International Conference
Nuclear Energy for New Europe 2003
Portorož, Slovenia, September 8-11, 2003
http://www.drustvo-js.si/port2003

IRIS Core Criticality Calculations

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ABSTRACT

Three-dimensional Monte Carlo computer code KENO-VI of CSAS26 sequence of SCALE-4.4 code system was applied for pin-by-pin calculations of the effective multiplication factor for the first cycle IRIS reactor core. The effective multiplication factors obtained by the above mentioned Monte Carlo calculations using 27-group ENDF/B-IV library and 238-group ENDF/B-V library have been compared with the effective multiplication factors achieved by HELIOS/NESTLE, CASMO/SIMULATE, and modified CORD-2 nodal calculations. The results of Monte Carlo calculations are found to be in good agreement with the results obtained by the nodal codes. The discrepancies in effective multiplication factor are typically within 1%.

1 INTRODUCTION

International Reactor Innovative and Secure (IRIS) is a modular, integral, light water cooled small to medium power (350 MWe/module) reactor, which is aimed at achieving the four major objectives set by the U.S. Department of Energy for the Generation IV nuclear systems including proliferation resistance, enhanced safety, economic competitiveness and reduced waste. An international consortium of industry, laboratory, university and utility establishments, led by Westinghouse, is currently developing IRIS. The Faculty of Electrical Engineering and Computing, University of Zagreb has participated in the IRIS project since the year 2001 and its involvement is primarily in the areas of neutronics design and safety analyses of IRIS transients.

This paper describes Monte Carlo criticality calculations of the first cycle IRIS reactor core benchmark without thermal-hydraulic feedback (so called Benchmark 44). The short description of the IRIS reactor core and modeling assumptions are presented in Section 2. Calculational tools are given in Section 3, while the results of calculations and comparison with the results obtained by nodal codes are presented in Section 4. Conclusion is given in Section 5.

2 DESCRIPTION OF THE IRIS REACTOR CORE AND MODELING ASSUMPTION

The IRIS reactor core consists of 89 fuel assemblies (FAs). Each fuel assembly contains 204 rods arranged in 15 × 15 matrix. The fuel assembly cross-section is given in Figure 1. Active fuel height is 426.72 cm with axially uniform enrichment (either 2.6 or 4.95 w/o ^{235}U). The total core height, including top and bottom axial reflector regions, is 506.72 cm. Radial reflector was modeled using reflector cells of the same dimensions as FA. Unit fuel cell

includes fuel pellet, clad and moderator regions. Guide thimble (GT) and instrumentation tube (IT) cells are identical. Unit fuel cell and instrumentation tube cell are given in Figure 2. According to the Benchmark 44 specification the grids were smeared over the moderator and assumed to occupy 1% of the moderator volume. Some FAs contain **I**ntegral **F**uel **B**urnable **A**bsorbers (IFBA) in form of a thin layer ZrB_2 coating on fuel pellets. The IRIS core and reflector configuration is depicted in Figure 3. As shown in Figure 3 the axial distribution of IFBA is not uniform. The fuel stack is axially composed of: 30.48 cm of enriched uncoated fuel, 365.76 cm of enriched coated fuel (lower half has 20% more ^{10}B than the upper half), and 30.48 cm of enriched uncoated fuel. Radius of coated pellets can be found from the Eq. (1):

$$r_{ZrB_2} = \sqrt{r_{UO_2}^2 + \frac{x \cdot 10^{-3}}{w_{B-10} \cdot \rho \cdot \pi}} \tag{1}$$

where

x = IFBA concentration expressed in mg/cm

r_{UO_2} = fuel pellet radius expressed in cm

ρ = nominal density of the ZrB_2 expressed in g/cm^3

$w_{B\text{-}10}$ = weight fraction of ^{10}B in the ZrB_2.

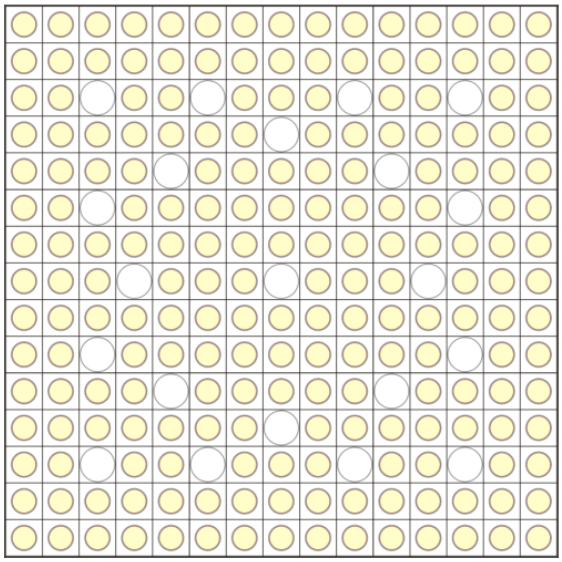

Figure 1: Fuel assembly cross-sectional view

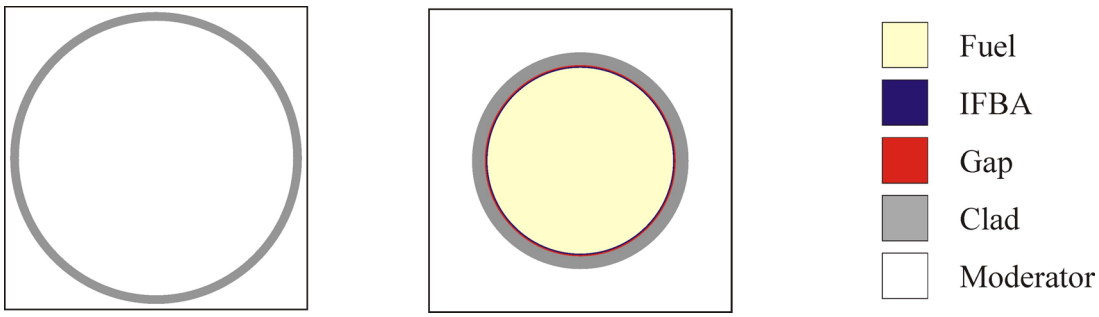

Figure 2: Instrumentation cell and fuel cell cross-sectional view

Fuel assembly dimensions, assumed materials, temperatures by region, isotopic composition and atomic number densities of materials are specified in the Benchmark 44 document [1].

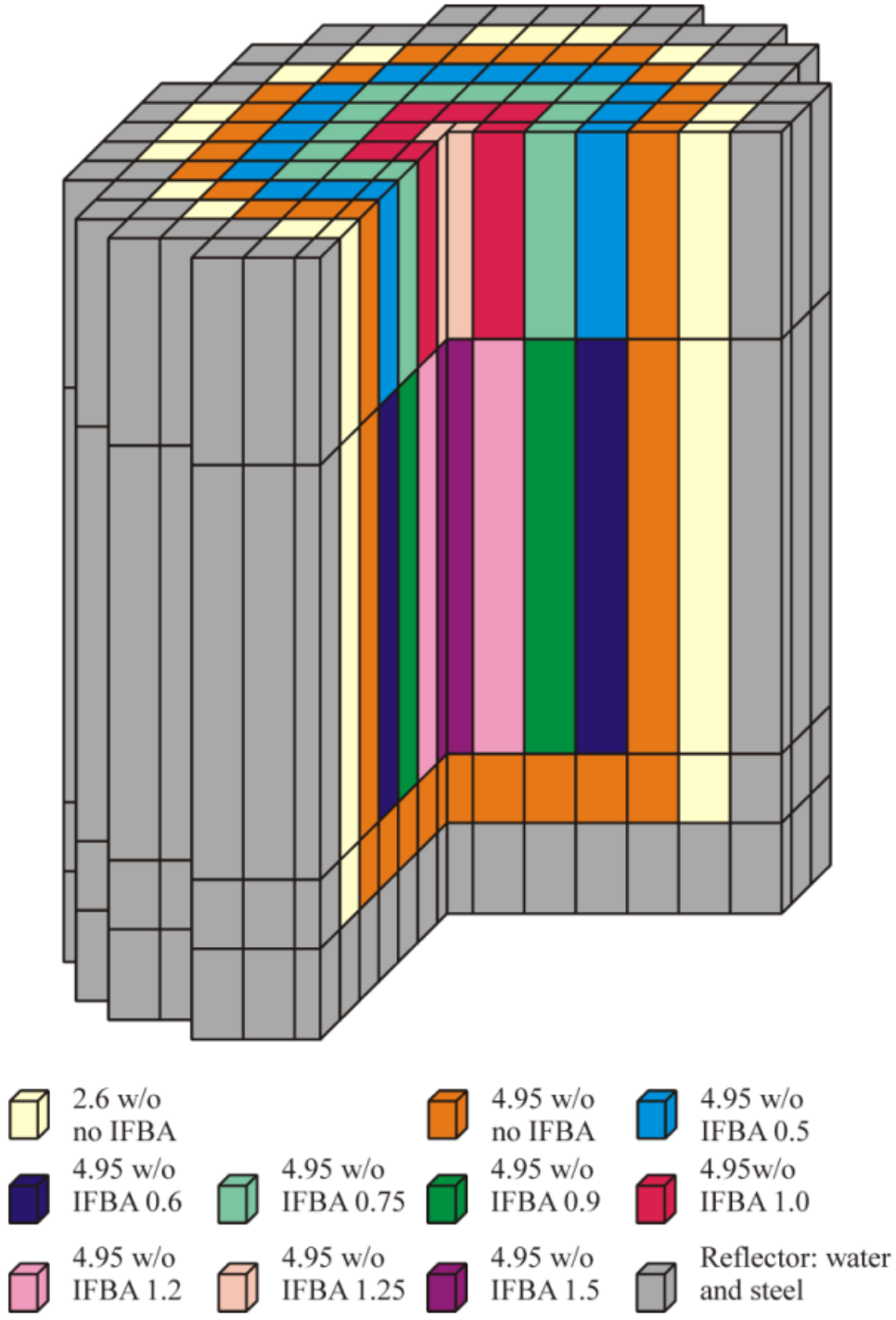

Figure 3: 3D Axial and radial distribution of IFBA

3 CALCULATIONAL TOOLS

Calculations of the IRIS core criticality have been performed by the SCALE-4.4 (**S**tandardized **C**omputer **A**nalyses for **L**icensing **E**valuations) code package developed at Oak Ridge National Laboratory. The SCALE system comprises a number of functional and control modules. The functional modules within SCALE package are the individual codes either selected from well-established computer codes or developed based on reliable nuclear methods. They provide specific capabilities required for solving of particular problems. Although, each of the functional modules can be executed as an individual module, automation of the calculational sequence can speed up solving the problem. Therefore, control modules are used to automate the necessary data processing and manipulation.

Criticality safety analyses are performed via the criticality safety analyses sequences (CSAS), and in the particular case of IRIS calculations, CSAS26 sequence has been used. The control module runs BONAMI, NITAWL and KENO-VI functional modules. BONAMI and NITAWL are used for the preparation of the resonance-corrected microscopic cross-section library. KENO-VI [2] is a multi-group Monte Carlo criticality program used to calculate the k_{eff} of a three-dimensional system.

We have chosen the Monte Carlo method because of the following advantages:

- accurate geometric models can be used
- there is no need for homogenized and adjusted cross-sections
- heterogeneity and voids cause no difficulty since individual neutrons are tracked collision by collision through every region specified.

Improvements of computer technology and usage of Windows operating systems enabled graphical input processors to be developed and used for simplified preparation of input data. CSPAN-VI [3] (**C**riticality **S**afety **I**nput **P**rocessor for **A**nalysis) is a Windows 95/98/NT/2000 program that assists the CSAS/KENO-VI users in creating and executing SCALE CSAS input files. It is specifically designed to run with SCALE-4.4 or later on a Windows PC.

4 RESULTS AND COMPARISON

The Monte Carlo pin-by-pin criticality calculations of IRIS Benchmark 44 for beginning of cycle conditions have been performed using ENDF/B-IV 27-group library and ENDF/B-V 238-group library, and the results obtained for effective multiplication factor (k_{eff}) are 1.2387 ± 0.0008 and 1.2428 ± 0.0007, respectively. The above-mentioned results were obtained by using 1000 generations of 1000 neutrons per generation and by skipping 14 generations and 18 generations, respectively. These results were compared with our results [4] obtained by nodal code (modified CORD-2 package [5,6]), with University of Tennessee/Oak Ridge National Laboratory (UT/ORNL) result (using HELIOS/NESTLE code system), and with Politecnico di Milano (POLIMI) result (using CASMO/SIMULATE code system). The above-mentioned results are listed in Table 1, where our results are denoted as FER (**F**akultet **e**lektrotehnike i **r**ačunarstva Zagreb). As shown in Table 1 cross-section libraries that were used in all codes were based on different nuclear data files. The maximal difference between the results obtained by the Monte Carlo method of calculation and the nodal code method of calculation was approximately 1%. It should be noted that radial reflector thickness in UT/ORNL simulation was higher than in all other simulations.

Table 1: Comparison of results for effective multiplication factor

Participant	Code System	Library	No. of Groups	k_{eff} results
UT/ORNL	HELIOS/ NESTLE	ENDF/B-VI.3	45	1.23254
POLIMI	CASMO/ SIMULATE	ENDF/B-IV	70	1.23862
FER-1	Modified CORD-2	ENDF/B-VI.5	69	1.24741
FER-2	Modified CORD-2	JEF 2.2	69	1.25615
FER-3	SCALE-4.4/ KENO-VI	ENDF/B-V	238	1.2428±0.0007
FER-4	SCALE-4.4/ KENO-VI	ENDF/B-IV	27	1.2387±0.0008

5 CONCLUSION

The Monte Carlo pin-by-pin criticality calculations of the first cycle IRIS reactor core benchmark without thermal-hydraulic feedback have been successfully performed using CSAS26 sequence of SCALE-4.4 code package. The effective multiplication factors obtained by the above mentioned Monte Carlo calculations using 27-group ENDF/B-IV library and 238-group ENDF/B-V library have been compared with the effective multiplication factors obtained by several nodal calculations. The comparison showed that our Monte Carlo results for k_{eff} are in good agreement with nodal code results (discrepancies are approximately 1%).

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