Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

A New Design of High Flux Research Reactor (HFRR) for the Developing Countries

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1. Introduction

In the previous study, the preliminary conceptual design of 10 MW research reactor was proposed with the purpose to have high flux especially for production of radioisotopes in developing countries. [1] Some basic design parameters of proposed design are described in Table 1.

Table 1. Basic design parameters

Parameter	HFRR
Power	10 MWth
Pressure	2 atm
Rx type	Tank pool
Fuel	U_3Si_2-Al (19.95% U235)
Fuel type	Tubular type, (1x8) , (1x3)
Fuel cladding	Al-Fe-Ni alloy
Active fuel length	50 cm
# of assemblies	25
Control rod material	B_4C
Control rod cladding	Zircaloy
Moderator matrix	Al or graphite
Coolant	H_2O, upward force convection
Reflector	D_2O
Flux level	>1E+14 n/cm^2-s (core)
Cycle length	1 month

As shown in figure 1, three kinds of fuel assemblies are used in that core. Each assembly is made up of tubular plate type fuels. The fuel meat is uranium silicate dispersive in aluminum and enrichment does not exceed 20% U-235. [2] One (1x3) fuel assembly is named as Assembly with Irradiation Hole (AIH) because its central part would be use as in-core irradiation site. The other fuel assemblies are (1x8) that can be hosted by moderator filler or control rod. They are known as Assembly with Moderator Filler (AMF) and Assembly with Control Rod (ACR).

(a) AIH (b) AMF (c) ACR
Figure 1. Assembly compositions

Each assembly has no stiffeners and is fixed in the upper and lower ends with a head and a tail. Assemblies are embedded as rectangular array into the moderator matrix that may be either aluminum or graphite and coolant is force convection water as shown in figure 1. [3]

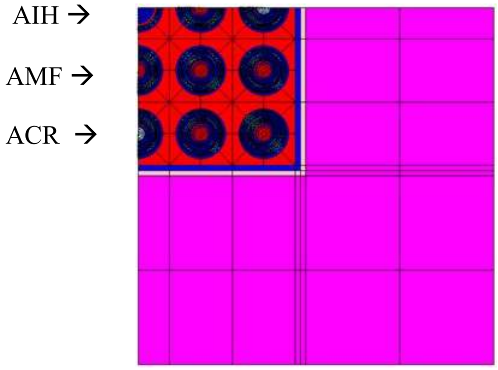

Figure 2. Conceptual quadrant core design

Core is square and moderator matrix is surrounded by 1 cm of thin water layer for matrix cooling. Reactor vessel is made up of Stainless Steel 304 with thickness of 1 cm as gamma shielding and 36 cm thick of heavy water outside the vessel reflects neutrons back into the core and maintain the nuclear reaction.

2. Results and Discussion

Reactor core is a square and 25 assemblies are located as 5x5 rectangular arrays in moderator matrix. The flux evaluations in quadrant core including reflector region was carried out. The optimized values in this proposed design are shown in Table 2. The reflector dimension is long enough for neutron leakage from safety point of view and it is longer than the expected one because of square shape core.

Table 2. Optimized design values

Parameter	Value
Moderator matrix dimension	60 cm x 60 cm x 100 cm
Fuel active length	50 cm
Water layer thickness	1 cm
Stainless steel vessel thickness	1 cm
Reflector thickness	36 cm

The numerical comparison of maximum flux levels at ARO state in both core and reflector regions are listed in Table 3 for both moderator options. Here the maximum thermal flux level in core region is especially referred to that in AIH located at core center.

Table 3 Maximum fast and thermal fluxes at ARO

(a) Aluminum-moderator core

Cycle	Core		Reflector	
	Fast	Thermal	Fast	Thermal
BOC	1.2699E+14	1.0483E+14	5.2375E+13	2.5974E+13
EOC	1.3144E+14	1.2022E+14	6.0417E+13	2.9859E+13

(a) Graphite-moderator core

Cycle	Core		Reflector	
	Fast	Thermal	Fast	Thermal
BOC	1.1600E+14	1.0802E+14	3.8642E+13	1.9236E+13
EOC	1.1314E+14	1.2175E+14	4.4899E+13	2.2473E+13

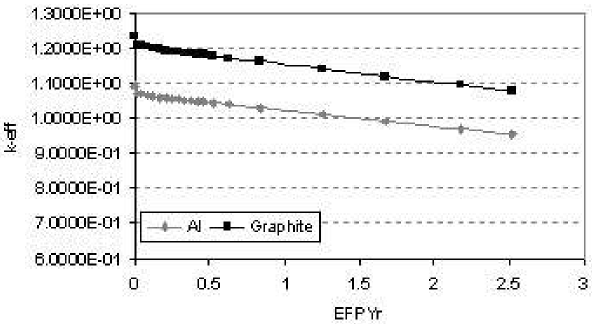

Figure 3. Excess reactivity and cycle length

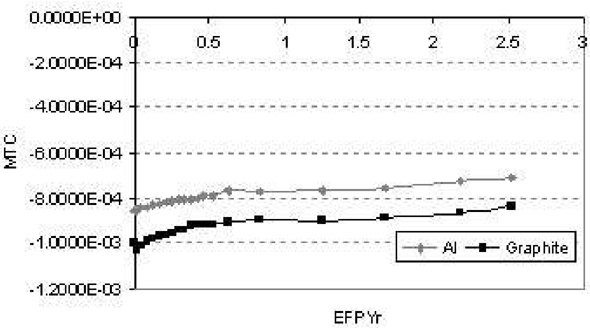

Figure 4. Moderator temperature coefficient

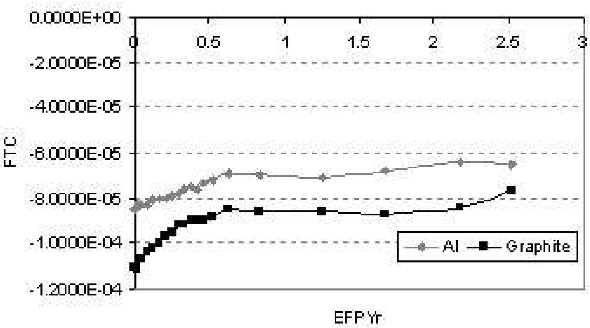

Figure 5. Fuel temperature coefficient

Figure 3 shows both moderator options can take place the flat characteristics of k-eff curves. Both moderator options give negative values of MTC and FTC throughout the operation as shown in figures 4 and 5. A negative MTC is desirable because of its self-regulating effect. In case of large positive reactivity insertion, however, MTC cannot turn the power raise for several seconds. For that kind of event, FTC starts adding negative reactivity immediately and hence a negative FTC is more important than a negative MTC.

Table 4. Reactivity worth for irradiation

Moderator	Irradiation Facility	CR Position	k-eff	Reactivity Worth (mk) For Irradiation
Al	No	ARO	1.0903	10.8
	Yes	ARO	1.0776	
Graphite	No	ARO	1.2332	7.2
	Yes	ARO	1.2223	

In Table 4, the world "Yes" means there is a sample, here natural sulfur for P-32 production, in irradiation hole whereas "No" is opposite meaning.

3. Conclusion

It can be said that the proposed HFRR has good characteristics from a reactor safety and a fuel economy point of view because of its large excess reactivity, negative values of MTC and FTC, the use of heavy water drainage system adopted as secondary shutdown system independently, and enough reactivity worth for irradiation. Graphite moderator option will be adopted in further study as a result of its advantages such as giving higher thermal flux level in core region, having longer cycle length, less excess reactivity reduction due to irradiation facility than aluminum moderator. Furthermore it can give higher negative values of MTC and FTC too and it has higher melting point as well as abundance. Finally, it can be concluded that there was an enough flux level for existence of irradiation hole at core center and it can be applied for production of radioisotopes, education and training, and supporting power reactor programs in advance in developing countries. It is aimed to expand for other design goals and to determine the arrangement of experimental facilities as much as possible as future study.

REFERENCES

[1] Win Naing and Myung-Hyun Kim, "Nuclear Design Concepts of Research Reactor for the Developing Countries", Transactions of the Korean Nuclear Society Autumn Meeting, Korea, September, 2007.

[2] J.L.Snelgrove et al., "Development of very-high density low-enriched-uranium fuels", Nuclear Engineering and Design, 178, pp.119-126, 1997.

[3] "Research Reactors", selected reference material, United States Atomic Energy Commission, Mc-Graw-Hill Book Company, Inc., 1955.