Three-Dimensional Benchmark Model Establishment for VENUS-3 Reactor

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1. Introduction

The benchmark-models for VENUS-3 reactor are established as a part of International Reactor Physics Experiments Evaluation Project (IRPhEP) managed by OECD/NEA. The benchmark models for VENUS-3 experiment consist of critical configuration benchmark-model, reaction-rate distribution benchmark-model and power distribution benchmark-model. The criticality calculation is performed to obtain the k_{eff} and 3-dimensional power distributions, and the neutron transport calculation is performed to obtain the reaction rates distribution. The results obtained using these benchmark-models are compared with the experimental data.

2. Specification of Benchmark-Models

For some early built reactors, it is proposed to reduce the lead factor at the level of the pressure vessel horizontal welding by loading partial length shielded assemblies (PLSA) at the most critical corners of the core periphery. For benchmarking this configuration, the VENUS-3 core has been built with 3/0-SS rods at the periphery (the 3/0-SS rods are made of half a length of stainless steel and half a length of 3.3% ^{235}U enriched UO_2 fuel). Thus, the 3-dimensional benchmark-model is necessary for the description of this heterogeneity and the experimental values are also provided as 3-dimensional distribution.

2.1 Critical Configuration Benchmark-Model

The core of VENUS-3 reactor has 4/0 fuel rods in the inner zone and has 3/0 fuel rods and 3/0-SS PLSA in the outer zone as shown in Figure 1(3/0 means 3.3% ^{235}U and 0% PuO_2, 4/0 means 4% ^{235}U and 0% PuO_2). The pyrex rods are distributed in the inner zone of the core so that the core is in critical condition without boron in water. The VENUS facility is a zero power reactor and the water temperature is 24.0℃[1].

The critical configuration benchmark-model is constructed based on the Monte carlo code, MCNP4C[2]. As the depletion calculation is not necessary for VENUS-3 reactor, the criticality calculation is performed using the initial core condition. As the PLSA are loaded at 0˚ and 180˚ in two arm of the cruciform core, the quadrant core model is constructed so that the quadrant region includes both the PLSA fuel region and the unperturbed reference fuel region. The structures outside the air jacket have negligible effect on the critical condition. Thus, the structures beyond the inner jacket are not modeled and the outer boundary condition is taken as vacuum.

Most structures are thoroughly described in the model to achieve the critical condition. Especially, the detailed fuel rod geometries including blanket, reflector and stop are described and the upper and lower structures are also thoroughly modeled. The upper and lower boundary conditions along the axial direction are taken as vacuum. The upper boundary is taken as the top surface of water level and the lower boundary is taken as the bottom surface of reactor support.

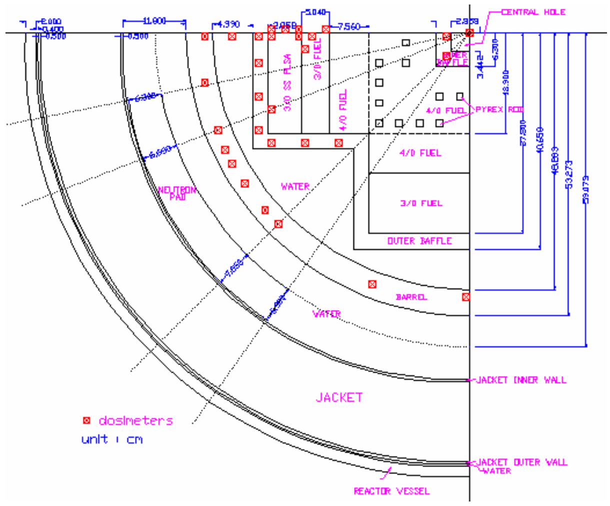

Figure 1. Cross sectional view of VENUS-3 reactor

2.2 Reaction Rate Distribution Benchmark-Model

The VENUS-3 reactor provides the 3-dimensional reaction-rate distribution measured at 386 dosimeters. The axial locations of these dosimeters are among 14 different levels between 105 cm and 155 cm. The experimental target quantities are three reactions with $^{58}Ni(n,p)$, $^{115}In(n,n')$ and $^{27}Al(n,\alpha)$. The nickel detector is comparable to fluxes above 3 MeV, the indium detector to fluxes above 1 MeV and the aluminum detector indicates the extreme hard end of the neutron spectrum above 8 MeV.

The reaction-rate distribution benchmark model is constructed based on three-dimensional discrete ordinates transport code, TORT[3]. The BUGLE96 cross section library[4] is used as microscopic cross sections for this transport calculation. Like the critical configuration model, the quadrant symmetric model is applied for neutron transport calculation. The structures beyond the neutron pad have negligible effect to the results, so the outer structures outside of neutron pad are not included. The 10 cm height water reflectors are assumed above and below the active core region.

The calculation model is described using XYZ co-ordinates. The core is assumed as homogenized material and the nuclides of the core compositions are uniformly mixed. All dosimeters are assumed to be point detectors without surrounding structures and the reaction rates are calculated using the fluxes at the corresponding detector position.

The fixed source transport calculation is performed and the measured 3-dimensional pin power distribution is used as the spatial source distribution. The reference core average fission rate is given as 5.652×10^{12} [fissions/sec/quadrant]. The local source is determined as the product of the fission rate and the neutron yield. As the VENUS-3 reactor is established to simulate a beginning of life-fresh UO_2 fuel, the fission spectrum and neutron yields of ^{235}U are adopted.

2.3 Power Distribution Benchmark Model

The 3-dimensional power distribution is obtained using the critical configuration benchmark-model described in section 2.1. The benchmark-model is based on 3-dimensional MCNP4C calculation and the fuel region is axially divided into several layers with the height of 3 ~ 4 cm according to the measured data. The detailed upper and lower structures are described without simplification for the credible simulation of the power at the top and bottom layers.

The power distributions are represented as a relative values to the average fission density over the quadrant core.

3. Comparison with Measurement

3.1 The k_{eff} and Power Distribution

The criticality calculations are performed to obtain k_{eff} and pin power distributions using quadrant core model with MCNP4C. The number of histories of the 3-dimensional core calculation is $10^3 \times 10^5$(10^3 cycles with 10^5 particles per cycle). The calculated k_{eff} is 0.99429 ± 0.00007. The VENUS-3 experiment satisfies the critical condition and the experimental k_{eff} is 1.0. Thus, the result shows some underestimation.

The 3-dimensional power distributions have been measured at fourteen different vertical planes. Each vertical plane consists of a 30×30 matrix of relative source values at each pin location. Not all sources were measured in the VENUS-3 experiment. The missing source values were interpolated by the NEA.

The calculated power distributions show quite good agreement except for the highest or lowest layer of the pins neighboring to the inner or outer baffle. The deviation from the measured values are represented in the form of 100(C-E)/E, where C is the calculated result and E is the experimental values. The average deviation of all results is calculated as $0.20\% \pm 3.18\%$. The nodes at the highest and lowest layers show some overestimation about 4%. The nodes at edge region show a little higher deviation. As a whole, most of the results show less than 5% deviation with the measurement data.

3.2 Reaction Rate Distribution

The calculated reaction rates are compared with measurements in terms of equivalent fission fluxes. The equivalent fission fluxes are defined as a ratio of activation cross sections weighted by neutron spectrum at each location and those weighted by fission spectrum of ^{235}U. Therefore, the comparison of equivalent fission fluxes gives better measures of the accuracy of transport calculation itself, reducing the dependence on the used activation cross section.

With few exceptions, all three-dimensional results fit within a narrow band of ±10% around the measurements. A few larger deviations are concentrated within the upper and lower regions of active core height because the simulated neutron behavior from the reflector region can be more uncertain. As a whole, the calculations show deviations less than ±5% to the experiment mainly in the high flux region, where 77% of all detectors are located. And slightly larger deviations in the low flux region at the axial core edges, where the remaining 23% of detectors are located.

4. Conclusion

The 3-dimensional benchmark-models for VENUS-3 reactor were established for the analysis of critical configuration, reaction-rate distribution and power distributions. The criticality calculation and neutron transport calculation were performed using these models and the results were compared with experimental data. The calculations showed good agreement with the measured data. The established benchmark-models in this paper will be described in experiment format for VENUS-3 reactor as a part of IRPhEP[5].

REFERENCES

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