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ANL Independent Verification Results

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Introduction

At the request of the Czech Technical University (CTU) in Prague, ANL has performed independent verification calculations using the MCNP Monte Carlo code for three core configurations of the VR-1 reactor: a current core configuration B1 with HEU (36%) IRT-3M fuel assemblies and planned core configurations C1 and C2 with LEU (19.7%) IRT-4M fuel assemblies. Details of these configurations were provided to ANL by CTU.

For core configuration B1, criticality calculations were performed for two sets of control rod positions provided to ANL by CTU. For core configurations C1 and C2, criticality calculations were done for cases with all control rods at the top positions, all control rods at the bottom positions, and two critical states of the reactor for different control rod positions. In addition, sensitivity studies for variation of the ^{235}U mass in each fuel assembly and variation of the fuel meat and cladding thicknesses in each of the fuel tubes were done for the C1 core configuration.

Finally, the reactivity worth of the individual control rods was calculated for the B1, C1, and C2 core configurations.

Core Configuration B1 with HEU (36%) IRT-3M Fuel Assemblies

A model for core configuration B1 of the VR-1 critical facility was received from CTU. This model was analyzed by ANL and found to be very well constructed.

Calculations were performed by ANL for the two sets of control rods positions provided by CTU that are required to obtain critical configurations for the Core B1, shown in Figure 1:

A) **Set #1**: Control Rods:
B1/B2/B3=680 mm; E1=500 mm; R1=369 mm; R2=532 mm
B) **Set # 2**: Control Rods:
B1/B2/B3=680 mm; E1=500 mm; R1=393 mm; R2=496 mm

The results of these calculations are provided in Table 1, followed by explanations for the different cases.

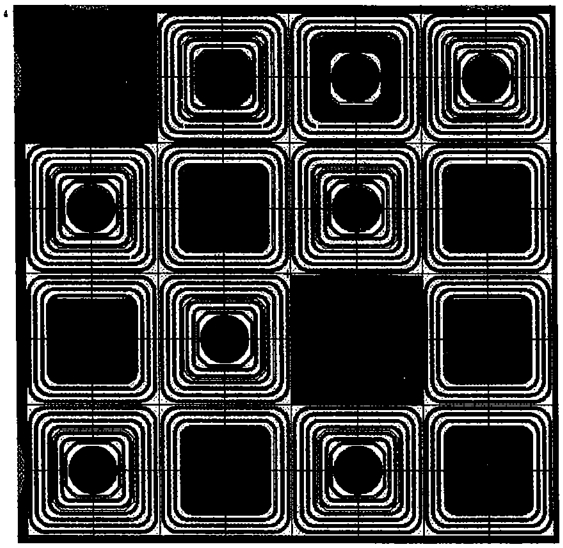

Figure 1. Core Configuration B1 with HEU (36%) IRT-3M FA.

Table 1. Results of Independent ANL MCNP Calculations Core Configuration B1 Using IRT-3M FA

	Set # 1 for CR k-eff	**Set # 2 for CR k-eff**
Base Case: Model of VR-1 as Received from CTU	1.00537 ± 0.00023	1.00496 ± .00021
Case 1: CR Modified to Include the SS below the Cd	1.00414 ± .00020 (-0.122%)*	1.00361 ± .00021 (-0.134%)*
Case 2: Added U-234 to Fuel Meat	1.00188 ± .00018 (-0.224%)*	1.00174 ± .00017 (-0.186%)*
Case 3: Changed Clad Material from Al to SAV-1 and Included 4 cm of SAV-1 tubes to bottom and top of fuel Assembly	1.00152 ± .00019 (-0.036%)*	1.00116 ± .00011 (-0.058%)*
Case 4: Changed radii of the corners of Fuel Elements Based on information received from the RF (fuel density modified to obtain same masses as in model received from VR-1)	0.99928 ± .00010 (-0.224%)*	0.99911 ± .00009 (-0.205%)*

* Difference in reactivity caused by specified change in model.

- **Base Case:** Model of the VR-1 reactor, as received from CTU.
- **Case 1:** Model of the control rods was modified to include the 4.35 cm of stainless steel below the Cd poison.
- **Case 2:** Model used in **Case 1** modified to include the ^{234}U isotope in the fuel meat. Based on information from references 1 and 2, the concentration of ^{234}U in Russian enriched uranium is assumed to be 1.1 w/o of the contained ^{235}U. The concentration of ^{234}U may be slightly different from that assumed but more precise information is not available.
- **Case 3:** Model used in **Case 2** modified to: a) change the fuel element clad from Al to SAV-1; b) increase the length of the fuel elements (58.0 cm) by adding 4.0 cm of SAV-1 tubes to the bottom and top of the fuel elements.
- **Case 4:** Model used in **Case 3** modified to change the corners of the fuel elements to agree with information provided to ANL by Russian colleagues. The outside corners of the fuel elements are provided below:

Outside Corner Radius

Tube #	VR-1 Model	ANL Information
1 (Outer)	1.12	0.92 (cm)
2	1.05	0.84
3	0.98	0.76
4	0.91	0.68
5	0.84	0.60
6	0.77	0.52
7	0.70	0.44

Fuel meat densities in the different fuel elements were changed to keep the masses equal to those used in the model of the VR-1 reactor that was received from the CTU.

The model used in **Case 4** is the model that has been used at ANL for calculations using the IRT-3M fuel assemblies.

Core Configuration C1 with LEU (19.7%) IRT-4M Fuel Assemblies

This configuration is defined as "the essential preliminary core mainly for education and training purposes." The core contains nine 6-tube assemblies and eight 8-tube assemblies. Figure 2 shows a cross section of the core. The input file for this configuration was provided to CTU by ANL. The nominal dimensions of the fuel elements (meat/clad = 0.7 / 0.45 mm) and the nominal ^{235}U masses (200.5 g for the 4-tubes FA, 263.8 g for the 6-tubes FA, and 300.0 g for the 8-tubes FA) were used. In all calculations presented in this study the clad used was SAV-1 and the ratio between the masses of ^{234}U and ^{235}U was assumed to be 1.1%.

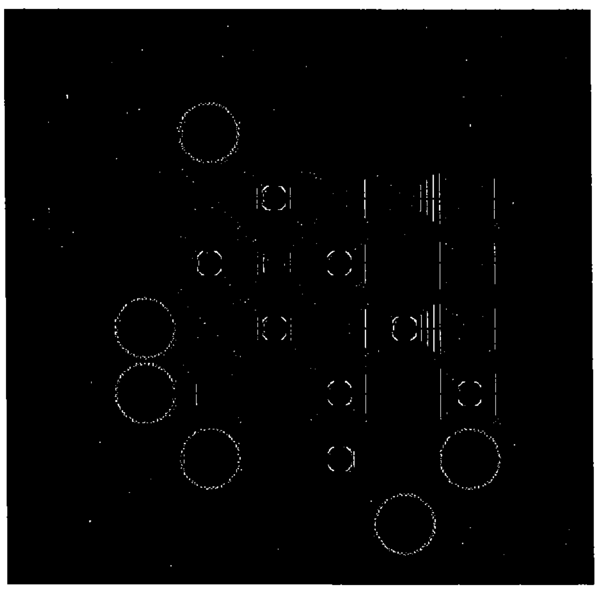

Figure 2. Core Configuration C1 with LEU IRT-4M FA.

The results for the requested calculations are presented below:

1. All control rods at the top positions (680 mm): k-eff = 1.00731 ± 0.00014

2. All control rods at the bottom positions (0 mm): k-eff = 0.92043 ± 0.00017

3. Finding two critical states (k-eff = 1.0) for different control rods positions:

a) CR Positions:

B1=B2=B3= 680 mm
E1=E2=R1=R2= 500 mm
k-eff = 0.99982 +/- 0.00015

b) CR Positions:

B1=B2=B3= 680 mm
E1=E2= 500 mm
R1= 425 mm
R2= 575 mm
k-eff = 1.00063 +/- 0.00013

4. Sensitivity Studies

a) <u>Variation of the total ^{235}U mass in the FA</u>

All the three cases below were analyzed for the CR at the top positions (680 mm), and using the nominal thicknesses for the fuel elements (meat/clad = 0.7 / 0.45 mm).

1. Base Case: All nominal masses as provided above:
   k-eff = 1.00731 +/- 0.00014

2. All FA with the maximum ^{235}U masses (210.5 g for the 4-tubes FA, 276.9 g for the 6-tubes FA, and 315.0 g for the 8-tubes FA)
   k-eff = 1.01392 +/- 0.00013

3. All FA with the minimum ^{235}U masses (190.5 g for the 4-tubes FA, 250.7 g for the 6-tubes FA, and 285.0 g for the 8-tubes FA)
   k-eff = 1.00014 +/- 0.00014

b) <u>Variation of the clad thickness</u>

All the three cases below were analyzed for the CR at the top positions (680 mm), and using the nominal U-235 masses for the fuel assemblies.

1. Base case: Nominal meat and clad thicknesses (meat/clad = 0.7 / 0.45 mm).
   k-eff = 1.00731 +/- 0.00014

2. Meat thickness equal to 0.6 mm and clad thickness equal to 0.5 mm.
   k-eff = 1.00801 +/- 0.00013

3. Meat thickness equal to 1.0 mm and clad thickness equal to 0.3 mm (minimum clad thickness).

k-eff = 1.00771 +/- 0.00014

Core Configuration C2 with LEU (19.7%) IRT-4M Fuel Assemblies

This configuration is defined "mainly for R&D purposes". The core contains ten 6-tube assemblies and ten 8-tube assemblies. In the center of the core is located large graphite unit occupying four positions. Figure 3 shows a cross section of the core. The nominal dimensions of the fuel elements (meat/clad = 0.7 / 0.45 mm) and the nominal ^{235}U masses (200.5 g for the 4-tubes FA, 263.8 g for the 6-tubes FA, and 300.0 g for the 8-tubes FA) were used. In all calculations presented in this study the clad used was SAV-1 and the ratio between the masses of ^{234}U and ^{235}U was assumed to be 1.1%.

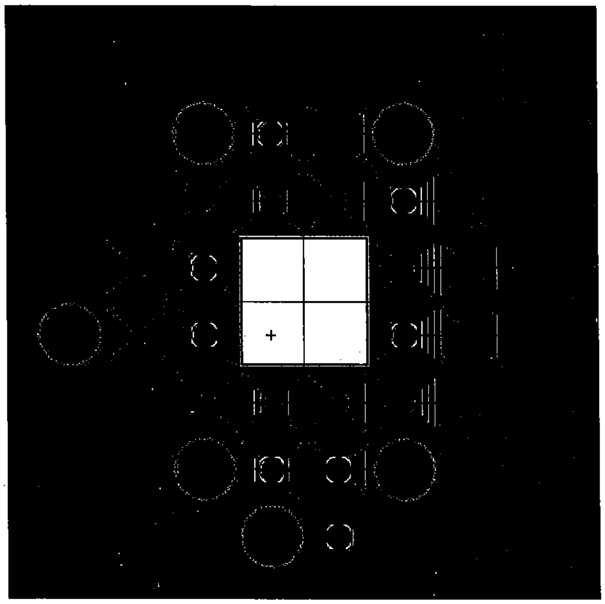

Figure 3. Core Configuration C2 with LEU IRT-4M FA

The results for the requested calculations are presented below:

1. All control rods at the top positions (680 mm): k-eff = 1.01380 ± 0.00013

2. All control rods at the bottom positions (0 mm): k-eff = 0.94615 ± 0.00017

3. Finding two critical states (k-eff = 1.0) for different control rods positions:
   a) CR Positions:
      B1=B2=B3= 680 mm
      E1= 500 mm
      E2= 0 (bottom)
      R1=R2= 375 mm
      k-eff = 1.00042 +/- 0.00015

b) CR Positions:

B1=B2=B3= 680 mm
E1= 500 mm
E2= 0 (bottom)
R1= 300 mm
R2= 450 mm

k-eff = 1.00054 +/- 0.00014

Reactivity Worth for the Individual Control Rods

The reactivity worth of all the individual control rods was calculated by ANL for core configurations B1, C1, and C2. The results are shown in Table 2.

Table 2. Reactivity Worth (% Δk/k) of Control Rods

	IRT-3M FA Configuration B1	IRT-4M FA Configuration C1	IRT-4M FA Configuration C2
B1 rod	2.037 ± 0.028	1.468 ± 0.028	1.291 ± 0.023
B2 rod	2.073 ± 0.028	2.050 ± 0.028	1.227 ± 0.023
B3 rod	1.196 ± 0.027	1.568 ± 0.028	1.203 ± 0.023
R1 rod	0.659 ± 0.026	0.411 ± 0.026	0.542 ± 0.021
R2 rod	0.617 ± 0.025	0.887 ± 0.026	0.590 ± 0.020
E1 rod	1.015 ± 0.025	1.099 ± 0.027	0.861 ± 0.022
E2 rod	Not Applicable	0.955 ± 0.027	0.477 ± 0.023

The control rod worth was calculated by using the difference between the configuration with all control rods out and the configuration with the specific rod fully inserted. This was done because all these three core configurations have a small excess reactivity and operate with the rods B1/B2/B3 always withdrawn, and the other rods inserted only a small fraction of their poison.

For the IRT-4M core configuration C1 calculations were also performed for a hypothetical case in which: a) Base case with control rods B1/B2/B3 withdrawn and all the other rods fully inserted; b) Same as case a) but the specific control rod for which the worth is to be determined is withdrawn. For all cases (control rods R1/R2/E1/E2) the worth of the rods increased (as expected) by less than 0.10%. Note that these calculations were performed just to show that the change in reactivity worth is very small. The results presented in Table 1 above are more appropriate and should be used.

References

1. Yu. V. Petrov, A. N. Erykalov, and M. S. Onegin, "A Neutronic Feasibility Study for LEU Conversion of the WWR-M Reactor at Garchina,", PNPI report to ANL, 2000.
2. Yu. V. Petrov, A. N. Erykalov, and M. S. Onegin, "Accuracy of WWR-M Criticality Calculations with Code MCU-RFFI," Proceedings of the 1999 RERTR International Meeting, Budapest, Hungary, 3-8 October, 1999.