	45.4191	16.2125	35.9462
Beryllium Block	0.4254	2.2694	48.4772	15.5836	33.2444
D_2O	0.4043	2.4141	49.5103	15.0104	32.6608

ii) Regional Contribution

Inner Material	Spatial Regiont				
	1	2	3	4	5
Shim Assembly	20.5759	13.9506	13.5833	19.0859	32.8043
Graphite Block	17.6266	13.2799	13.7161	19.9627	35.4146
H_2O	24.3607	14.9843	13.2156	17.6783	29.7611
Moly Target Fuel	21.1428	14.0902	13.5095	18.8635	32.3940
Beryllium Block	18.6148	13.4543	13.6214	19.6203	34.6892
D_2O	17.4742	13.3430	13.8155	20.0299	35.3373

+4.5mm thick hafnium shroud is divided into 5 parts with the same volume element

iii) Isotopic Contribution

Inner Material	Hafnium Isotope					
	Hf^{174}	Hf^{176}	Hf^{177}	Hf^{178}	Hf^{179}	Hf^{180}
Shim Assembly	0.3867	3.0076	61.5035	16.8731	13.3645	4.8646
Graphite Block	0.3885	3.1768	60.8201	16.5177	13.9556	5.1413
H_2O	0.4070	2.8631	62.6424	17.1825	12.1362	4.7688
Moly Target Fuel	0.3898	2.9967	61.6667	16.8977	13.1803	4.8688
Beryllium Block	0.3858	3.1663	60.9243	16.5176	13.8775	5.1287
D_2O	0.3876	3.2176	60.5383	16.4352	14.2080	5.2134

The absorption contribution also depends on the energy and space-dependent neutron fluxes. The regional % contribution illustrates the spatial self-shielding phenomena. In all the cases, the self-shielding effect occurs on both surfaces of the hafnium shroud, since the absorber is in a tube form. Table 3 compares the spectral, regional and isotopic % contribution of the neutron absorption in the hafnium absorber shroud. Some observations can be made from the results:

- The neutron absorption dominantly occurs in the resonant region ranging from 4 eV to 9118 eV(40.1−49.51%), and in the thermal region below 0.625 eV(32.7−42.6%). This firstly depends on behavior of the microscopic absorption cross sections of the hafnium isotopes along with the neutron energy and secondly on the neutron spectrum in the analyzed model.

—The segment facing the driver fuel assembly absorbs 29.8—35.4% neutrons and the inner segment contributes 17.7—24.4% absorption to the total neutron absorption by the shroud. The reason why the outermost segment shows major contribution to the total neutron absorptions is that the neutrons captured by the absorber are originated mostly from the surrounding driver assembly.

—Hf^{177} contributes 60.5—62.6% absorption to the total neutron absorption, regardless of the inner materials. Hf^{178} and Hf^{179} give 16.4—17.2% and 12.1—14.2% contribution, respectively.

The analyses for the absorption contribution helps the understanding of the trends of the reactivity worth variation according to the inner materials. The reactivity worth of the absorber shroud becomes larger :

—as the spatial self-shielding effect is smaller : H_2O case,

—as the neutron spectrum becomes softened: H_2O case,

—as the contribution of Hf^{177} and Hf^{178} is larger.

2. Absorber Thickness

The thickness of the hafnium shroud was also analyzed to know how the hafnium reactivity is related with the thickness of the hafnium shroud. The reference hafnium is 4.5 mm thick and three directions are considered in the change of thickness : inward, outward, and center point. The inward or outward direction mean that the inner or outer diameter is fixed and the thickness is reduced, respectively. The center point implies that the center point of the shroud is fixed and the thickness is diminished from both sides by the same amount. The fresh 18-element shim assembly and the graphite block are selected as the inner material inside the circular flow tube. Fig.4 illustrates % difference of the reactivity worth as a function of the outer surface area to volume ratio.

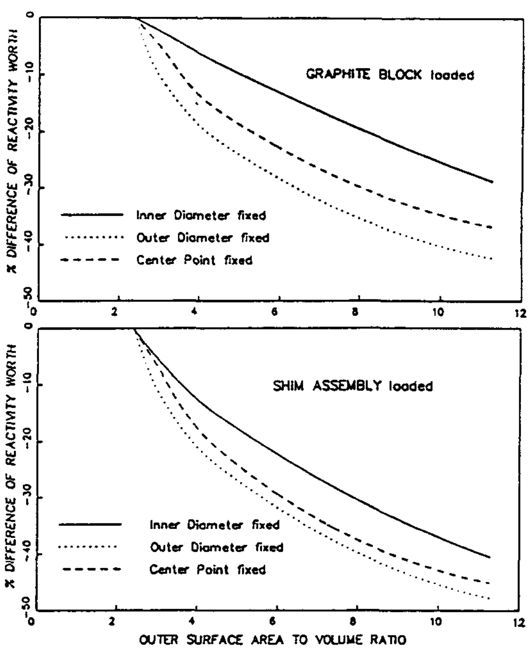

Fig. 4 % Difference of Reactivity Worth versus the Outer Surface Area-to-Volume Ratio

Table 4 summarizes the reactivity worth depending on the hafnium absorber thickness. The absorption capability of a strong absorber depends on the surface area facing on the dominant neutron multiplying media. Although the shim assembly is loaded inside the control shroud, the magnitude of contribution to the neutron production is larger from the surrounding driver assembly. Thus the reactivity woth of the absorber shroud becomes larger when the absorber shroud is squeezed outwardly than inwardly. This result verifies that the importance of the absorber material depends on the position where the absorber is located. Through analyzing the results, the followings can be mentioned :

—If the thickness of the shroud is reduced, the reactivity loss depends on the squeezed directions. If the clearance between the absorber shroud and the elongated inner core wall forces the absorber thickness to be reduced to 3.0 mm, the reactivity loss becomes 10—15% according to the squeezed directions.

Table 4. Reactivity Worth depending on the Absorber Position and Thickness

Thickness(mm)	K_{out}	K_{in}	Reactivity Worth(mk)	Difference(%)
Shim Assembly Contained				
O.D. Fixed				
0.9	1.648201	1.242662	198.0019	−40.51
1.8	1.648201	1.150143	262.7350	−21.06
2.7	1.648201	1.110424	293.8348	−11.71
3.6	1.648201	1.083221	316.4505	−4.92
4.5	1.648201	1.064347	332.8211	0.0
I.D. Fixed				
0.9	1.648201	1.281017	173.9076	−47.75
1.8	1.648201	1.193028	231.4812	−30.45
2.7	1.648201	1.144715	266.8578	−19.82
3.6	1.648201	1.103661	299.3532	−10.06
4.5	1.648201	1.064347	332.8211	0.0
Center Point Fixed				
0.9	1.648201	1.266523	182.8411	−45.06
1.8	1.648201	1.181463	239.6861	−27.98
2.7	1.648201	1.130053	278.1921	−16.41
3.6	1.648201	1.087900	312.4800	−6.11
4.5	1.648201	1.064347	332.8211	0.0
Graphite Block Contained				
O.D. Fixed				
0.9	1.618199	1.188056	223.7402	−28.76
1.8	1.618199	1.119120	275.5883	−12.25
2.7	1.618199	1.094005	296.1016	−5.72
3.6	1.618199	1.080037	307.9232	−1.96
4.5	1.618199	1.072917	314.0676	0.0
I.D. Fixed				
0.9	1.618199	1.251461	181.0951	−42.34
1.8	1.618199	1.181011	228.7612	−27.16
2.7	1.618199	1.141856	257.7962	−17.92
3.6	1.618199	1.108077	284.4934	−9.42
4.5	1.618199	1.072917	314.0676	0.0
Center Point Fixed				
0.9	1.618199	1.224950	198.3889	−36.83
1.8	1.618199	1.157717	245.7980	−21.74
2.7	1.618199	1.120839	274.2178	−12.69
3.6	1.618199	1.088708	300.5490	−4.30
4.5	1.618199	1.072917	314.0676	0.0

3. Absorber Burnout

As the fuel burnup progresses the composition of the natural hafnium in the control shroud varies due to neutron exposure. One isotope changes to the next one by capturing neutron. Thus the dependence of the neutronic properties on the hafnium isotope number density change should also be investigated. For this, the control lattice is analyzed using the supercell modeling technique and the fuel undergoes the burnup at the power level derived from the fuel management study, i.e., 356.68 MW/MTU. From this analysis, the isotopic number densities of the hafnium shroud are retrieved. The analyses shows that the atomic number densities from Hf^{174} to Hf^{177} decreased by the neutron capture but Hf^{178} to Hf^{180} atomic number densities increased owing to compensation by the lower mass isotope.

The basic cross section data for the respective hafnium came from JENDL-2 files[15] and Hf^{174} is assumed to be directly changed to Hf^{176} by capturing one neutron, because Hf^{175} does not exist in a natural state. This assumption is physically acceptable due to the negligible contribution of Hf^{174} and Hf^{176} to the total absorption of the natural hafnium. Using this hafnium isotopic number densities and the fresh fuel assembly design data, the control lattice is reanalyzed using the model shown in Fig.2.

As the hafnium burns out, the reactivity worth of the hafnium decreases. However, the loss of the reactivity worth due to the burnout is small, because capture in one isotope frequently produces another isotope still having good neutronic capture properties. Table 5 summarizes the lattice multiplication factor along with the reactivity worth of the hafnium shroud during the hafnium burnout. Even though the control shroud is inserted into the core during 450 FPDs (Full Power Days), the reactivity is decreased by 5.0% compared with fresh hafnium shroud.

Table 5. Reactivity Worth Variation during Hafnium Depletion

Full Power Days[1]	K_{in}	K_{out}	Reactivity Worth(mk)	Difference(%)
0	1.064347	1.648201	332.8211	0.0
4	1.064464	1.648201	332.7178	−0.03
10	1.064647	1.648201	332.5563	−0.08
50	1.065869	1.648201	331.4795	−0.40
100	1.067462	1.648201	330.0794	−0.82
150	1.069153	1.648201	328.5977	−1.27
200	1.070962	1.648201	327.0178	−1.74
250	1.072919	1.648201	325.3147	−2.26
300	1.075070	1.648201	323.4499	−2.82
350	1.077484	1.648201	321.3659	−3.44
400	1.080272	1.648201	318.9707	−4.16
450	1.083626	1.648201	316.1055	−5.02

Note: 1) The Full power Days mean that the hafnium is irradiated at a constant power level of 356.68 MW/MTU.

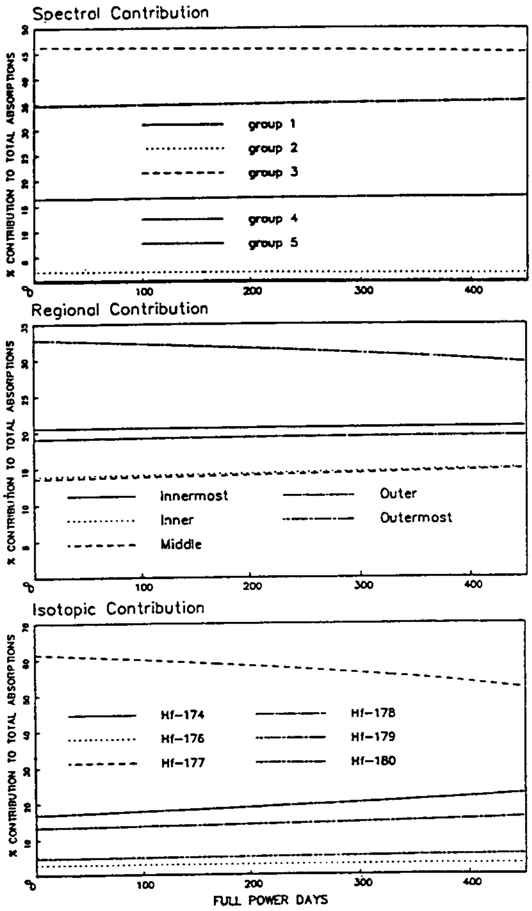

Fig. 5 % Contribution to Total Absorptions during Hafnium Depletion

Fig. 5 illustrates the spectral, regional and isotopic % contributions of the neutron absorption in the hafnium absorber during the hafnium isotopic number density change. Along with the change of the isotopic composition in the hafnium shroud,

- The spectral contribution is almost equal to the fresh hafnium shroud case, but the thermal contribution becomes slightly greater while the resonance contributes smaller portion compared with the natural hafnium case,
- The outermost segment provides less contribution (29.7%) to the total neutron absorption than the fresh hafnium case (32.8%), since Hf^{177} in outermost segment is burned out faster than that in the other segments,
- The decrease of Hf^{177} number density yields the contribution of Hf^{177} to be smaller by 11.5% while Hf^{178} and Hf^{179} contribution becomes larger by 5.8% and 2.6%, respectively, if the control shroud is inserted into the core during 450 FPDs.

4. Fuel Burnup

To take into account the fuel burnup impact on the hafnium sbsorber characteristics, two kinds of fuel burnup model were assumed. Firstly, as the fuel burnup proceeds, the compositions of both the inner shim assembly and the outer driver assembly are considered to be changed. This fuel burnup may give impact on the reactivity characteristics of the hafnium shroud. The shim lattice without the hafnium shroud is modeled using supercell approach and the burnup-dependent nuclide number densities of the fuel materials are retrieved from the results. Using these nuclide number densities of the fuel materials and the fresh natural hafnium data, the control lattice with the hafnium shroud is reanalyzed.

Secondly, the environment was constituted using the results of the fuel management study. The fuel management study shows that the average exit burnup of the 36-element driver fuel assembly is about 120,000 MWD/MTU and thus it is appropriate that the average burnup of the 36-element driver assembly surrounding the 18-element shim assembly is assumed to be about 60,000 MWD/MTU. Using the nuclide number densities coming from the burnup calculation for both the driver (single lattice model) and the shim assembly (supercell model), the control lattice is recalculated according to the burnup of the inner shim assembly while the surrounding driver fuel assembly assembly burnup is fixed at 61,639 MWD/MTU.

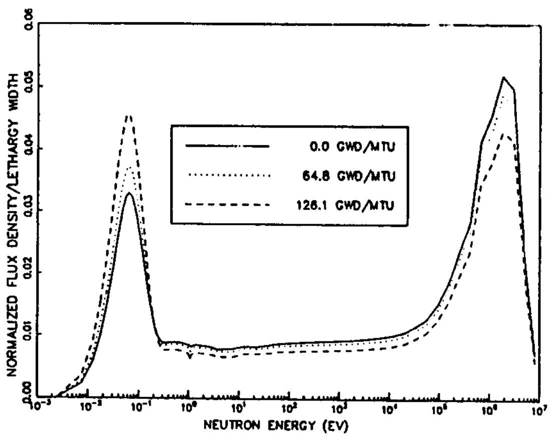

Fig. 6 Burnup-dependent Neutron Energy Spectra in Shim Assembly

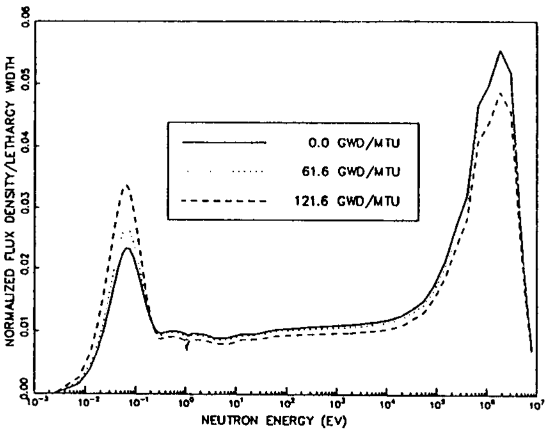

Fig. 7 Burnup-dependent Neutron Energy Spectra in Driver Assembly

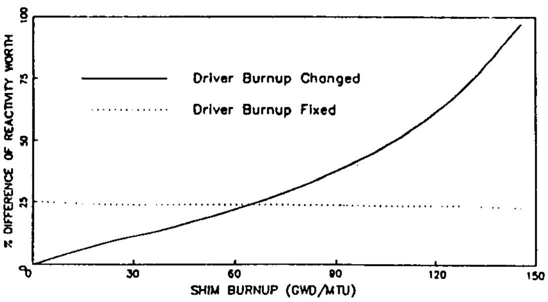

Fig. 8 Variation of Reactivity Worth % Difference during Fuel Burnup

Fig.6 shows the burnup-dependent neutron spectra inside the flow tube in the system used in analyzing the shim assembly. The burnup-dependent neutron spectra for the driver fuel assembly are shown in Fig.7. All figures verifies that the fuel burnup makes the neutron spectra be softened. Fig.8 compares the reactivity worth of the hafnium shroud in the KMRR as a function of the fuel burnup. Since the fuel burnup yields softer neutron spectra, the fuel burnup significantly increases the reactivity worth of the hafnium shroud in the KMRR. Assuming that the average burnup of the driver fuel assembly is about 60,000 MWD/MTU, the reactivity worth gain is about 25% compared with fresh clean fuel case. This phenomenon is similar to the PWR control rod case.[16] The higher the fuel enrichment of the fuel elements enclosing the control rod, the lower the reactivity worth of the corresponding control rod. Therefore the reactivity worth of the hafnium shroud becomes larger as the fuel burnup proceeds.

Fixing the driver assembly burnup, the shim assembly burnup slightly reduced the reactivity worth, because the importance of the burned shim assembly becomes smaller compared with that of the fresh shim assembly.

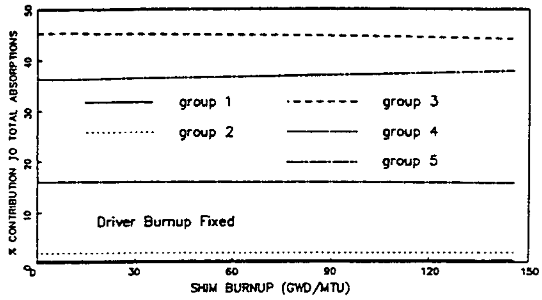

Fig. 9 Spectral Contributions to Total Absorptions during Fuel Burnup

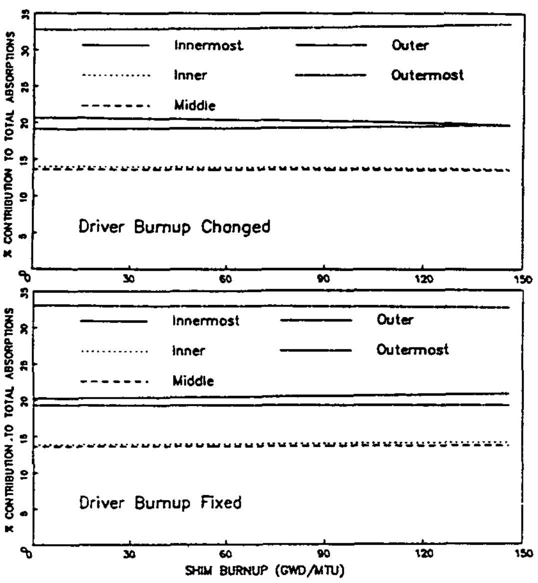

Fig. 10 Regional Contributions to Total Absorptions during Fuel Burnup

Fig.9 and 10 show the spectral and regional contribution to the neutron absorption in the hafnium absorber, respectively, during the burnup of both the shim and the driver fuel assembly. From the figures, the followings are derived:

—The neutrons are dominantly absorbed in the resonant energy region from 4 eV to 9118 eV for the fresh fuel assembly case while after a fuel burnup of 120,000 MWD/MTU the thermal absorption below 0.625 eV leads the absorption contribution in the hafnium shroud. The variation of the absorption contribution from the fresh to the final burnup is:

for both assembly burnup,

the resonant contribution: 46.3% to 34.7%(−7.6%)

the thermal contribution: 34.7% to 51.1% (+16.4%)

for fixed burnup of the driver assembly,

the resonant contribution: 45.2% to 43.4%(−1.8%)

the thermal contribution: 36.3% to 38.8%(+2.5%)

—The regional contribution is almost unchanged during the fuel burnup.

for both assembly burnup,

the outermost segment contribution: 32.8% to 34.5%(+1.7%)

the innermost segment contribution: 20.6% to 18.6%(−2.0%)

for fixed burnup of the driver assembly,

the outermost segment contribution: 33.0% to 32.3%(−0.7%)

the innermost segment contribution: 20.3% to 21.1%(+0.8%)

IV. Conclusion

The KMRR control/shutoff shroud may contain the fuel assembly in the normal operation. This is primarily different from the power reactor control rod design policy. In this paper, 4 kinds of the environmental effect on the hafnium absorber characteristics were analyzed. The inner materials inside the absorber shroud, the hafnium isotopic number density variation, the different fuel properties, and the thickness of the absorber shroud were included in the investigations, in which the variations of the reactivity worth and the absorption contribution are focused. The following remarks may be derived from the analyses:

—The dominant isotope in the neutron absorption is Hf^{177} and its contribution is nearly 60%.

—The outer segment absorbs more neutrons (about 30%) compared to other segment and this illustrates the spatial self-shielding effect on the surface of the absorber shroud.

—The resonance (4eV−9118eV) and the thermal (<0.625eV) energy region accounts for about 80% neutron absorption.

—The hafnium burnout diminishes the reactivity worth of the absorber shroud but the loss is minimal, about 5%, even thouth the hafnium shroud is burned during 450 FPDs.

—The fuel burnup significantly increased the hafnium reactivity worth. When the average burnup of the driver fuel assembly is assumed to be 61,639 MWD/NTU, the reactivity increase is 25% compared with the case of the fresh fuel assembly.

—The hafnium thickness is directly biased to the surface area of the absorber shroud and the reactivity worth is almost inearly dependent on the outer surface area to volume ratio.

This analysis was performed under two assumptions that the control/shutoff lattice is surrounded by the driver fuel assembly only and the KMRR core periodically consists of the modeled system. However, the actual environment of the control/shutoff lattice is partly D_2O and mainly the driver fuel assembly, and moreover the KMRR core is strongly heterogeneous. The neutron mean free path is considerably large in D_2O compared to the driver fuel assembly. Thus the eccentric boundary condition should be tested to determine the accurate neutron flux distribution inside the control/shutoff lattice. The appropriate neutron flux distribution gives the accurate reactivity worth of the absorber and the reaction contribution. From the lattice analyses, the reduction of the absorber shroud thickness from 4.5mm to 3.0mm decreases the absorber reactivity worth by 15% but the driver fuel burnup increases the worth by 25%. This gain and loss of the reactivity worth is based on the lattice analyses results. Therefore the overall reactor modeling is necessary to get the more accurate gain and loss of the reactivity worth coming from the environment effect and the thickness change.

Reference

1. T.F. Ruane and M.L. Storm, "Epithermal Hafnium Parameters for the Calculation of Control Rod Worth in Thermal Reactors", Nucl. Sci. Eng., 6, 119–127(1959)
2. C.W. Maynard, "Blackness Theory and Coefficients for Slab Geometry", Nucl. Sci. Eng., 6, 174–186(1959)
3. E.P. Gyftopoulos and L.D. Sobrino, "Variational Calculation of Control Rod Reactivity", Nucl. Sci. Eng., 6, 135–139(1959)
4. H. Aisu, "Effective Surface of a Tubular Absorber in the Calculation of Resonance Integrals", Nucl. Sci. Eng., 21, 250–255(1965)
5. W.J. Eich et al., "Calculation of Reactivity Worth of Rod-Cluster Control Elements and Correlation of Theory with Experiment", Nucl. Sci. Eng., 24, 272–283(1966)
6. E. Saji, et al., "Control Rod Worth in High Conversion PWR," J. Nucl. Sci. Tech., 23, 745(1988)
7. H.B. Choi, "WIMS Modification Deck for Data Transfer", KAERI Internal Report, 1987.
8. J.R. Askew, et al., "A General Description of the Lattice Code WIMS", J. Brit. Nucl. Energy Soc., 5, 564, 1966.
9. M.J. Halsall, "A Summary of WIMSD4 Input Options", AEEW-M1327, U.K., 1980.
10. M.J. Halsall, "Recent Adjustment to the WIMS Nuclear Data Library", AEEW-R1492, U.K., 1982.
11. R. Chawla, "An Assessment of Methods and Data for Predicting Integral Properties for Thermal Reactor Physics Experiments", AEEW-R797, U.K., 1972.
12. H.R. Kim, et al., "Validation of Lattice Design Code 'WIMS-KAERI' and its Library", KAERI Internal Report, 1987.
13. B.G. Kim, "The Fuel Management Calculations", KAERI Technical Note, TN–DA–002, 1988.
14. H.J. Smith, "Revision 3 of Specifications for Physics Calculations on the MAPLE–X10 Reactor", Technical Note, SAB–701.001/mx10–03100–200–TN(Rev. 3) WNRE, AECL, 1988.
15. T. Nakagawa, "Summary of JENDL–2 General

Purpose File", JAERI-M 84–113, JAERI, 1984.
16. H.R. Kim, "On the Reactivity Worth of Control Rod in PWRs", KAERI Internal Report, 1988.