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INTRODUCTION

One of the high priority benchmarking activities for corroborating the Next Generation Nuclear Plant (NGNP) Project and Very High Temperature Reactor (VHTR) Program is evaluation of Japan's existing High Temperature Engineering Test Reactor (HTTR). The HTTR is a 30 MWt engineering test reactor utilizing graphite moderation, helium coolant, and prismatic TRISO fuel. A large amount of critical reactor physics data is available for validation efforts of High Temperature Gas-cooled Reactors (HTGRs).

Previous international reactor physics benchmarking activities provided a collation of mixed results that inaccurately predicted actual experimental performance.[1] Reevaluations were performed by the Japanese to reduce the discrepancy between actual and computationally-determined critical configurations.[2-3] Current efforts at the Idaho National Laboratory (INL) involve development of reactor physics benchmark models in conjunction with the International Reactor Physics Experiment Evaluation Project (IRPhEP) for use with verification and validation methods in the VHTR Program. Annular cores demonstrate inherent safety characteristics that are of interest in developing future HTGRs and have recently been assessed evaluated as benchmarks.

DESCRIPTION OF THE ACTUAL WORK

The initial fully-loaded, cold-critical, configuration of the HTTR start-up core[4] was previously evaluated for inclusion in the IRPhEP Handbook[5] and summarized elsewhere.[6] A comprehensive description of the benchmark models for the five annular core configurations developed during the start-up physics tests, which is being discussed in this paper, have also been evaluated for inclusion in the IRPhEP Handbook.[7]

The publicly available dimensions, compositions, and uncertainties for defining and analyzing the HTTR benchmark were obtained.[1-4,8-9] Nozomu Fujimoto, from the Oarai Research Development Center, was instrumental in correctly identifying and applying values from the open literature. Unfortunately, much of the data regarding the HTTR that would be fundamental in developing an in-depth benchmark analysis are not publicly available.

The annular core configurations (Figure 1) include the initial critical configuration achieved with 19 fuel columns. The non-fueled columns, or dummy fuel, were blocks of graphite that were replaced column-by-column until the core was fully loaded. As the dummy fuel columns were replaced with fuel, additional geometries were developed that represented both thin and thick annular cores. The 24-fuel-column core had two criticality conditions measured: a configuration controlled by the in-core control rods and another controlled solely by the control rods inserted into the radial reflectors. The fully-loaded core configuration (not shown) consists of 30 fuel columns, which was previously benchmarked.[5-6] The benchmark analysis of the HTTR annular core configurations was performed using MCNP5 (Reference 10) with the ENDF/B-VII.0 neutron cross-section data.[11]

RESULTS

A summary of the benchmark analysis results is provided in Table I. As discussed in the full-core benchmark analysis,[5-6] significant uncertainty in the effective eigenvalues can be attributed to the uncertainty in the boron content of the IG-110 and PGX graphite found in the core and reflector, respectively. Additional significant uncertainty unique to the annular core geometries includes the boron content of the IG-11 graphite in the dummy blocks. The expected benchmark eigenvalues have been corrected for the removal of instrumentation from the HTTR core. The calculated eigenvalues are approximately 2-3% greater than the expected benchmark eighenvalues, similar to results obtained for the fully-loaded core benchmark assessment. Additional HTTR data is necessary to improve the quality of the benchmark evaluation prior to further assessment of the implications regarding the calculated benchmark results.

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REFERENCES

1. "Evaluation of High Temperature Gas Cooled Reactor Performance: Benchmark Analysis Related to Initial Testing of the HTTR and HTR-10," IAEA-TECDOC-1382 (2003).
2. K. YAMASHITA, et al., "Startup Core Physics Tests of High Temperature Engineering Test Reactor (HTTR), (I)," *J. At. Energy Soc. Jpn.*, **42**, 30 (2000) [in Japanese].
3. N. FUJIMOTO, et al., "Start-Up Core Physics Tests of High Temperature Engineering test Reactor (HTTR) (II)," *J. At. Energy Soc. Jpn.*, **42**, 458 (2000) [in Japanese].
4. N. FUJIMOTO, et al., "Annular Core Experiments in HTTR's Start-Up Core Physics Tests," *Nucl. Sci. Eng.*, **150**, 310 (2005).
5. J. D. BESS and N. FUJIMOTO, "Evaluation of the Start-Up Core Physics Tests at Japan's High Temperature Engineering Test Reactor (Fully-Loaded Core)," HTTR-GCR-RESR-001, *International Handbook of Evaluated Reactor Physics Benchmark Experiments*, NEA/NSC/DOC(2006)1, OECD-NEA, March (2009).
6. J. D. BESS, "Preliminary Benchmark Evaluation of Japan's High Temperature Engineering Test Reactor," *Proc. M&C 2009*, Saratoga Springs, New York, May 3-7.
7. J. D. BESS and N. FUJIMOTO, "Evaluation of the Start-Up Core Physics Tests at Japan's High Temperature Engineering Test Reactor (Annular Core Loadings)," HTTR-GCR-RESR-002, *International Handbook of Evaluated Reactor Physics Benchmark Experiments*, NEA/NSC/DOC(2006)1, OECD-NEA, March (2010).
8. "Topical Issue on Japan's HTTR," *Nucl. Eng. Des.*, **233**, 1 (2004).
9. S. SAITO, et al., "Design of High Temperature Test Reactor (HTTR)," JAERI 1332, Japan Atomic Energy Research Institute, September (1994).
10. F. B. BROWN, et al., "MCNP Version 5," LA-UR-02-3935, Los Alamos National Laboratory (2002).
11. M. B. CHADWICK, et al., "ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology," *Nucl. Data Sheets*, **107**, 2931 (2006).

Table I. Comparison of Calculated and Benchmark Eigenvalues for Critical Configurations of the HTTR.

Fuel Columns	Control Rod Configuration[a]	Benchmark[b] k_{eff}	$\pm$	σ	Calculated k_{eff} [c]	(K-B)/B[d] (%)
19	Central	1.0048	±	0.0104	1.0283	2.33
21	Flat Standard	1.0040	±	0.0096	1.0304	2.63
24	Flat Standard	1.0035	±	0.0087	1.0260	2.24
24	Radial Reflectors	1.0032	±	0.0076	1.0296	2.63
27	Flat Standard	1.0029	±	0.0081	1.0225	1.96
30[e]	Flat Standard	1.0025	±	0.0078	1.0248	2.13

[a] Criticality is obtained using one of three methods (see Figure 1 for control rod locations):

- the Central pattern where the C control rods are inserted and all other control rods are all withdrawn,
- the Flat Standard pattern where the C, R1, and R2 control rods are inserted to the same level in the core and the R3 control rods are fully withdrawn, and
- the Radial Reflectors pattern where the C and R1 control rods are completely withdrawn while the R2 and R3 rods in the reflector region are withdrawn to the same level.

[b] Comprehensive bias calculations have not been evaluated due to lack of sufficient data. A bias for the removal of reactor instrumentation in the instrumentation columns has been assessed and applied to an experimental k_{eff} value of 1.0000.

[c] Eigenvalue calculations were performed using MCNP5.1.40 with ENDF/B-VII.0 neutron cross-section libraries. The statistical uncertainty in the MCNP calculations is less than 0.0001.

[d] This column represents the percent difference between the calculated, K, and expected benchmark, B, eigenvalues.

[e] Data regarding the fully-loaded core configuration are taken from Reference 5 and provided for comparison.

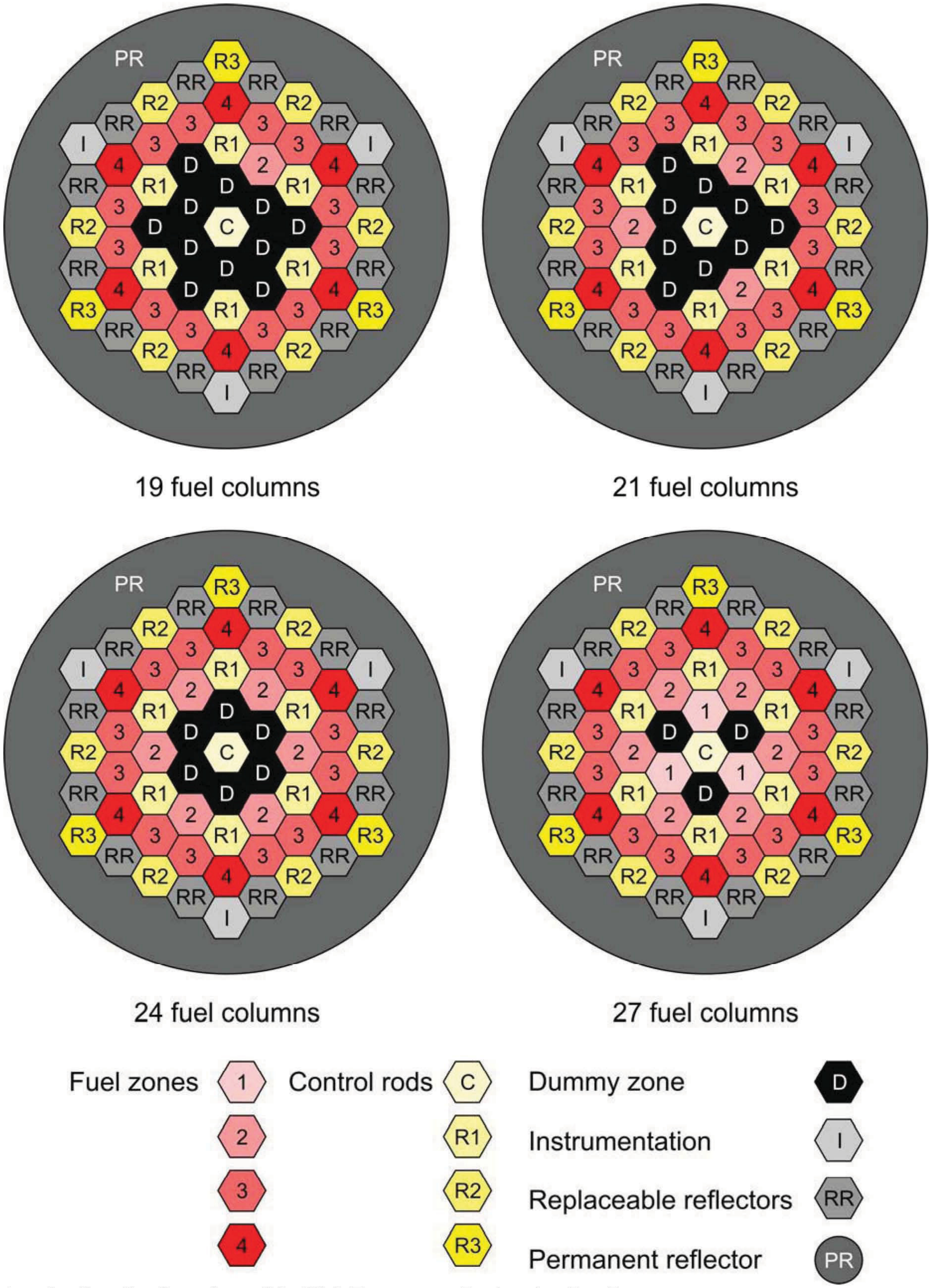

Fig. 1. Annular Core Configurations of the High Temperature Engineering Test Reactor.