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# DEMONSTRATION OF THE AVERAGE BEHAVIOR OF THE NEUTRON ABSORPTION RESONANCES IN SILVER-107

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## ABSTRACT

An MCNP5 study was carried out to compare the neutronic behavior of LR-0 reactor when controlled by Boron (thermal neutron absorber) or Silver (resonant epithermal neutron absorber) control rods. Several neutronic parameters were tallied, including neutron flux and absorption spectra in control rods, and neutron flux in fuel and in moderator. Epithermal neutron absorption resonance in Silver didn't affect the overall neutronic behavior of LR-0 if controlled by Silver control rods. This suggests that for dense oscillation resonances, an average cross section value of the resonances dominates the reaction rate.

## KEYWORDS:

LR-0 reactor, Boron control rods, Silver control rods, Thermal neutron absorber, Resonant epithermal neutron absorber

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## INTRODUCTION

The Thermal nuclear reactors typically utilizes thermal neutron absorbers, usually Boron, as control materials (IAEA, 1993). This is based on a fact that in a thermal nuclear reactor, the longest time of a neutron's life is spent as thermal neutron (approximately 97% of a neutron's life time) (Kaye & Laby, 1995). So, it was assumed that a thermal neutron absorber is the best to control reactivity of thermal reactors. However, from another point of view, all thermal neutrons must have been epithermal before being thermalized, so worth inquiry whether an epithermal neutron absorber (e.g. Silver) can control reactivity of thermal reactors or not, based on the concept that if a neutron was eliminated from the system while it is epithermal (however short its epithermal lifetime is) it will not become thermal, and this should be more efficient than waiting for a neutron to become thermal to eliminate it.

In the present research, 2 MCNP5 models of LR-0 reactor were used, one was controlled by natural Boron (greedy thermal neutron absorber) control rods, and the other by natural Silver (having dense large neutron capture resonances at epithermal energies) control rods. Several neutronic parameters of the two models were compared, including: neutron flux and absorption spectra in control rods, and neutron flux in fuel and in moderator.

## OBJECTIVES

The main objective of the study is to investigate the neutronic behavior of a resonant epithermal neutron absorber (Silver-107) when used as control material in thermal control rods. Specifically, it was meant to demonstrate how the average behavior of the epithermal neutron absorption resonances of Silver-107.

## MATERIALS

### LR-0 Model (Kyncl, et al., 2005)

In the present study, LR-0 reactor core model was assembled of 13 fuel assemblies, see figures 1, 2.

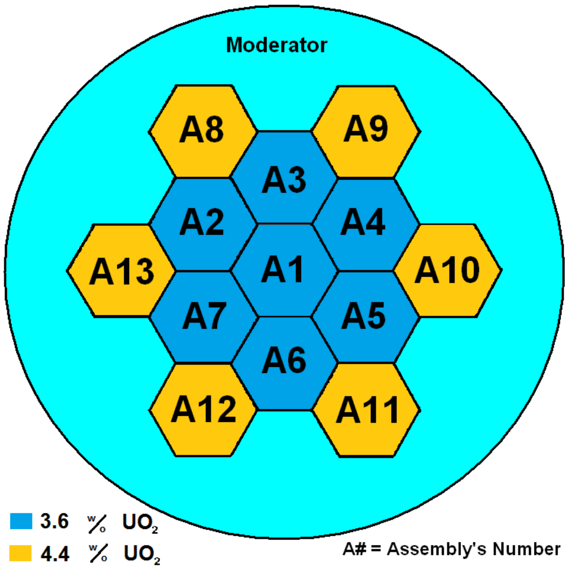

**Fig. 1.** Fuel assembly numbering and core configuration.

***Fuel Pins***

Fuel in assemblies number 1–7 is $UO_2$ of enrichment = 3.6 $^{w}/o$ and density = 10.32 g/cm$^3$. Fuel in assemblies number 8–13 is $UO_2$ of enrichment = 4.4 $^{w}/o$ and density = 10.08 g/cm$^3$, see figure 1.

***Control Rods***

On first trials, natural Silver was used for control rods. However, it was found that the LR-0 model can never be critical even with full length of the natural Silver control rods, it was supercritical all the time. Investigating the reason, it was because Silver atom is very heavy compared to Boron atom, so the atom density in natural Silver was too low compared to that in natural Boron. So, the decision was to use equal atom densities in both Boron and Silver control rods. Since natural Boron (as $B_4C$) control rods are now standard in many nuclear reactors, atom density of natural Boron was adopted for both Boron and Silver control rods used in the present research. Thus, in one model natural Boron was used as control rod material, while in the other model "super-dense" Silver was used. Atom density in both natural Boron and "super-dense" Silver control rods were equal, and were that for natural Boron. Thus, we can compare the influence of neutron capture cross section of Boron and Silver unbiased by the too low atom density of natural Silver. Though at such high atom density, the mass density of Silver is extremely large, but this was a good approach to compare the neutronic influence of Silver vs. that of natural Boron overcoming the difference in atom densities.

To change reactivity; the control rods were only shortened or elongated inside the core, see figure 2. In both models, boric acid was eliminated from the moderator to avoid its neutronic influence on the reactor.

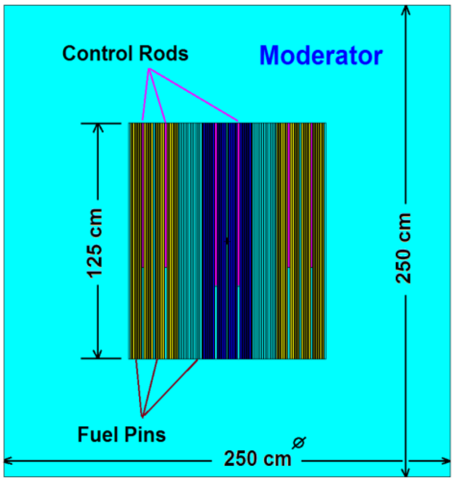

*Fig. 2. Reactor layout.*

## METHODOLOGY

### Code

MCNP5 was used to model the LR-0 reactor and carry out the study. The reactor was assumed to be at room temperature and atmospheric pressure.

### Model Reactivity

In one model, natural Boron was used as control rod material. Control rods lengths were adjusted so that $k_{eff}$=1.00000 (S.D. = 0.00015).
In the second model, Silver at atom density equals that of natural Boron was used as control rod material. Control rods lengths were adjusted so that $k_{eff}$=1.00007 (S.D. = 0.00014).
So, both models are critical and contain equal atom densities of the neutron poison in the control rods. Hence, any difference in neutronic behavior will be due to the difference in neutron capture cross section between Boron (mainly thermal neutron absorber) and Silver (mainly epithermal neutron absorber).

### Tallies

Neutron energies were classified into 3 groups; viz. thermal (< 1 eV), epithermal (1 eV–0.1 MeV), and fast (> 0.1 MeV) (U.S.DOE-HDBK, 1993; Elmer, 2008).
Tallies included: neutron flux and absorption spectra in control rods, neutron flux in fuel, radial distribution of neutron flux and reaction rates in fuel, and power peaking factor.

## RESULTS

***Table 1. Properties of the control rods used in the study***

| Control Rods | Atom Density Atom/cm.barn | Density g/cm$^3$ | Total Volume cm$^3$ | Total Mass g | Total number of control atoms |
|---|---|---|---|---|---|
| Boron | 0.1292 | 2.34 | 2.27420E+04 | 5.3216E+04 | $2.9383 \times 10^{27}$ |
| Silver | 0.1292 | 23.3587 | 2.35652E+04 | 5.5045E+05 | $3.0446 \times 10^{27}$ |

The total volume of Boron and Silver control rods were almost equal. So, the geometry in both LR-0 models was very similar. Thus, the only variable in the two models was the type of control material, since the two models had: same fuel, same moderator, same geometry, and almost same number of control atoms.
Thus, any difference in neutronic behavior in the two models will be due to the different neutron absorption cross sections of Boron and Silver.

## Three Groups Neutron Flux in Fuel

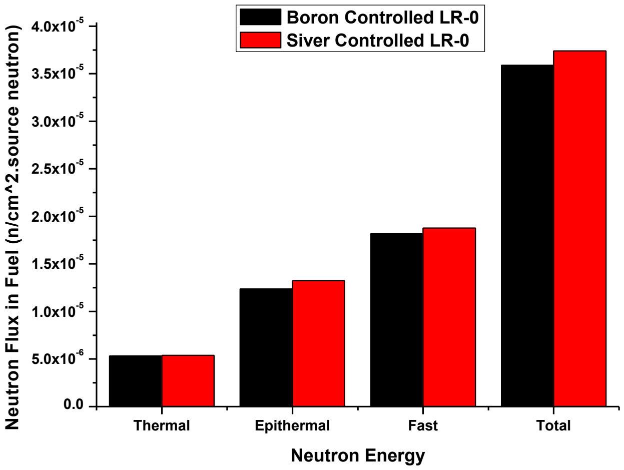

*Fig. 3. Three groups average neutron flux in fuel.*

There were no significant differences between neutron flux in fuel cells in the three energy groups in the two study cases (B and, Ag controlled LR-0 reactors). However, Ag controlled LR-0 reactor showed slightly greater epithermal and fast neutron fluxes, as seen in figure 3.

## Neutron Energy Spectrum in Fuel Cells

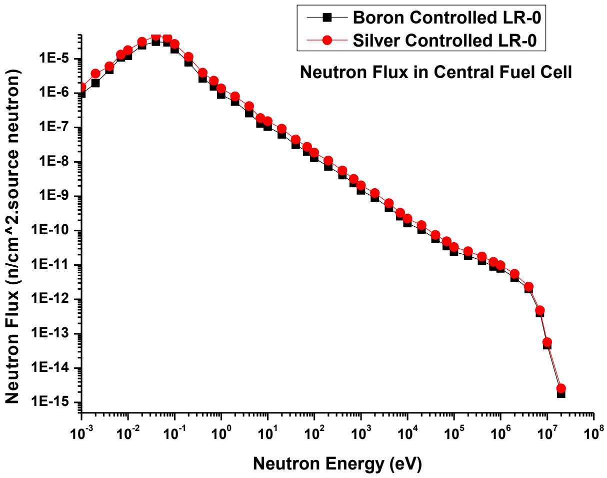

*Fig. 4. Neutron spectrum in central fuel cell.*

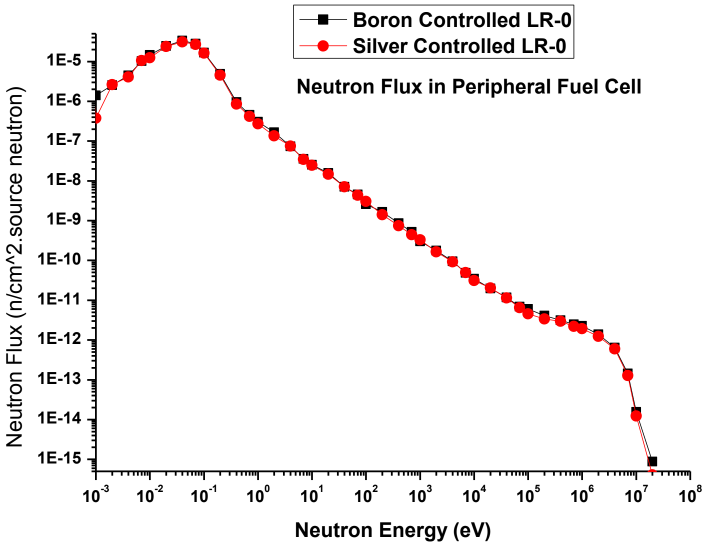

*Fig. 5. Neutron spectrum in peripheral fuel cell.*

Figures 4 & 5 show that neutron spectra in central and peripheral fuel cells were almost identical in both of the study cases.

**Three Groups Neutron Flux in Moderator**

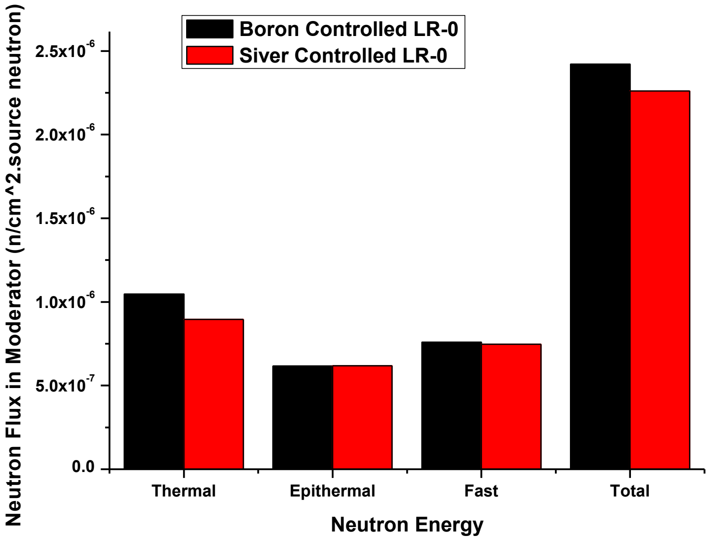

*Fig. 6. Three groups neutron flux in moderator.*

Thermal and total neutron fluxes in moderator were slightly higher in the Boron controlled LR-0, while epithermal and fast neutron fluxes in moderator were almost equal in both cases. See figure 6.

### Total Fission Rate & Energy per Source Neutron

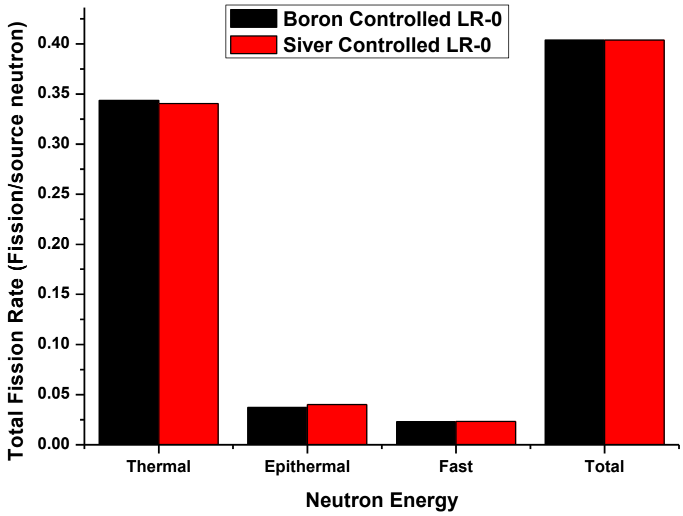

*Fig. 7. Total fission rate per source neutron.*

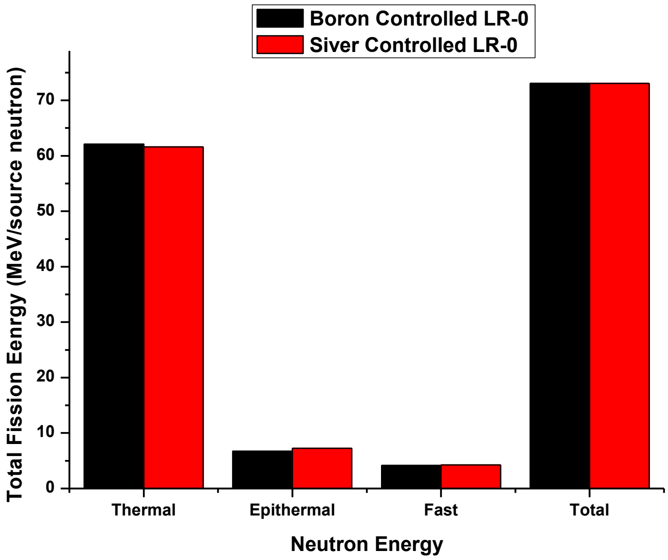

*Fig. 8. Total fission energy per source neutron.*

Figures 7 & 8 shows that both total fission rate and energy per source neutron were almost equal in both Boron & Silver controlled LR-0 reactors.

### Neutron Absorption Spectrum in Control Rods

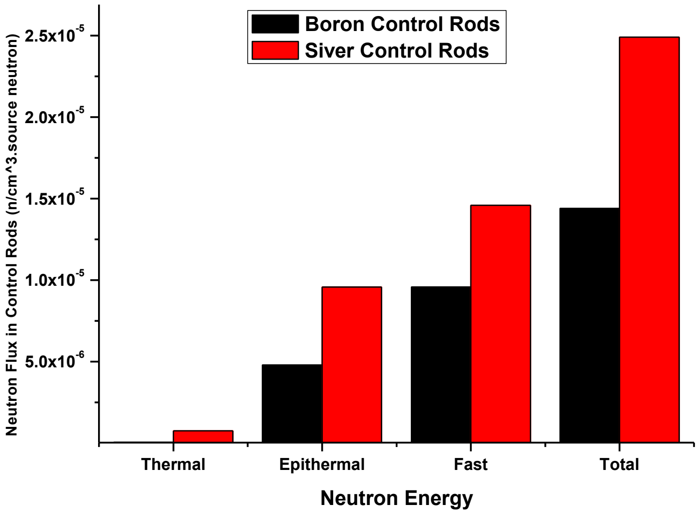

***Fig.9. Three groups neutron flux in control rods.***

Figure 9 shows that neutron flux in control rods was lower in Boron than in Silver control rods for all the three energy groups. This is probably due to the high neutron absorption cross section in Boron, which consumes the neutron flux.

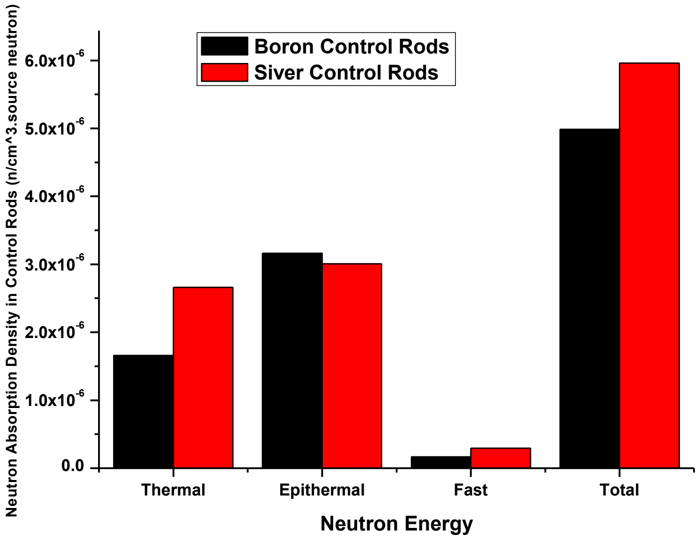

***Fig.10. Three groups neutron absorption in control rods.***

Figure 10 shows that neutron absorption in control rods was different in both cases. Silver absorbed more neutrons than Boron. Remarkably, Silver absorbed more thermal neutrons than did Boron. Also, Boron absorbed more epithermal neutrons than Silver.

## DISCUSSION

Figure 11 introduces the cross sections for the major neutron absorption reactions in Boron [(n,α) reaction for $^{10}$B], and Silver [(n,non) reaction for $^{107}$Ag]. It shows that neutron absorption cross section in $^{10}$B was generally greater than that of $^{107}$Ag over the thermal and epithermal neutron energies, but was less over the fast range. $^{107}$Ag showed marked neutron absorption resonances between 100 eV – 1 keV (within the epithermal range).

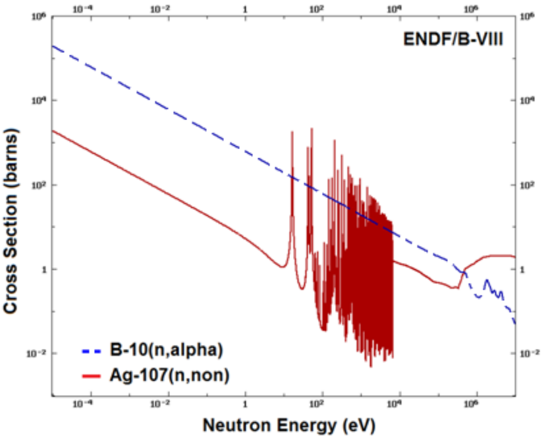

*Fig. 11. Neutron absorption cross section in $^{10}$B and $^{107}$Ag (ENDF/B-VIII).*

As was shown in figure 10, neutron absorption was markedly less in Boron than in Silver control rods over the thermal and fast neutron energy ranges, but was greater over the epithermal range.

It is logic that fast neutron absorption in Boron was less than in Silver control rods, since fast neutron absorption cross section of $^{10}$B is less than that of $^{107}$Ag.

However, epithermal neutron absorption in Boron was greater than in Silver control rods. Referring to figure 11, it may be concluded that the high resonances in neutron absorption cross section of $^{107}$Ag were not enough to surpass the purely linear epithermal neutron absorption cross section of $^{10}$B. This suggests that the average cross section over a region of dense resonances can be simply averaged about the mean-value of the resonances.

Thermal neutron absorption in Boron was also less than in Silver control rods, despite the fact that thermal neutron absorption cross section of $^{10}$B is greater than that of $^{107}$Ag over the thermal neutron energy range. This finds its explanation in figure 9 which shows that the greater epithermal neutron absorption in Boron consumes the neutron flux, leaving too few thermal neutrons to be absorbed in Boron control rods.

## CONCLUSION

Epithermal neutron absorption resonance in Silver didn't affect the overall neutronic behavior of LR-0 if controlled by Silver control rods. Moreover, the great epithermal neutron absorption in Boron-10 efficiently reduced the thermal neutron flux to catch with the reduction in thermal neutron flux induced by the greater thermal neutron absorption in Silver. This raise questions on the convention that Boron is used in control rods for thermal nuclear reactors due to its higher thermal neutron absorption cross section. It is rather its capacity to absorb epithermal neutrons that made it successful thermal nuclear reactor control material.

This opens the gate to the fundamental question of the present paper, that's would epithermal neutron absorbers be more efficient to control thermal nuclear reactors, as they will absorb neutrons much earlier than would thermal neutron absorbers? This suggests further investigation of the neutron absorption in Boron control rods, and other known epithermal neutron absorbers.

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