Advances in Physics Theories and Applications
ISSN 2224-719X (Paper) ISSN 2225-0638 (Online)
Vol.23, 2013
www.iiste.org

Designing a 2D RZ Venture Model for Neutronic Analysis of the Nigeria Research Reactor-1 (NIRR-1)

Salawu, A.[1*], John R.White[2], Balogun, G.I.[3], Jonah, S.A.[3], Zakari, Y.I[4]

1. Department of Physics, University of Abuja, Gwagwalada, Abuja, Nigeria
2. Department of Chemical and Nuclear Engineering, UMASS Lowell, MA-USA
3. Center for Energy Research and Training, ABU, Zaria, Nigeria
4. Department of Physics, Ahmadu Bello University, Zaria, Nigeria

* E-mail of the corresponding author: salawuhameed@yahoo.com*,

Abstract

A 2D RZ VENTURE model has been developed for the Nigeria Research Reactor-1 (NIRR-1) and this model was used to perform neutronic analysis for the system using the code "VENTURE-PC". The major homogenized regions in the 2D VENTURE model include the active fuel region and the control region while the remaining components in the system geometry where modelled as closely as possible. The reactor physics parameters generated from the neutronic calculations include excess reactivity, control rod worth, shim worth, shutdown margin. The model predictions of these parameters for NIRR-1 system were in good agreement with experimental results as well as the results from similar calculations using different nuclear analysis tools. This 2D RZ VENTURE model gives an excellent simulation of the Nigeria Research Reactor-1 and the model will be very helpful in the future analysis of the system, as well for developing an LEU core model for future conversion of NIRR-1 from HEU to LEU fuelled research reactor.

Keywords: Model, Neutronics, geometry, code, Design, Reactor, Simulation, Calculations, NIRR-1, Shim, Control, Shutdown, Physics. Peak, Density, Power, Flux, Neutron

1. Introduction

The initial model for the Nigeria Research Reactor (NIRR-1) core physics calculations was designed by the China Institute of Atomic Energy with computer codes HAMMER and EXTERMINATOR-2 (FSAR, 2005). These design calculations were repeated in Nigeria with WIMS/CITATION and MCNP (See references 1 and 2). HAMMER and EXTERMINATOR are the first set of codes used to solve reactor physics problem (using diffusion theory method) followed by WIMS and CITATION. Another set of codes that is manufactured and used today in the United States (the originator of EXTERMINATOR, CITATION and MCNP) are the SCALE code system and the VENTURE code. Many regulators, licensees, and research institutions around the world have used these codes for reactor safety analysis and design (SCALE, 2011). The U.S Nuclear Regulatory Commission (NRC) used SCALE code a lot for their licensing operations and evaluations. The successful core conversion studies of the University of Massachusetts Lowell research reactor was done with the codes SCALE, VENTURE and MCNP (White, 2011). Information available to us from the literature has shown that research has never been conducted on any MNSR type reactors around the world using this version of the diffusion theory code (i.e. VENTURE-PC). Therefore, a repeat design calculation for NIRR-1 is required with a view to validate the SCALE and the VENTURE codes for the MNSR before designing an LEU core model (in the future) for core conversion study of the system from HEU to LEU fuel. Since the present NIRR-1 core was designed with diffusion theory codes, utilizing a recent version of such code to design an LEU core model for the system is extremely important. The 2D RZ VENTURE model developed in this work for the present NIRR-1 system was used to perform neutronic calculations for the system and a number of reactor design parameters were generated. It gives an excellent simulation for NIRR-1 system and such model will be very helpful in the future analysis of any MNSR type research reactors.

Methodology

A manual sketch of the basic geometry for the 2D RZ VENTURE model for NIRR-1 core arrangement, showing the dimensions of some important components, is provided in figure 1. The active core region of this model is a homogenized mixture of the fuel pin, the tied rods, the dummy pins and the moderating material (i.e. water). The active region of the control rod is also a mixture of the poison material, the clad, the water and the control rod guide tube. The non fuel region shown in the figure is a homogeneous mixture of water and Al alloy plug on each end of the fuel pin. Note that the big arrow head shown in the figure 1 indicate the direction of the coolant flow in and out of the reactor core. Figure 2 shows the result of the Matlab code written to reproduce this 2D RZ VENTURE model as well as generating automatically some of the input data require for the criticality calculation using the VENTURE code. In this VENTURE model for NIRR-1, the active poison region of the control material and the control rod follower was broken into 26 and 18 regions respectively (see figure 2). This was done in order to allow easy movement of the control rod for various criticality calculations. The result from this calculation was used to determine the integral worth of the control rod. A total of 10 different regions were created for the placement of top beryllium shims (see figure 2) and these were used to determine the reactivity worth associated with beryllium shims addition.

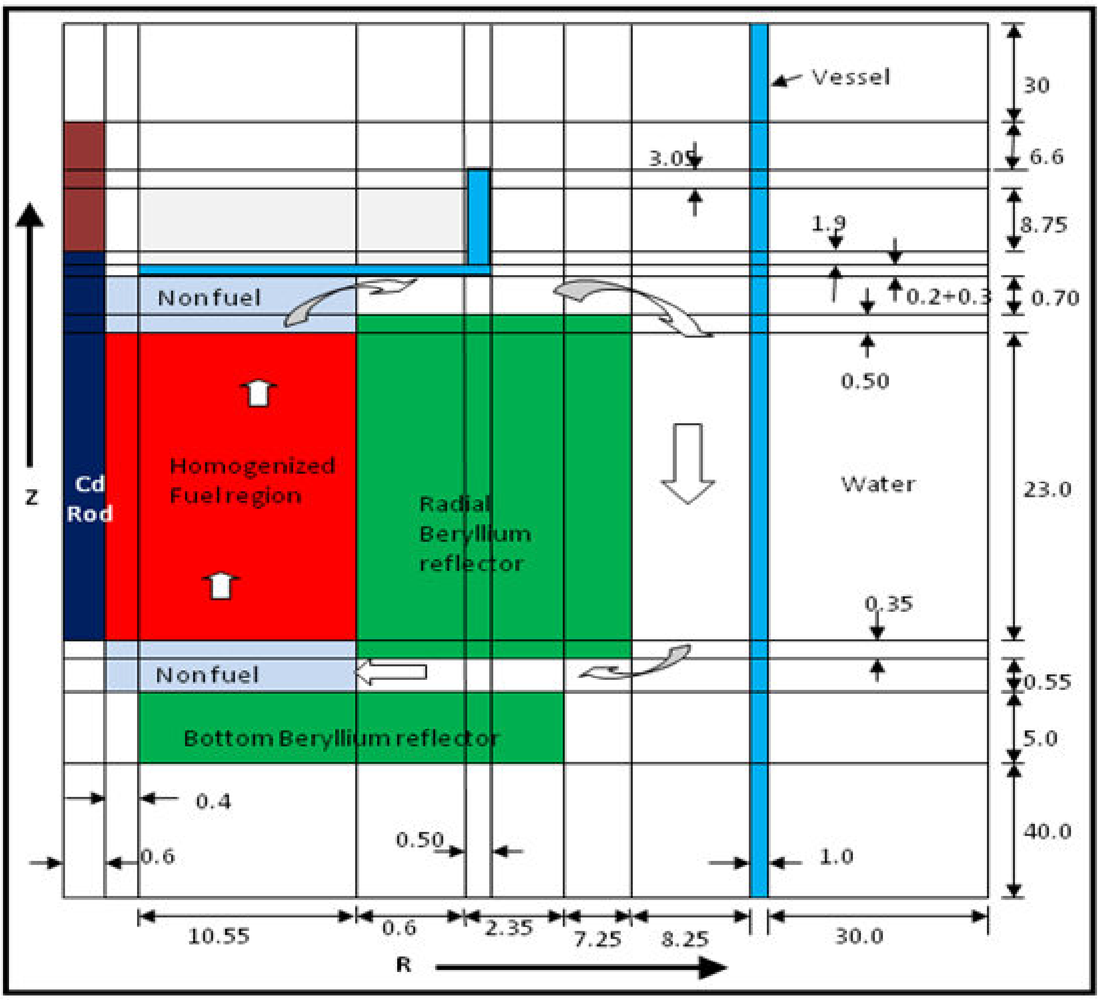

Figure 1: A manual sketch of the basic geometry of the 2-D VENTURE model for NIRR-1 (Note: dimensions in cm)

Result and Discussion

The 2D RZ VENTURE model developed in this work was used within the VENTURE code to generate a number of k-effective data at different control rod withdrawal positions for the NIRR-1 system and these data were used to determine the reactivity worth of the control rod. A plot of the reactivity changes as a function of the control rod withdrawal distance for the present NIRR-1 system is shown in figure 3. These calculations using the 4 group theory as well as the similar result using a simple 2-group method provided the total control rod worth for NIRR-1 as shown in table 1. The observed slight difference in these results as provided in the table is due to the differences in energy resolution between the two methods used. Since we could not model the reactivity regulators in the 2D VENTURE model for NIRR-1, such a slight increase in the value of the control rod worth shown in the table as compared to the experimental result of 7.0mk is actually expected.

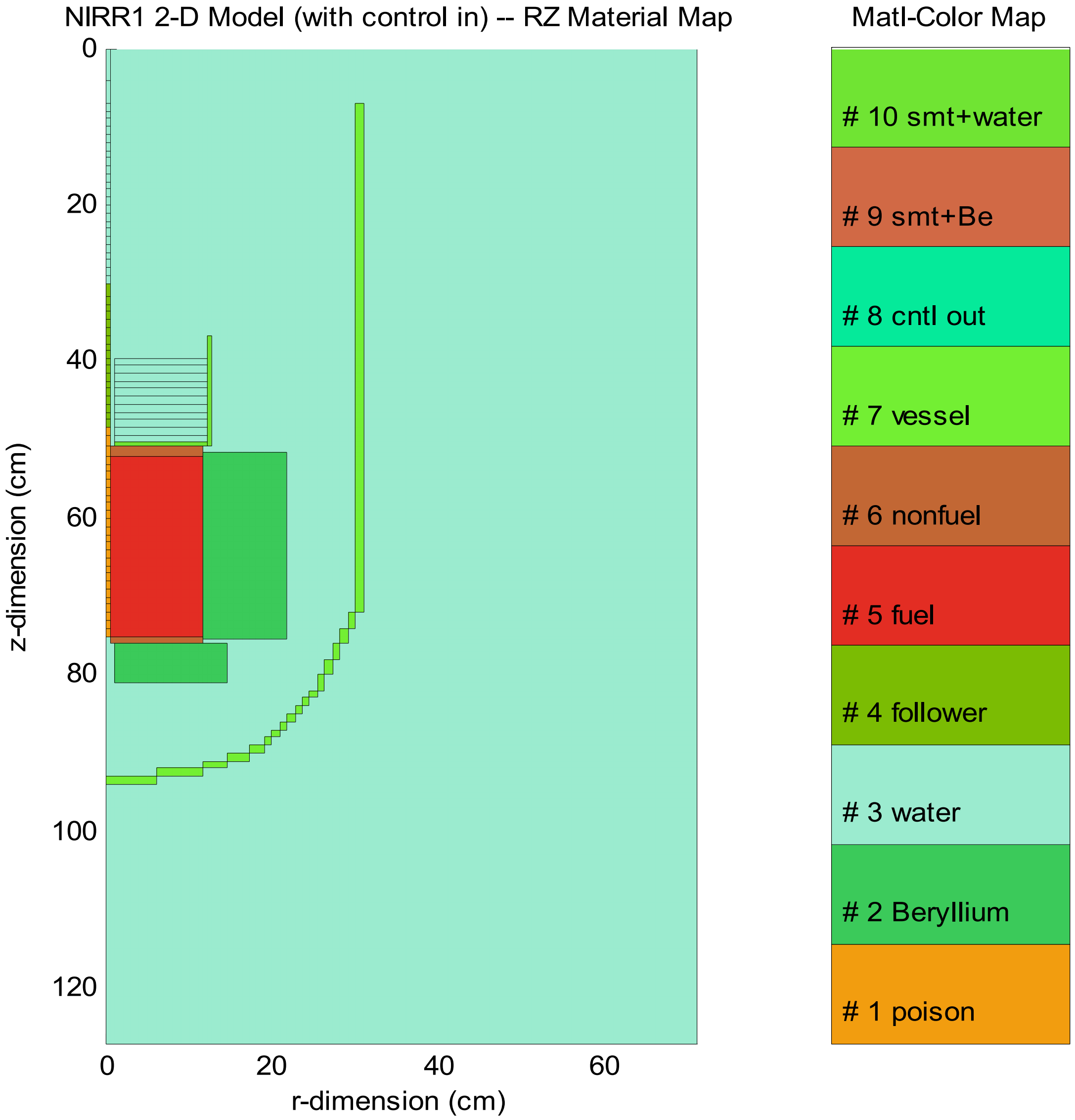

Figure 2: The main geometry and material layout of NIRR-1 core configuration showing control rod at fully inserted position without top beryllium shims.

The value of 7.2mk of the total control rod worth obtained in this work from the 4g calculation is in good agreement with the result of the similar calculations performed at the Centre for Energy Research and Training of Ahmadu Bello University here in Nigeria (see references 1 and 2). Note that the total control rod worth of 7.61mk reported in the 2007 MCNP calculation was for the control rod travel length of about 27.0cm. Since the actual travel length of NIRR-1 control rod is 23.0 cm, the total rod worth of about 7.1mk associated with 23cm travel length from this MCNP calculation was used to make the comparison.

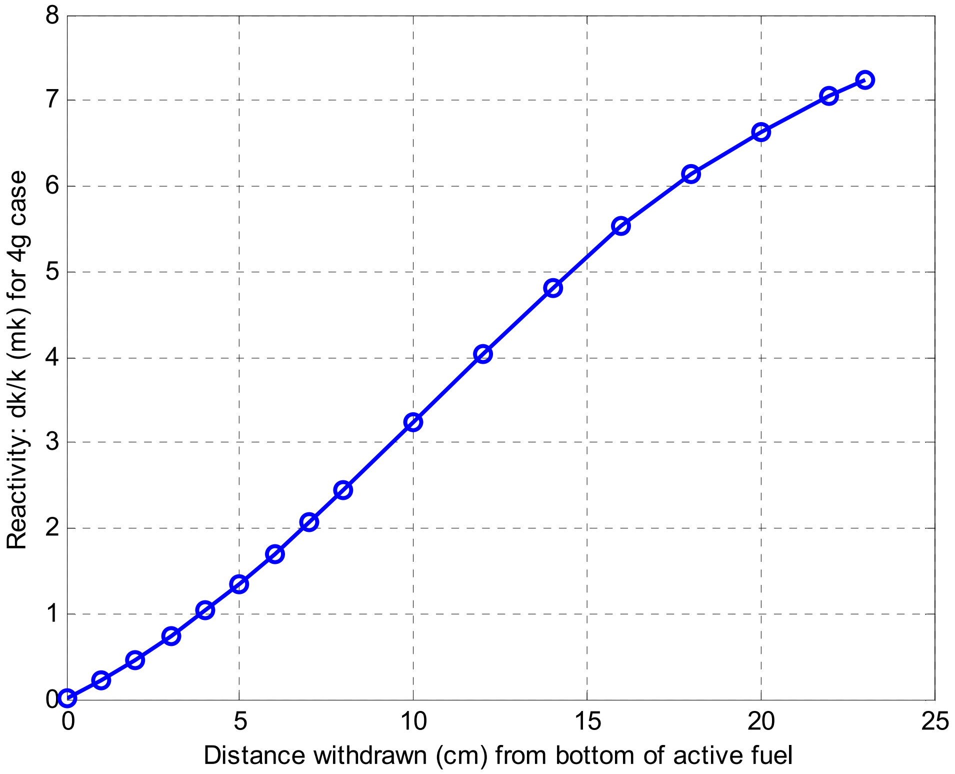

Figure 3: Reactivity versus control rod withdrawal length for NIRR-1 system.

The result from the simple 2 group calculations as shown in table 1 does not seem unreasonable as compared with the experimental result or the results from the 4 group calculation which is more computationally intensive and time consuming. It was included in this work in order to demonstrate that a simple 2 group calculation can also give a good result for a nuclear system as compared to a more complicated calculation method.

Table 1: Total control rod worth: 2 group versus 4 group theory result (worth in mk).

Name of the Parameter	**4 group theory**	**2-group theory**
Control Rod worth	7.20	7.83
Shim worth (10.95cm)	19.64	16.15
Excess reactivity	5.55	5.63

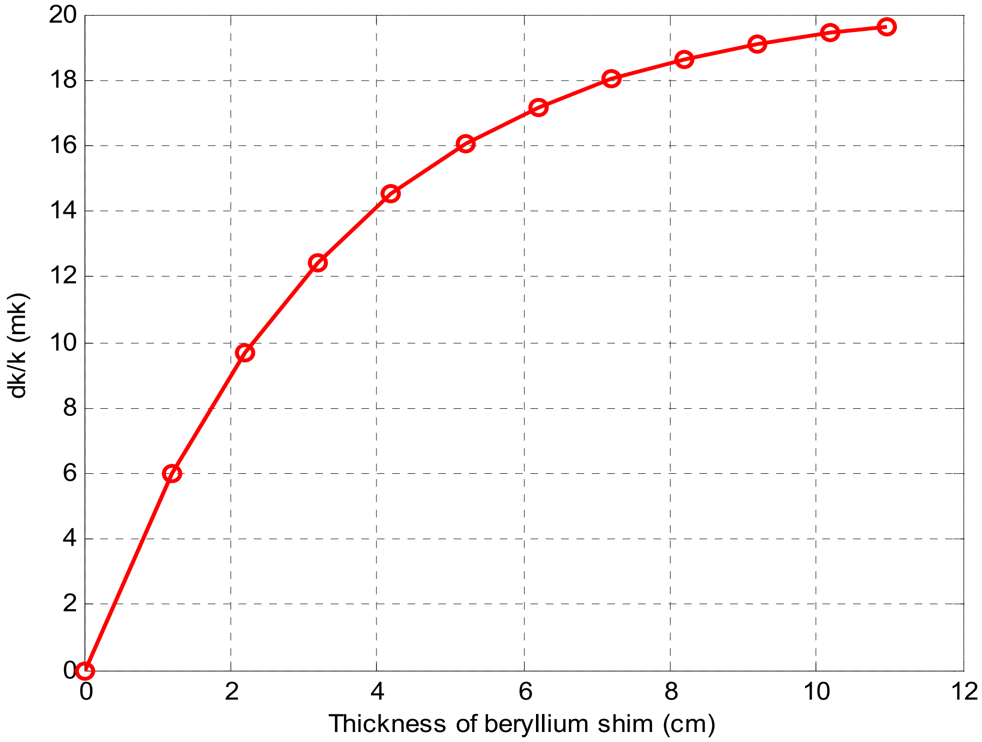

Figure 4: The top beryllium shim worth curve for the present NIRR-1.

Similarly, a number of k-effective data as a function of top beryllium shim thickness using the 2 group and the 4 group calculation methods was also generated. These data was used to determine the reactivity worth of the top beryllium shims. A plot of the shim worth curve generated from such data for the present NIRR-1 system using the 4 group calculation method is as shown in figure 4.

Conclusion

The results from the neutronic calculation using the VENTURE computer code were in good agreement with similar calculations using either the MCNP or the CITATION/EXTERMINATOR code. The control rod worth as well as the top beryllium shim worth was slightly higher than the experimental result. This is exactly what was expected since the reactivity regulators were pulled out of the reactor core in the 2D VENTURE model for NIRR-1 system. The model developed in this work can be very helpful in future analyses of NIRR-1 system. The result from the 2 group calculation does not seem unreasonable as compared with the experimental result. It was included in this work in order to demonstrate that a simple 2 group reactor physics theory can also give a good result as compared to the experimental result or a more complicated 4 group or higher group calculation method.

References

1. Balogun, G.I. (2003): Automating some analysis and design calculation of miniature neutron source reactors at CERT (I), Annals of nuclear energy, Vol. 30, 81-92
2. Jonah, S.A., Liaw, J.R. and Matos, J.E. (2007): Monte Carlo simulation of core physics parameters of the Nigeria Research Reactor-1 (NIRR-1), Annals of nuclear energy, , Vol. 34 953-957
3. FSAR, 2005: Safety Analysis Report for Nigeria Research Reactor-1, Centre for Energy Research and Training ABU Zaria, Nigeria.
4. SCALE (2011): A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design, ORNL/TM-2005/39 , Version 6.1, June 2011. Available from Radiation Safety Information Computation Center at Oak Ridge National Laboratory as CCC-785
5. J. R. White and L. Bobek, “Startup Test Results and Model Evaluation for the HEU to LEU Conversion of the UMass-Lowell Research Reactor,” 24th Intl. Mtg. on Reduced Enrichment for Research and Test Reactors, San Carlos de Bariloche, Argentina (Nov. 2002).

This academic article was published by The International Institute for Science, Technology and Education (IISTE). The IISTE is a pioneer in the Open Access Publishing service based in the U.S. and Europe. The aim of the institute is Accelerating Global Knowledge Sharing.

More information about the publisher can be found in the IISTE's homepage:
http://www.iiste.org

CALL FOR JOURNAL PAPERS

The IISTE is currently hosting more than 30 peer-reviewed academic journals and collaborating with academic institutions around the world. There's no deadline for submission. **Prospective authors of IISTE journals can find the submission instruction on the following page:** http://www.iiste.org/journals/ The IISTE editorial team promises to the review and publish all the qualified submissions in a **fast** manner. All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Printed version of the journals is also available upon request of readers and authors.

MORE RESOURCES

Book publication information: http://www.iiste.org/book/

Recent conferences: http://www.iiste.org/conference/

IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digtial Library , NewJour, Google Scholar