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■ 論 文 ■

Nuclear Energy Depositions in the Primary End Shields and Side Primary Shield Systems

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ABSTRACT

It was carried out to analyze the nuclear energy deposition rates for the bulk shield components including materials of the primary end shield and side primary systems of Wolsong 2 during steady state operations at 100% full power using ANISN code. This paper has been prepared to support system design of Wolsong 2.

Key words : Wolsong 2, ANISN, neuclear energy deposition

INTRODUCTION

The nuclear radiation absorbed in the lattice cell components (viz., fuel, fuel sheath, coolant, pressure tube, calandria tube and moderator), other in-core components (viz., reactivity mechanisms especially adjuster rods and their guide tubes) and materials and structures outside the reactor core (viz., reflector, calandira shell, vault water, primary end shields, primary side shields) generate heat, which in turn sets up thermal stresses in the structures. This paper presents the heat deposition rates and the total heating in the end shield and side shield systems (bulk shields) during full power operation.

The up-to-date reactor physics analysis of the reactor core for Wolsong 2[1] showed slight changes in the bundle power distribution which has some effect on the energy escaping from the core. The heating calculations performed with the current core bundle power distribution showed that there will be an increase in the energy deposited in the end shield components reported in Shielding Design Manual[2], although no significant changes were observed in the side shield heat deposition rates.

There is not any acceptance criterion for providing the nuclear heat generation rates other than usual checks which are normally done throughout the calculation process. These checks will ensure that the analysis input information are up-to-date and the results obtained are realistic with respect to similar calculations made for other operating CANDU reactors or available measured data.

It was assumed that moderator and end shield cooling systems are operating properly, i. e., no accident scenarios regarding loss of end shield cooling and moderator flow or loss of inventory(low level).

CALCULATION METHOD

The source specifications for the axial and radial ANISN[3] calculations for the primary end shields and side shield were taken from the core bundle power disrtibution calculated by the FMDP[4] code reported in Shielding Design Manual[2]. The slab geometry model of the end shield was based on dimensions given in engineering design[5] The cylindrical geometry calculation for the side primary shield used data given in the other engineering drawings[6] A one-dimensional discrete ordinates transport code ANISN was used to calculate the heat deposition rates and the total heating in a) the calandria side tubesheet, carbon steel balls and water region, fuelling machine tubesheet of primary end shield and b) the reflector, the calandria shell, the vault water, the reactor vault concrete and the reactor wall concrete of the side primary shield. The slab and cylindrical geometry representation of the reactor core and primary shield regions was made in the ANISN calculations.

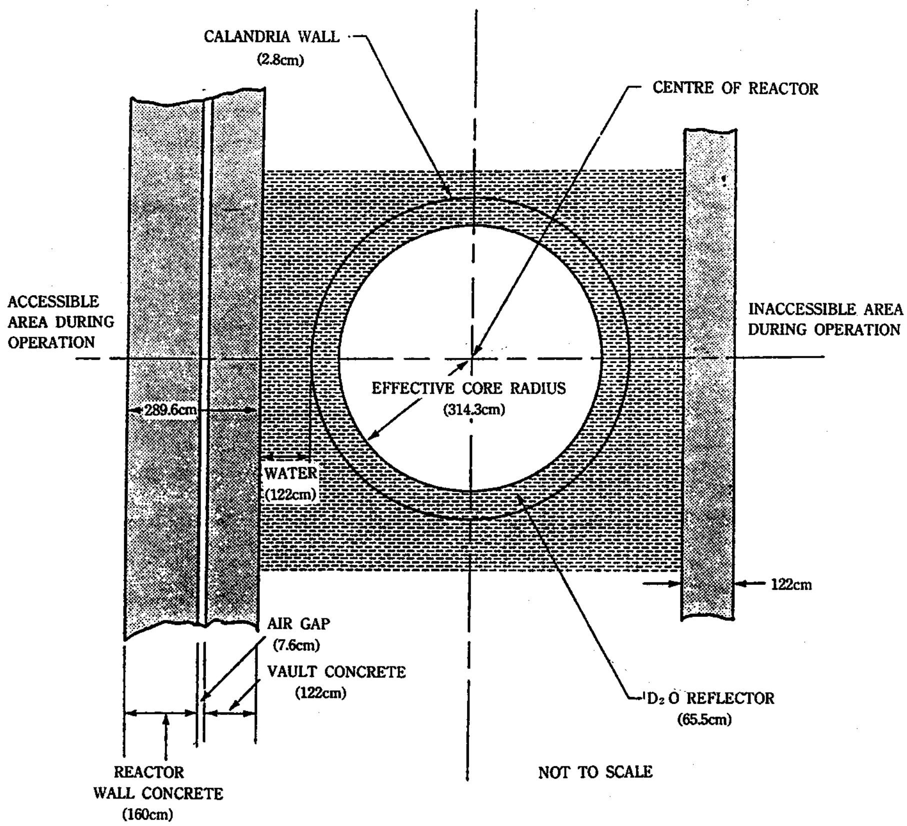

FIGURE 1. Side Primary Shield System

Heat Deposition Rates Calculation in the Side Primary Shield

The side primary shield system at the 'D' side shown in Figure 1 and consists of the following:

1. vault water, 122 cm at the horizontal mid-plane
2. steel liner, 0.635 cm
3. vault concrete, 122cm
4. air-gap, 7.62 cm and
5. reactor wall concrete, 160 cm

A one dimensional discrete ordinates transport code ANISN was used in cylindrical geometry to calculate the heat deposition rate and the total heating in each shield component. A 38 energy group scheme which consists of 27 neutron energy groups and 11 gamma energy groups was used for this analysis, where 27 neutron energy groups include seven fast neutron groups, 19 intermediate neutron groups, and one thermal neutron group. The energy group scheme is taken from GAM II[7]. The number of neutrons per fission event was taken to be 2.62. The gamma source spectrum was calculated using ORIGEN[8] with the gamma spectrum from ORIGEN repartitioned into the eleven gamma group scheme of ANISN.

The radial fission density distribution on the central plane of the reactor calculated from Fuel Management Report[1] is shown in Figure 2. A interpolation code, SOURCE was used to calculate 38 group neutron-gamma source distribution in the 51 core meshes of ANISN. The fission density was 2.82×10^{11} fissions/cm$^3\cdot$ s.

To reduce the ANISN core memory require ments, a group independent tape has been prepared using the TAPEMAKER code, which is part of ANISN. The microscopic cross-sections from the library have been mixed in the same run to obtain the macroscopic cross-sections for the materials in Table 1. The atomic densities of the core elements, which were derived from the lattice cell composition used in POWDERPUFS V[9] run, are shown in Table 2.

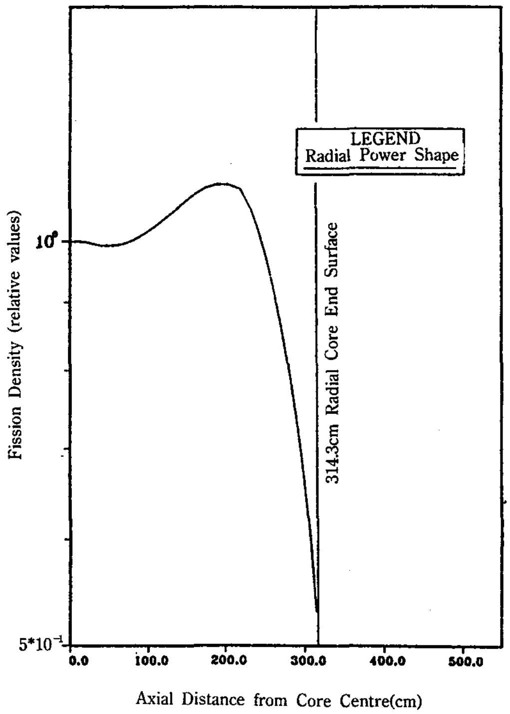

Figure 2. Radial Power Shape Along Central Plane of Fuel Channels Used in ANISN Calculation

A P_3 order of scattering and S_8 order of angular quadratures were used. The core and shield region numbers, number of meshes in each region and their dimensions are shown in Table 3. It should be noted that the air space between the vault water concrete and reactor wall concrete has been suppressed in the calculations.

Table 1. Element Atomic Densities for the Materials Used in TAPEMAKER Calculation

#	Material	Element	Atomic Density [(atoms/cm^3) X 10^{-24}]
1	Core	H	1.097E-4
		D	5.638E-2
		O	2.825E-2
		Zr	1.443E-3
		U-235	8.605E-6
		U-238	1.187E-3
2	D_2O Reflector	H	1.839E-4
		D	6.599E-2
	(ρ=1.1 g/cm^3)	O	3.309E-2
3	Zr	Zr	4.325E-2
4	H_2O	H	6.639E-2
		O	3.346E-2
5	Stainless Steel 304L	C	1.387E-4
		Si	1.271E-3
	(ρ=7.9 g/cm^3)	Cr	1.734E-2
		Mn	1.732E-3
		Fe	5.812E-2
		Ni	8.107E-3
6	Stainless Steel 410	Si	1.670E-3
		Cr	1.080E-2
	(ρ=7.9 g/cm^3)	Mn	8.550E-4
		Fe	7.220E-4
7	Carbon Steel ball/H_2O	H	2.674E-2
	(60/40 Region)	C	7.794E-4
		O	1.337E-2
		Si	2.525E-4
		Mn	5.010E-4
		Fe	5.002E-2
8	Ordinary Concrete	H	9.583E-3
		C	1.143E-2
	(ρ=2.3 g/cm^3)	O	4.531E-2
		Mg	6.018E-3
		Al	1.534E-4

Table 1 (Continued)

#	Material	Element	Atomic Density [(atoms/cm^3) X 10^{-24}]
		Si	1.783E-3
		Ca	7.498E-3
		Fe	1.112E-4
9	Ilmenite Concrete	H	4.618E-3
		C	8.930E-4
	(ρ=3.36 g/cm^3)	O	4.293E-2
		Mg	1.257E-3
		Al	1.598E-3
		Si	2.507E-3
		Ca	8.983E-3
		Fe	1.431E-2
10	Air*	O	4.536E-5

* Treated as oxygen.

Table 2. Lattice Cell Composition for Wolsong 2 from POWDERPUFS-V Used in TAPEMAKER

	Volume/cm [cm^2]	ρ [g/cm^3]
Fuel(UO_2)	41.000	10.67
Sheath(Zr)	6.828	6.55
Coolant*	34.734	0.82 (287.5℃)
Presure Tube	14.697	6.55
Calandria Tube	5.721	6.55
Moderator*	680.201	1.09 (68℃)
Void	33.349	
Total	816.531	

* Coolant and moderator purity: 99.811%.

Heat Deposition Rates Calculation in the Primary End Shields

The primary end shield system consists of the following (see Figure 3) :

1. calandria side tube sheet, 5.08cm

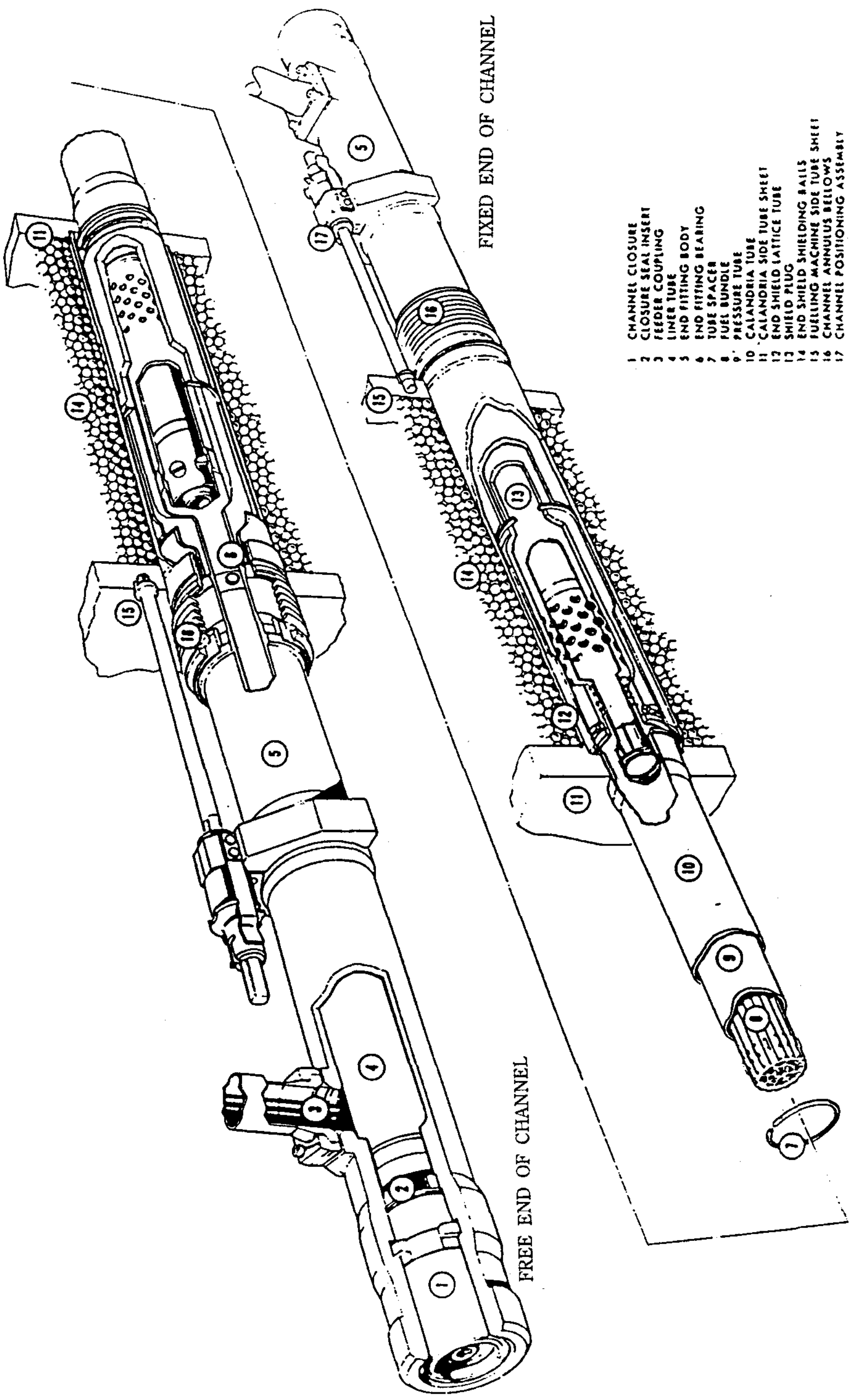

Figure 3. Fuel Channel Assembly

2. end shield shielding balls(carborn steel balls/water region), 78.4cm and
3. fuelling machine side tube sheet, 7.62cm.

An ANISN code was used in slab geometry to calculate the heat deposition rate and the total heating in each shield component. As mentioned above, a 38 energy group scheme was used for this analysis.

The axial fission density distribution on the horizontal mid plane of the reactor is shown in Figure 4. A interpolation code, SOURCE was used to calculate 38 group neutron-gamma source distribution in the 85 core meshes of ANISN.

The macroscopic cross sections for the material present in the core and shield regions in the form required by ANISN has been calculated using TAPEMAKER, which is part of ANISN.

A P_3 order of scattering and S_{16} order of angular quadratures were used. The core and shield region numbers, numbers of meshes in each region and their dimensions are shown in Table 4.

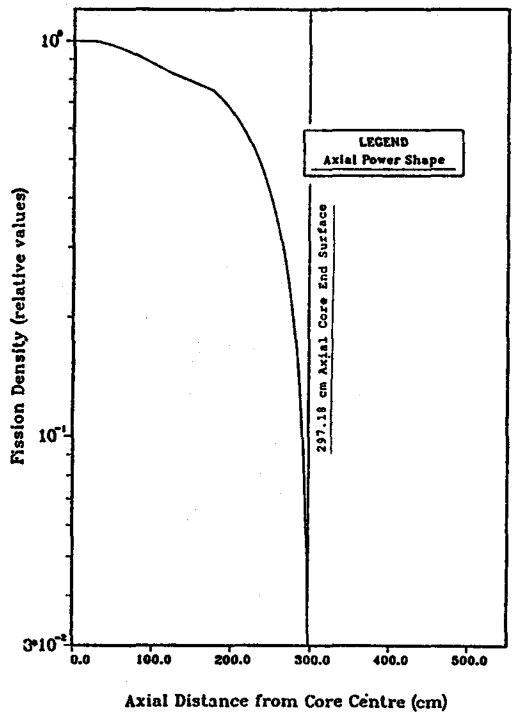

Figure 4. Axial Power Shape Along Horizontal Mid-Plane of Fuel Channels Used in ANISN Calculation

Table 3. Region Dimensions and Number of Meshes Used in Side Shield ANISN Calculation

Region	Region ID	Number of Meshes	Thickness (cm)	Radial distance form Core Centre (cm)
1	Core	51	314.30	314.30
2	Reflector	36	65.46	379.76
3	Calandria Wall	5	2.858	382.62
4	Vault Water	80	121.92	504.54
5	Liner	5	0.635	505.17
6	Concrete I	40	121.92	627.09
7	Concrete II	80	160.02	787.11
8	Air I	5	700.00	1487.11
9	Air II	6	975.00	2462.11
	Total	308		

RESULTS AND DISCUSSION

Heat Deposition Rates in the side Primary Shield

ANISN multiplied the neutron and gamma fluxes with the appropriate response functions (i. e., the energy deposition rates per unit flux) and summed over all the energy groups to calculate the heating values. The heat deposition rate distributions in the reactor central plane for the reflector, calandria shell, the vault water, steel liner and the concrete walls are shown in Figures 5 to 9.

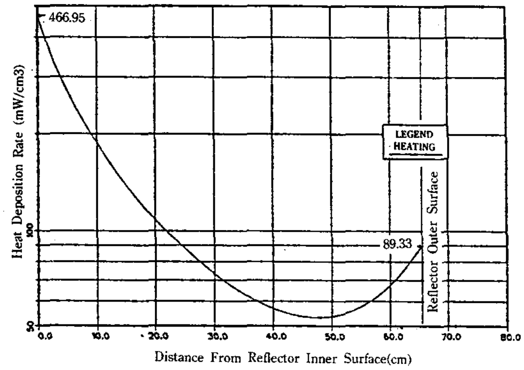

Figure 5. Heat Deposition Rate in The Reflector Through The Radial Shield System During Full Power Operation(ANISN)

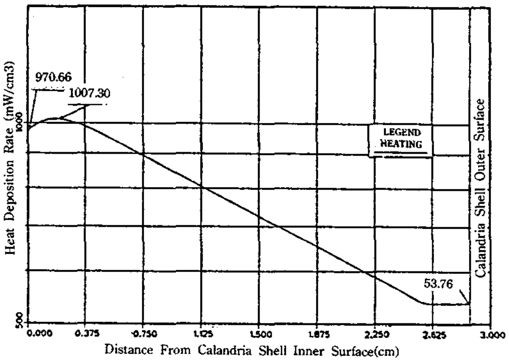

Figure 6. Heat Deposition Rate In The Calandria Shell Through The Radial Shield System During Full Power Operation(ANISN)

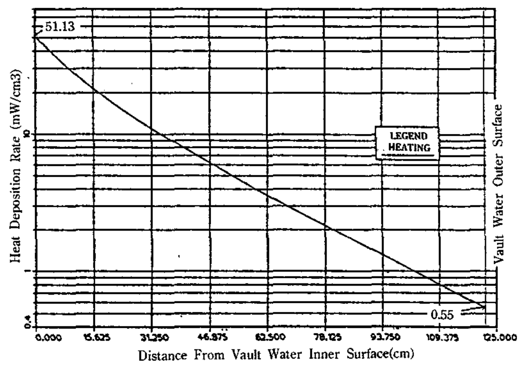

Figure 7. Heat Deposition Rate In The Vault Water Through The Radial Shield System During Full Power Operation (ANISN)

TABLE 4. Region Dimensions and Number of Meshes Used in End Shield ANISN Calculation

Region	Region ID	Number of Meshes	Thickness (cm)	Axial distance form Core Centre(cm)
1	Core	85	297.18	297.18
2	Calandria Side Tube Sheet	10	5.08	302.26
3	60/40 Region	90	78.4	381.00
4	Fuelling Machine Tube Sheet	15	7.62	388.62
5	Concrete*	20	30.48	419.10
6	Concrete*	50	70.20	495.30
	Total	270		

* The concrete regions were added after the fuelling machine tubesheet for dose rate calculation purposes only.

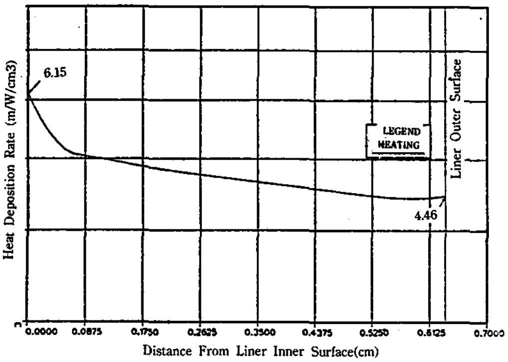

Figure 8. Heat Deposition Rate In The Liner Through The Radial Shield System During Full Power Operation(ANISN)

The total neutron and gamma energies deposited in the side shield system (based on the distribution given in Figures 5 to 9) were calculated from the ANISN run. The total nuclear energy depositions in the side shield components during reactor operation are shown in Table 5. The one dimensional cylindrical geometry calculation performed by ANISN does not take account of the finite length of the core and assumes that the axial power shape is flat.

The total neutron and gamma energy deposited in the calandria is multiplied by the length of the core (594.4cm) and the axial form factor at the

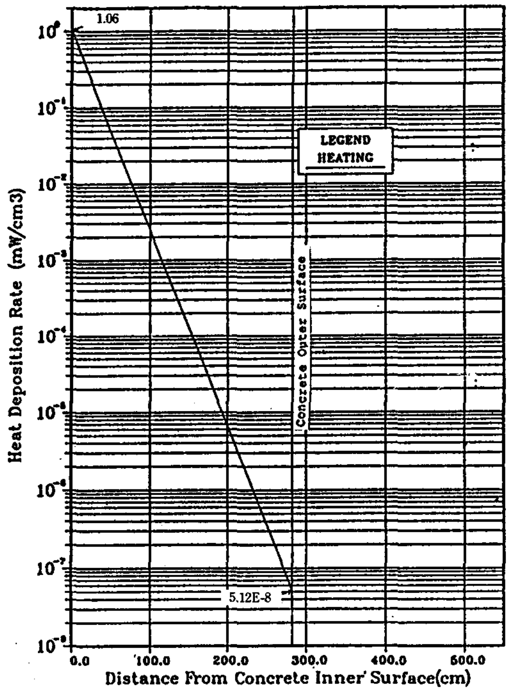

Figure 9. Heat Deposition Rate In The Concrete Through The Radial Shield System During Full Power Operation(ANISN)

core edge (0.635) to find the total energy deposition of 2.00MW. Also the total energy depositions in the refector, the vault water, the steel liner and the vault concrete are 5.90MW, 1.00MW,

TABLE 5. Total Heating in Side Shield Componets During Reactor Operation

Component	ANISN Heating (mW/cm)			Total (MW)
	Neutron	Gamma	Total	
Reflector	1.54 E6	1.41 E7	1.57 E7	5.9
Calandria Shell	1.73 E1	5.30 E6	5.30 E6	2.0
Vault Water	2.37 E2	2.72 E6	2.72 E6	1.0
Liner	3.83 E-6	9.52 E3	9.52 E3	4.0 E-3
Concrete	1.95 E-3	5.63 E4	5.63 E4	2.1 E-2

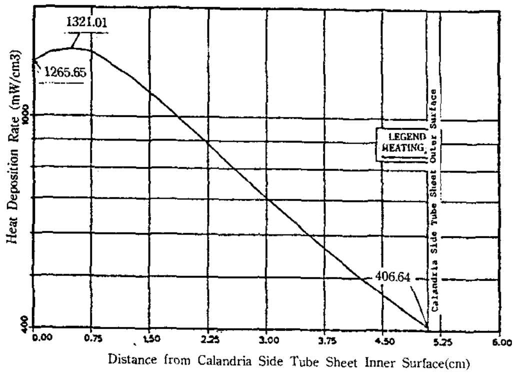

Figure 10. Heat Deposition Rate In The Calandria Side Tube Sheet Through The Axial Shield System During Full Power Operation(ANISN)

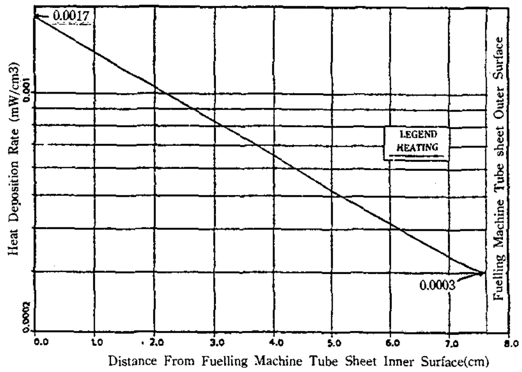

Figure 12. Heat Deposition Rate In The Fuelling Machine Tube Sheet Through The Axial Shield System During Full Power Operation(ANISN)

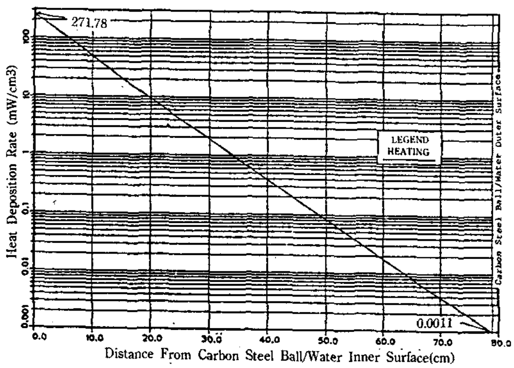

Figure 11. Heat Deposition Rate In The Carbon Steel Ball/Water Region Through The Axial Shield System During Full Power Operation(ANISN)

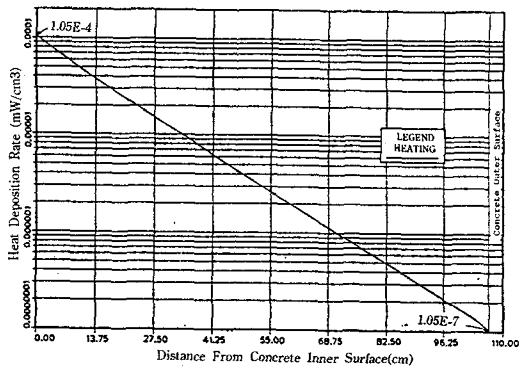

Figure 13. Heat Deposition Rate In The Concrete Through The Axial Shield System During Full Power Operation(ANISN)

4.0 kW and 21.0kW at full power respectively.

Heat Deposition Rates in the primary End Shields

ANISN mulplied the neutron and gamma fluxes with the response functions as mentioned above. The heat deposition rate distributions in the reactor horizontal mid plane for the calandria side tube sheet, carbon steel balls/water region, fuelling machine tube sheet and concrete walls are shown in Figures 10 to 13.

The total neutron and gamma energies deposited in the end shield system were calculated from the ANISN run. The total nuclear energy depositions in the end shield components during reactor operation are shown in Table 6.

The total neutron and gamma energies deposited in the calandria side tube sheet are 0.015W/cm^2

TABLE 6 Total Heating in Two End Shield Components During Reactor Operation

Component	ANISN Heating (mW/cm^2)			Total(MW)
	Neutron	Gamma	Total	
Calandria Side Tube Sheets	1.53 E1	4.35 E3	4.37 E3	1.91
Carbon Steel Ball/Water Regions	5.00 E1	1.67 E3	1.72 E3	0.75
Fuelling Machine Tube Sheets	8.20 E-6	5.95 E-3	5.96 E-3	2.60 E-6

and 4.353W/cm^2 respectively, a total of 4.368W/cm^2. This value is multiplied by the area of the two end shields(2×380 channels×28.575cm^2) and the radial form factor at the core end(0.703) to find the total energy deposition of 1.91 MW. The carbon steel balls and water region(60/40 region) consists of 60% steel and 40% water. The total neutron and gamma energies deposited in the 60/40 rigion (one end shield) are 0.050W/cm^2 and 1.671W/cm^2. Using the method given above, the total energy deposited in the two 60/40 regions is 0.75MW at full power. And the total neutron and gamma energies deposited in the fuelling machine tube sheet are 8.20×10^{-6} mW/cm^2 and 5.95×10^{-3} mW/cm^2 respectively, a total of 5.96×10^{-3} mW/cm^2. Using the method given above, the total energy deposited in the two fuelling machine tube sheet is 2.6×10^{-6} MW at full power, i. e., not significant. The total neutron and gamma energies deposited in the end shield ring will be calculated using DOT IV code although it is expected that the value will be negligible.

Although it leaves something to be desired in view of no comparing the nuclear heat deposition rates in CANDU reactor systems from this analysis with any comparable data which is not available at this time, these data resulted from an use of ANISN, the verified computer code about radiation shielding analysis, can be used as an actual data.

CONCLUSION

The heat deposition rates due to gammas and neutrons in the side primary shield and the primary end shield systems during full power operation were determined from the radial and the axial ANISN calculations. The data resulted from this analysis as an application to the power reactor, especially CANDU reactor, can be used to support system design of Wolsong 2. And it is significant that the technology about the nuclear heat depositions of CANDU reactor were maintained following this analysis under the circumstance to be constructed more CANDU reactors in Korea.

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월성 2호기 종단 및 측면 차폐체에의 핵에너지축적 해석

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요 약

월성 원자력 발전소 2호기의 1차 종단 및 측면 차폐 계통의 각 차폐체에 대한 100% 출력 가동시 핵에너지 축적율 해석을 ANISN 코드를 이용하여 수행하였다. 본 해석 결과는 월성 원자력 발전소 2호기 계통 설계시 고려 사항으로 이용될 수 있다.

Key words : 월성 원자력 발전소 *2*호기, *ANISN*, 핵에너지축적