Increasing the Neutron Flux Study for the TRR-II Core Design

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ABSTRACT

The maximum unperturbed thermal flux of the originally proposed core design, which is a 6x6 square arrangement with power level of 20 MW and has been presented at the 6th Meeting of IGORR, for the TRR-II reactor is about 2.0×10^{14} n/cm^2-sec. However, it is no longer satisfied the user's requirement, that is, it must reach at least 2.5×10^{14} n/cm^2-sec. In order to enhance the thermal neutron flux, one of the most effective ways is to increase the average power density. Therefore, two new designs with more compact cores are then proposed and studied. One is 5x6 rectangular arrangement with power of 20 MW; the other one is 5x5 square arrangement with power of 16 MW. It is for sure that both core designs can satisfy thermal hydraulic safety limits. The designed parameters related to neutronics are listed and compared fundamentally. According to our calculation, although both cores have similar average power density, the results show that the 5x6/20 MW design has the maximum unperturbed thermal flux in the D_2O region about 2.7×10^{14} n/cm^2-sec, and the 5x5/16 MW design has 2.5×10^{14} n/cm^2-sec. The maximum thermal flux in the neighborhood of the longer side of the 5x6 core is about 7% higher than the one in the neighborhood of any side of the 5x5 core. This "long-side effect" gives the 5x6/20 MW core design an advantage of the utilization of the thermal neutron flux in the D_2O region. In addition, the 5x5 core is also more sensitive to the reactivity change on account of in-core irradiation test facilities. Therefore, under overall considerations the 5x6/20 MW core design is chosen for further detailed design.

INTRODUCTION

The earlier TRR-II core design[1] shown in Figure 1 is a 6x6 square arrangement, and it is based on the user's requirement that the unperturbed thermal flux in the D_2O reflector should be more than 2.0×10^{14} n/cm^2-sec. The detailed description about this original design can be found in Reference 1. However, according to the TRR-II Technical Review Committee's opinion at the first meeting in the March of 1999, in order to have competitiveness in the twenty-first century, the maximum unperturbed thermal neutron flux should be raised to 2.5×10^{14} n/cm^2-sec at least. Therefore, to increase the neutron flux performance is the most important issue since then for the TRR-II Core Design Group.

DESIGN SCENARIOS

To enhance the neutron flux, one of the most effective methods is to increase the core average power density. Generally, there are two ways for increasing power density. One is to increase power level; the other way is to reduce core size. The former may result in a considerable change of entire system because of the requirement for the increase of heat removal capacity. Thus the latter method is selected for its smaller impact to system. On the other hand, the power density should be bounded by the thermal hydraulic safety criteria. Under this thumb of rule, two new core designs are proposed and studied. The first one is a 5x6 arrangement with 20 MW; the second is a 5x5 arrangement with 16 MW (see Figures 2a and b, respectively). Both designs

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have the similar power density that is about 400 watts/g-U and just can protect reactor from the onset of nucleate boiling (ONB) during normal operation while the departure of nucleate boiling and flow instability were prevented at anticipated transients.

As illustrated in Figure 2, the 5x6 core contains 21 standard fuel elements, 4 control/follow-fuel elements, and 5 vertical irradiation elements, and the 5x5 core is composed of 16 standard fuel elements, 4 control/follow-fuel elements, and 5 vertical irradiation elements. The five in-core irradiation elements are reserved for the use of fuel and material tests. Since these two designs have more compact core size than the original one, the excess reactivities become, of caurse, smaller. This results in two advantages that: 1) the number of control rods can be reduced, and 2) the burnable poison wires in fuel bundles are no longer necessary.

Besides the change of core size, the new cores also make some improvements in fuel elements. The old fuel element, as shown in Figure 3a, contains 21 fuel plates. The new fuel element has 22 fuel plates (see Figure 3b). This allows the new fuel to have somewhat lower average heat flux than the old one. In addition, the old fuel element is added burnable poison (cadmium) wires on its side plates in order to control the large excess reactivity. For the new fuel bundle, it is unnecessary to use burnable poison since the new cores have smaller excess reactivities. This could save about 50% of fuel cost.

COMPARISONS AND RESULTS

The thermal flux distributions of the 5x6 and 5x5 cores are plotted in Figures 4 and 5, respectively. It can be found that In Figure 4 the maximum thermal flux in the D_2O reflector is about $2.7x10^{14}$ neutrons/cm2-sec, which is happened at around 10 cm distance from the longer side. In the vicinity of the shorter side, the highest thermal flux is only $2.4x10^{14}$ neutrons/cm2-sec. In Figure 5 the flux distribution is well symmetric, and the maximum thermal flux is about $2.5x10^{14}$ neutrons/cm2-sec. In other words, the maximum thermal flux near the longer side of the 5x6 core is about 7% higher than that in the neighborhood of any side of the 5x5 core. This “long-side effect” gives the 5x6/20 MW core design the advantage of a better utilization of the thermal flux in the D_2O region. Except the thermal flux values mentioned above, other parameters related to neutronics for these two designs are also listed in Table 1.

Concerning fuel management, the cycle length of the 5x6/20 MW core is set to 39 effective full power days (EFPDs), and the average discharged fuel burnup is around 60%. For the 5x5/16 MW core, the cycle length is 45 EFPDs, and the average discharged fuel burnup is only 43%. Based on the operation efficiency of 70%, the former needs to replace 26 fuel bundles average per year, and the latter needs 29 fuel bundles per year. That is, the 5x6 core has better efficiency on the fuel usage than the 5x5 core. This phenomenon is induced by the facts that 1) the change of reactivity versus burnup for the 5x5 core is faster than that for the 5x6 core, and 2) the reactivity needed to compensate the experimental cost (~45 mk) for the 5x6 core is smaller than the 5x5 core (~50 mk).

The power peaking factor of the 5x5 core design is 2.28, which is about 9% smaller than the power peaking factor (2.50) of the 6x5 core. In addition, the control rod shutdown margin of the 5x5 core is larger than the 5x6 design. That means the former has more safety margins to thermal hydraulic limits than the latter.

CONCLUSIONS

In order to improve the neutron flux performance for the TRR-II reactor, two new core designs, 5x6/20 MW and 5x5/16 MW, are proposed and analyzed. Although the two new designs have similar power density, their characteristics are quite different. From the safety point of view, the 5x5 core design has more margins than the 5x6 design, but both satisfy the thermal hydraulic safety criteria. Under the economic consideration, the efficiency of the fuel utilization for the 5x6 core design is better than the 5x5 design. Importantly, the neutron flux performance of the 5x6/ 20 MW core design is better than that of the 5x5/16 MW design. In conclusion, the 5x6/20 MW core is more suitable for the multipurpose applications, and is also a better design for TRR-II. Therefore, it is chosen to further detailed design.

REFERENCE

[1] Chien-Hsiang Chen and Jing-Tong Yang, "Preliminary Study of Core Design," *Procs. of 6th Meeting of the International Group on Research Reactors*, pp. 65~70, Taejon, Korea (1998)

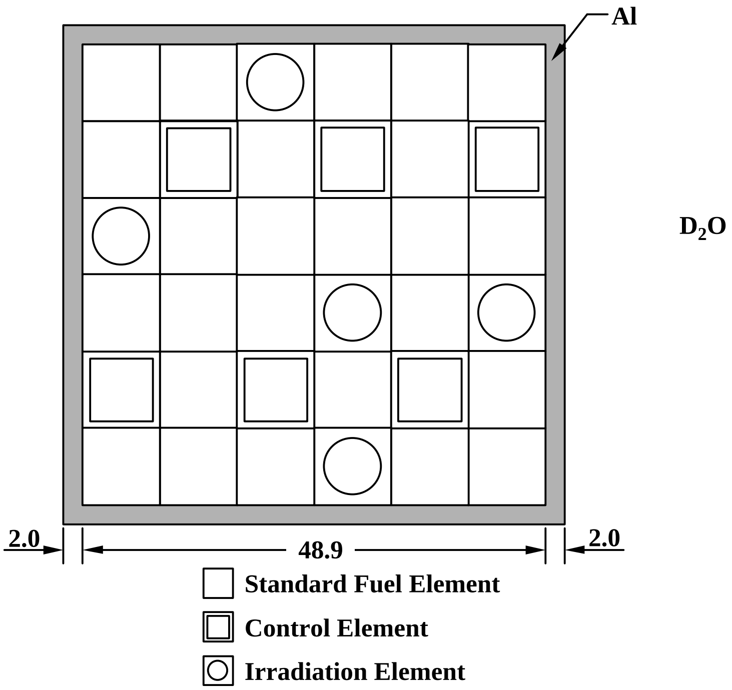
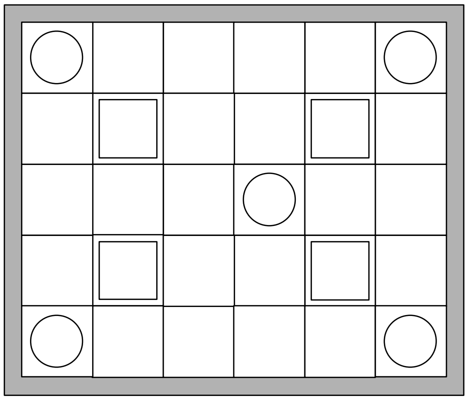
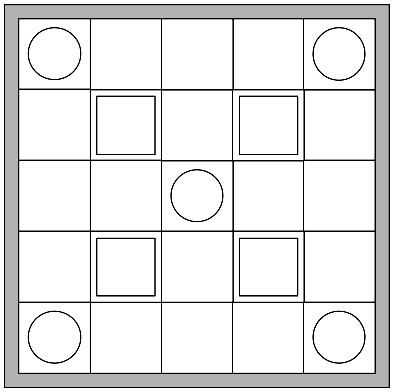


Figure 1. The Original 6x6 Core

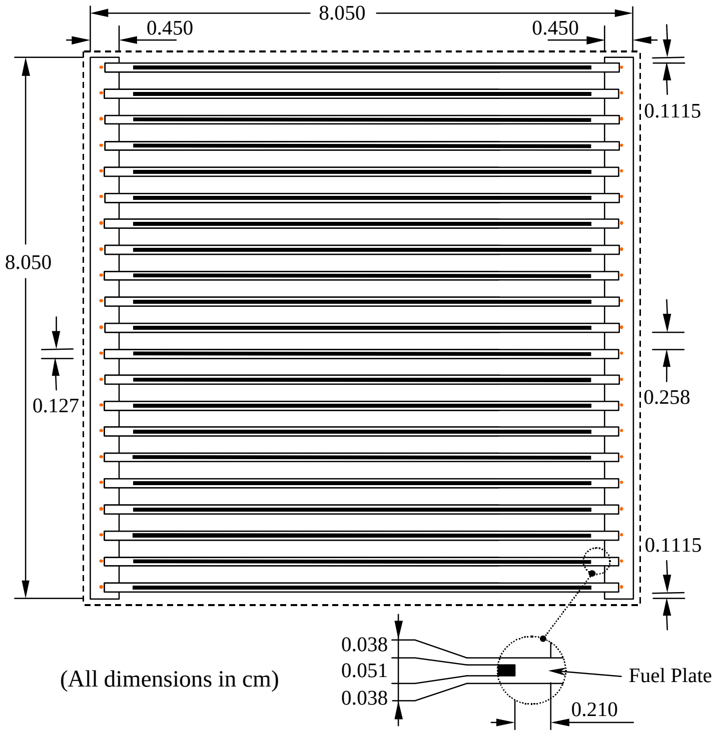


(a) 5x6

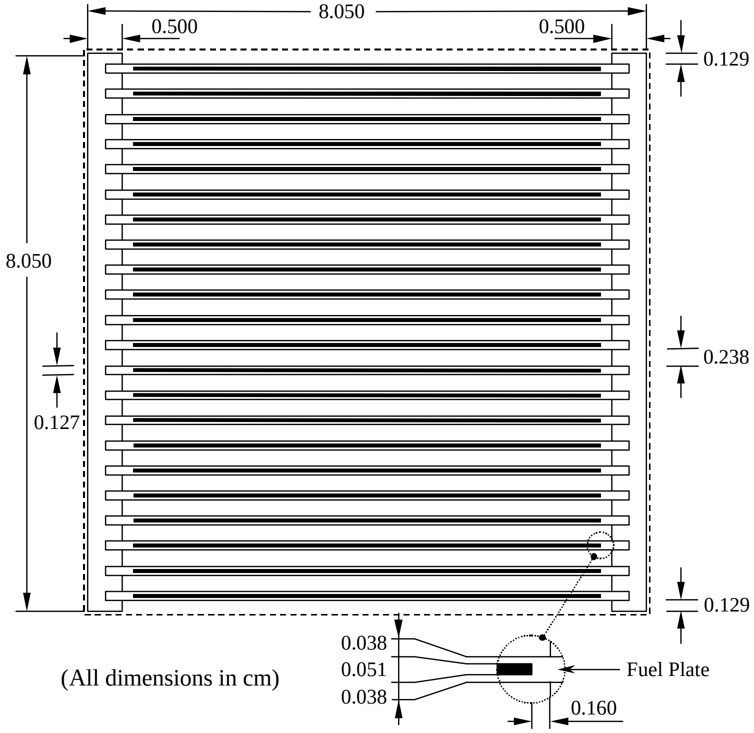


(b) 5x5

Figure 2. The New 5x6 and 5x5 Cores



(a) Old



(b) New

Figure 3. The Old and New Fuel Bundles

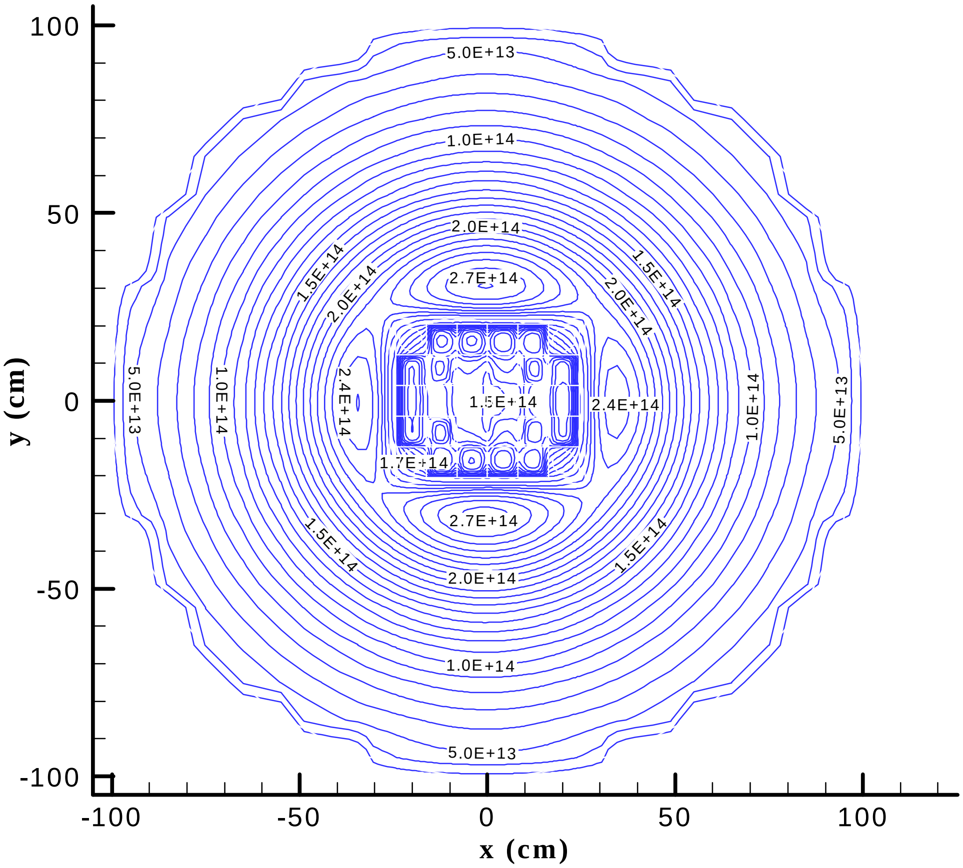


Figure 4. The Thermal Neutron Flux Distribution of the 5x6 Core

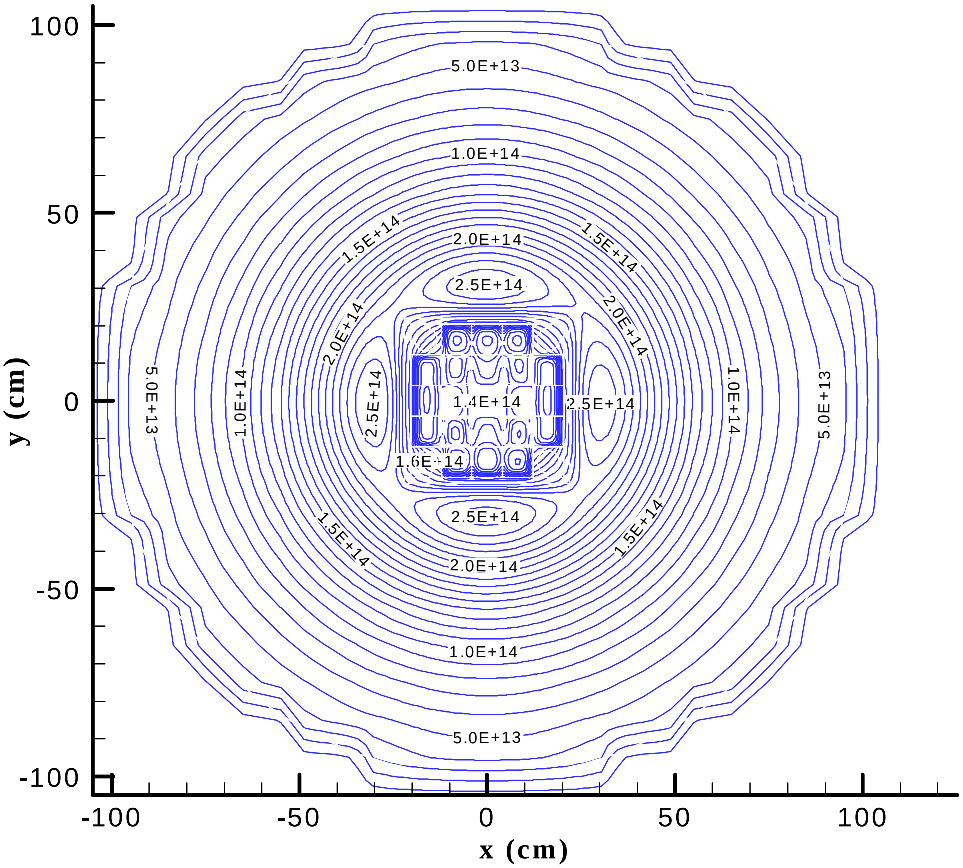


Figure 5. The Thermal Neutron Flux Distribution of the 5x5 Core

Table 1. Design Parameters of 5x6 and 5x5 Cores

Parameter	**5×6**	**5×5**
Power Level (MW, Fission)	20	16
Fuel Meat Material	U_3Si_2-Al	U_3Si_2-Al
U^{235} Enrichment (w-%)	19.75	19.75
Uranium Density (g/cm^3)	4.80	4.80
No. of Fuel Element	21	16
No. of Control Element	4	4
No. of Irradiation Element	5	5
Core Cross Section Area (cm^2)	48.9x40.75	40.75x40.75
Core Active Height (cm)	60	60
Core Loading of U^{235} (kg)	10	8
Unperturbed Max. Thermal Flux (n/cm^2-s) in D_2O @ Critical	2.7E+14	2.5E+14
Excess Reactivity (mk)		
• Cold without Xenon @ BOC	139	143
• Cold with Xenon @ BOC	102	111
• Hot with Xenon @ BOC	99	108
• Hot with Xenon @ EOC	49	51
Shutdown System Capabilities (mk)		
• Total Control Rod Worth	221	262
• Without the Most Worth Control Rod	151	183
• Shutdown Margin @ BOC (Cold, No Xenon)	12	40
Experimental Loading Cost (mk)	45	50
Cycle Length (Full Power Day, FPD)	39	45
Average No. of Fuel Elements Discharged per Year	26	29
Average U^{235} Consumption Ratio in Discharged Fuels (%)	60	43
Nuclear Power Peaking Factor	2.503	2.276