LEU-FUELED SLOWPOKE-2 MODELING WITH MCNP4A

By J.R.M. Pierre and H.W.J. Bonin

Department of Chemistry
And Chemical Engineering
Royal Military College of Canada-Collège Militaire Royal du Canada
Kingston, Ontario
Canada
K7K 5L0

Introduction

Following the commissioning of the Low Enrichment Uranium (LEU) Fueled SLOWPOKE-2 research reactor at Royal Military College-Collège Militaire Royal, excess reactivity measurements were conducted over a range of temperature and power. The results showed a maximum excess reactivity of 3.37 mk at 33°C (the measurements were taken at 10W, and the temperature was attained by heating the reactor pool, therefore permitting the assumption of a uniform reactor temperature)(1). First calculations showed a maximum excess reactivity occurring at 12°C, and the calculated absolute values of the excess reactivity was off by more than 80 mk. Further calculations and simulations were performed by Robert T. de Wit (2), using 1-dimension WIMS-AECL and 2-dimensions CITATION (coupled with WIMS-AECL) models. Although no significant progress could be obtained on the temperature trend, the absolute value was improved but remained off by some 16 mk.

École Polytechnique de Montréal also attempted to simulate the temperature trend for their (HEU-fueled) research reactor. The data taken out of C. Guertin's thesis[3] reproduce the temperature trend using the TRIVAC code, but this model overestimated the absolute value of the excess reactivity by 119 mk. Although the calculations using DRAGON did not reproduce the temperature trend as well as TRIVAC, these calculations made a significant improvement on the absolute value at 20°C reducing the discrepancy back to 13 mk

Given the advance in computer technology, the use of Monte Carlo N-Particle Transport Code System MCNP 4A (4) appeared possible for the simulation of the LEU-fueled SLOWPOKE-2 reactor core, and this work demonstrates that this is indeed the case.

The code

MCNP 4A is a full three dimensional programme allowing the user to enter a large amount of complexity. The limit on the geometry complexity is the computing time required to achieve a reasonable standard deviation. To this point several models of the SLOWPOKE-2 have been developed giving some insight on the sensitivity of the code. MCNP4A can use various cross section libraries. At this time, all models have been based on the ENDF/B-V library as it is the most complete one available on site. For light water and heavy water, special material cards have also been used (LWTR.01T and HWTR.01T).

Geometry

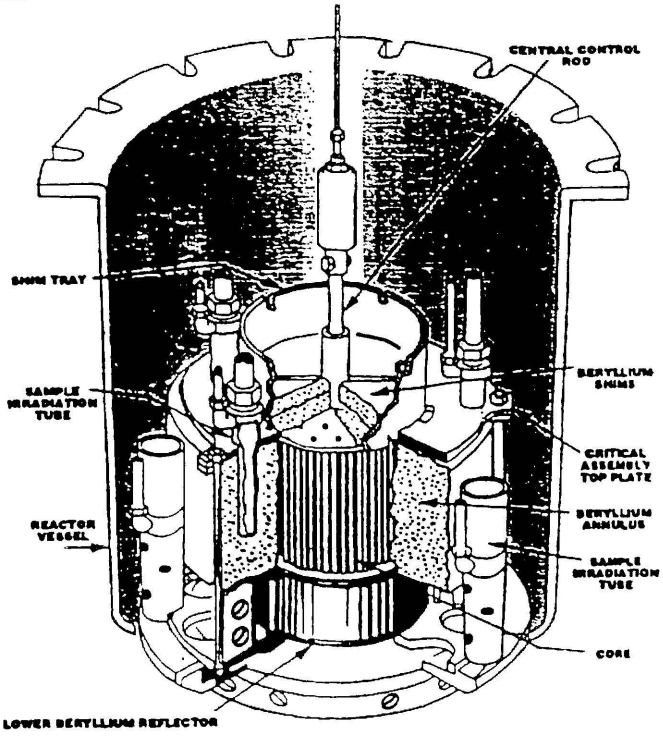
The main problem, when simulating the SLOWPOKE-2 reactor at RMC-CMR is the lack of symmetry and its small size (Figure 1). The core is composed of 198 fuel rods distributed to maximize the neutron flux on the periphery where the irradiation sites are found. It was also designed to have a relatively high flux at the centre where a single control rod is found. The reactor has:

A. A beryllium reflector composed of an annulus, a lower reflector and a top reflector shim;
B. Five internal irradiation sites distributed at regular intervals within the beryllium

annulus;

C. One large outside irradiation site in the water of the reactor container, between the beryllium reflector and the container wall;
D. Two small outside irradiation sites in the water of the reactor container;

E. One cadmium lined irradiation site again in the water of the reactor container;
F. A thermal column, consisting of an aluminum container filled with heavy water and located between the radial beryllium reflector and the reactor vessel wall (not represented in Figure 1);
G. The unique control rod located at the centre of the reactor;
H. Several structural devices holding these components together (not represented in the simulation);
I. The reactor container vessel; and
J. The reactor pool.



SLOWPOKE-2 Reactor Core

Figure 1

The model

The aim of this work is to calculate accurately the reactivity of the core and reproduce the temperature trend of the reactivity. The model preserved as much as possible the details of the core

and facility in order to allow further study in flux mapping.

The main advantages of this model as provided by the Monte-Carlo approach are:

A. All the reactor components and the reactor as a whole were modeled in three dimensions;
B. The 198 fuel pins were located according to the drawing AL82245, and reference 5, therefore reproducing a heterogenous model. Each of the fuel pins was modeled accurately, including the gap between the fuel pellets and the cladding (Figure2);
C. Although simplified, the control rod was modeled with the dimensions of the cadmium conserved (Figure 3);
D. All the irradiation sites were modeled by cylinders of appropriate material and size (Figure 3);
E. The reflector was modeled in accordance with the appropriate drawing but the holes containing the irradiation sites were simplified (figure 4);
F. The thermal column was included in the model (Figure 5);
G. Although simplified, the reactor container was modeled in its entirety; and
H. The pool was modeled up to the stainless steel liner.

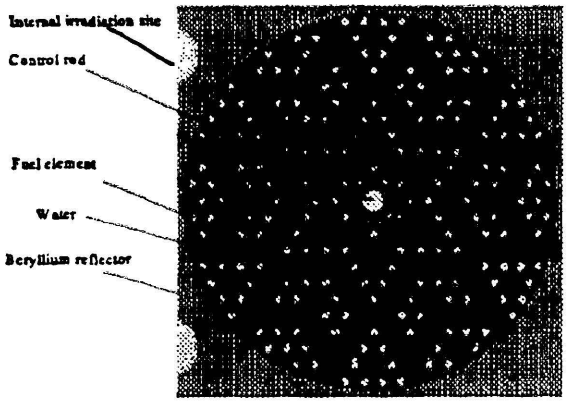


Figure 2
Horizontal Cut showing Fuel Element Distribution

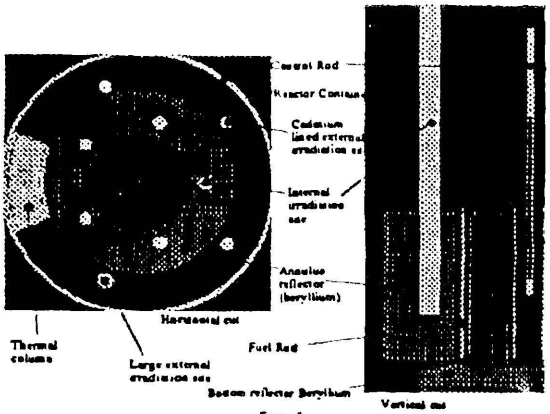


Figure 3
General Layout

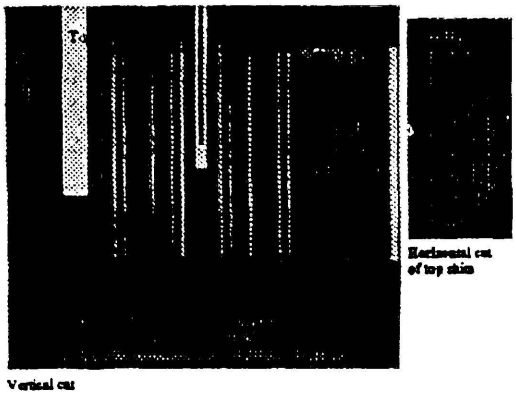


Figure 4
Reactor Reflectors

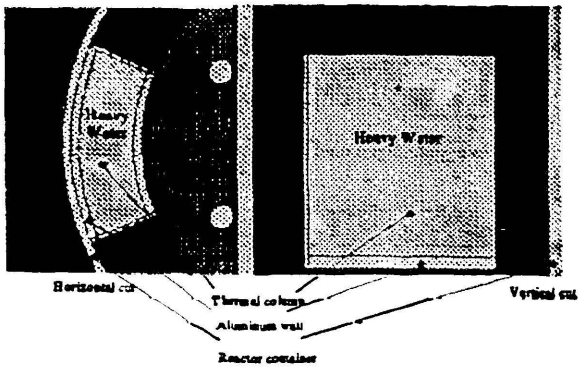


Figure 5
Thermal Column

Results

The results obtained so far can be divided in three groups, the reproduction of the excess reactivity at 20°C, the simulation of the control rod positioning, and the reproduction of the temperature trend.

Two models were used to calculate the excess reactivity at 20°C: first the control rod was located in its fully out position, and secondly it was completely replaced by water. These models yield respectively 3.17mk with a standard deviation of 0.2mk and 3.85mk with a standard deviation of 0.19mk for the excess reactivity. The standard deviation does not include here the modelling error. Therefore, the uncertainty on these calculations is larger than the simple standard deviation if one accounts for the inaccuracies in the geometrical dimensions and the materials cross sections. During the commissioning of the RMC-CMR SLOWPOKE-2 reactor the excess reactivity was measured at 3.15mk when corrected to 19.4°C by control rod balance (or period measurements).

The simulation of the reactor was then carried out at 20°C for three control rod positions, fully in, centred, and fully out. These calculations can be compared with the experimental measurements conducted during the commissioning at Table I. The simulated control rod reactivity worth is slightly higher than what was observed experimentally both when comparing the position of the control rod for low power and when comparing the calculated reactivity worth with the experimental evaluation. The discrepancies may be explained by these most likely factors:

A. Geometry error: the actual location of the control rod in the core may not be duplicated in the model accurately enough,
B. Material error: the cross sections libraries used may not be sufficiently accurate;
C. Statistical error: the control rod may not be sampled adequately.

Table I Control Rod Reactivity Worth

	Reactivity (mk)	number active cycles	number neutrons /cycle	1 Standard deviation (mk)	2 Standard Deviations (mk)
Control Rod Position (from bottom reflector)	Simulation				
Fully out (20.32 cm)	3.17	180	$1x10^5$	0.2	0.4
Centred (10.16 cm)	-0.79	410	$1x10^5$	0.14	0.28
Fully inserted	-4.68	100	$1x10^5$	0.26	0.52
Control Rod Worth	7.85mk			0.33	0.66
Experimental Data					
Estimated Control Rod Worth (reference 1)(mk)					5.45
Control Rod Position for 0 excess reactivity and low Power (reference 34) (from bottom reflector)					6.86 cm

The temperature trend was simulated by varying the density of the water as well as changing the volume and density of the UO_2. It was performed for all three control rod positions (Figures 6 to 8). Since MCNP 4A calculates the reactivity of the system only the results obtained with the control rod in the fully out position can be compared directly with the experimental data. The simulations for the other control rod positions used the same scale but are placed on a different range in order to help in comparing the results. Although the shape of the temperature trend is not reproduced accurately, the simulations clearly display the inherent safety of the LEU fueled SLOWPOKE-2.

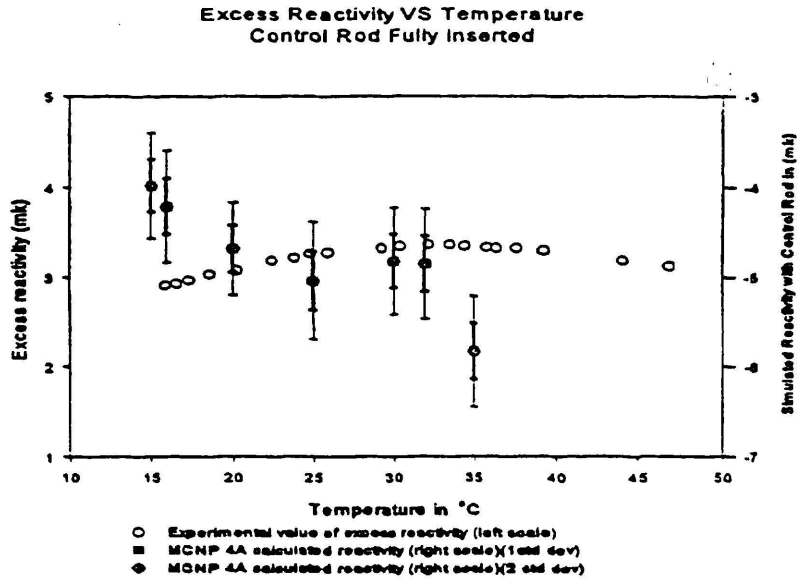


Figure 6

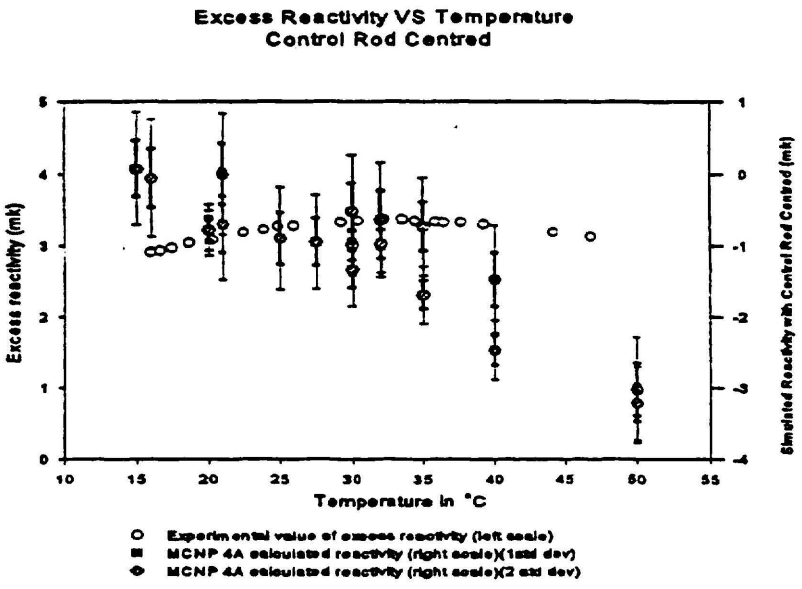


Figure 7

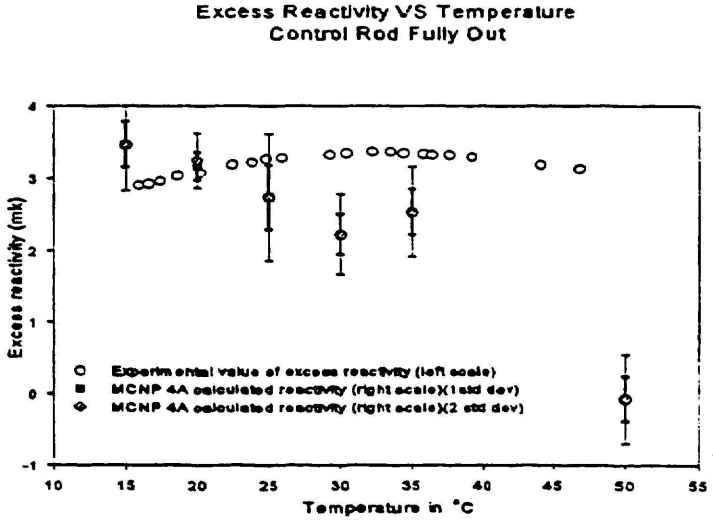


Figure 8

Discussion & Conclusion

The simulation of the RMC-CMR SLOWPOKE-2 reactor by Monte-Carlo method was successfully accomplished using MCNP 4A. The main advantages of MCNP 4A were the ability to model the entire reactor in three dimensions and the ability to use transport theory instead of the limiting diffusion calculation. These advantages lead to significant improvement in reproducing the experimental excess reactivity of the RMC-CMR SLOWPOKE-2 reactor.

MCNP 4A also allowed the modeling of the unique control rod in different positions, permitting the calculation of the reactivity worth of the control rod. Although the simulation overestimated the reactivity worth, the discrepancy with the experimental data was less than 50 percent for this hard problem.

When the reproduction of the trend of the reactivity of the RMC-CMR SLOWPOKE-2 reactor with the temperature was attempted, some of the disadvantages of the Monte-Carlo methods became evident, specifically:

a. The high computing cost involved in producing the highly precise results, required in the study of the relative effects of the temperature; and
b. The lack of adequate treatment for modifying cross sections for the temperatures of interest.

Within the limitation of the computing facilities and the code, the temperature trend was simulated for the three different control rod positions. These curves clearly show that the reactivity of the RMC-CMR SLOWPOKE-2 reactor decreases as the temperature increases. The inherent safety of the reactor is indeed demonstrated, and provides the MCNP 4A-based model with the potential of being used for investigating the effects of proposed modifications and licensing procedures.

Unfortunately, the experimentally-determined peak of the reactivity versus temperature could not be reproduced accurately with the MCNP 4A-based model for the SLOWPOKE-2 reactor at RMC-CMR. No hard conclusion can be reached at this point, but there are indications that a possible cause for this problem may be the representation of the temperature effects on the cross sections, which needs to be significantly improved. The results presented here come from a compromise between the computer resources presently available and the quest for minimizing the standard deviations through larger number of cycles and histories. With more performing computers and improved Monte-Carlo methods just around the corner, the problems encountered in this studies may soon be resolved.

References:

1. P.A Beeley and L.G.I. Bennett, " Reactivity Measurements", letter to AECB, RMC-CMR, 4 Jun 86.

2. R. T. de Wit, " Reactivity Calculations for the Low Enrichment Uranium Fuelled SLOWPOKE-2 Reactor At the Royal Military College of Canada",Master Degree Thesis, RMC-CMR, April 1989.

3. C. Guertin, "Calcul du Coefficient de Temperature du Réacteur SLOWPOKE-2", Thèse de Maîtrise, École Polytechnique de Montréal, Octobre 1991.

4. G.A. Burbidge, R.T. Jones and B.M. Townes, " Commissioning of the SLOWPOKE-2 (RMC) Reactor", Atomic Energy of Canada Limited Report, RCC/TR-85-004, Rev. 1, 1985.

5. RISC Computer Code Collection, MCNP4A, Contributed By Los Alamos National Laboratory, J.Briesmeister (editor), December 1993.