INL/CON-11-20811
PREPRINT

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2011 ANS Annual Meeting

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June 2011

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U.S. Department of Energy
National Laboratory
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Battelle Energy Alliance

Idaho National
Laboratory

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INTRODUCTION

The Prismatic Modular Reactor (PMR) is one of the High Temperature Reactor (HTR) design concepts that have existed for some time. Several prismatic units have operated in the world (Dragon, Fort St. Vrain, Peach Bottom) and one unit is still in operation (HTTR in Japan). The deterministic neutronics and thermal-fluids transient analysis tools and methods currently available for the design and analysis of PMRs have lagged behind the state of the art compared to LWR reactor technologies. This has motivated the development of more accurate and efficient tools for the design and safety evaluations of the PMR.

In addition to the work invested in new methods, it is essential to develop appropriate benchmarks to compare the capabilities of various computer codes. The purpose of this benchmark is to establish a well-defined problem, based on a common given set of data, to compare methods and tools in core simulation and thermal hydraulics coupled analysis with a specific focus on transient events and lattice depletion. The benchmark-working group is currently seeking OECD/NEA sponsorship. This benchmark is heavily based on the success of the PBMR-400 exercise [1].

THE BENCHMARK DEFINITION

The reference design is based on the General Atomics MHTGR-350 MW reactor [2]. The primary focus of the reference design is to maintain a reasonably accurate representation of the actual physical design while allowing the participants to make simplifications, as needed. This should encourage broad participation in the benchmark. The reactor fuel specification was chosen for the end of equilibrium cycle (EOEC) core state because it leads to the highest decay heat load for the system and narrowest safety margins.

Geometric Description

The geometric description of the neutronic and thermal fluids is given in full 3-D with a 1/3rd symmetric core design specification. The core consists of an array of hexagonal fuel elements in a cylindrical arrangement surrounded by a single ring of identically sized solid graphite replaceable reflector elements, followed by a region of permanent reflector elements all located within a reactor pressure vessel. The core is designed to provide 350 MWt at a power density of 5.9 MW/m^3. A core radial view is shown in Fig. 1 and the axial view in Fig. 2. The active core consists of hexagonal graphite fuel elements containing blind holes for fuel compacts and full-length channels for helium coolant flow. The fuel elements are stacked to form columns (10 fuel elements per column) that rest on support structures. The active core columns form a three-ring annulus with columns of hexagonal graphite reflector elements in the inner and outer regions. Thirty reflector columns contain channels for control rods. Twelve columns in the core also contain channels for reserve shutdown material.

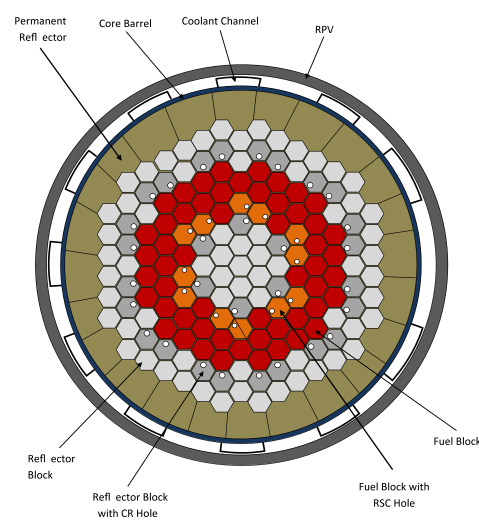

Fig. 1. Core Radial Layout

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Data Specification

The data specifications include cross sections, thermo-physical properties, and detailed distributions for decay heat (based on the DIN 25485 standard [3]), burnup and irradiation, representative of the MHTGR design.

A set of cross section and thermo-physical property lookup modules programmed in the FORTRAN language will be distributed. This will ensure a common dataset among benchmark participants.

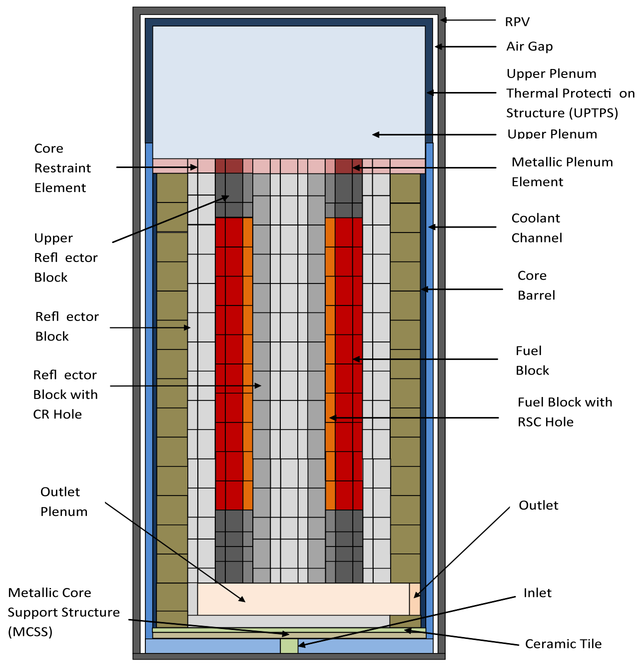

Fig. 2. Core Axial Layout

Cross Sections

Weighted multigroup macroscopic cross sections will be developed with DRAGON-4 [4] from a full block configuration with a double heterogeneity treatment of the fuel. The cross section tabulation will include 4 fuel temperatures, 7 moderator temperatures, 3 xenon concentrations, and 4 hydrogen concentrations. The hydrogen concentrations will be used for the water ingress analysis. The dataset will contain 26 energy groups.

Thermo-Physical Properties

The thermo-physical properties include, where applicable, temperature and burnup dependence for the fuel. Similarly, temperature and irradiation dependence of the constituent graphite will also be made available.

BENCHMARK CASES

Phase I: Steady State

The purpose of this first phase is to perform some preliminary testing of the codes to better understand their differences using a simpler set of problems. Furthermore, it also serves to distinguish the initial conditions for the transient codes. The following is a list of the proposed exercises for the steady state calculations:

1) Neutronics solution with fixed cross sections.
2) Thermal fluids solution with given power /heat sources.
3) Coupled neutronic-thermal fluids steady state solution.

Phase II: Transient Cases

The cases chosen for the transient phase are a common set based on the MHTGR Safety Report [2] and PRA [5]. For this benchmark, some modifications were made to the event sequences to enable the completion and/or isolation of some phenomena. The event sequences specified here should therefore not be seen as representative of the MHTGR's safety case in any way, but purely as the basis for code-to-code comparisons. The following is a list of the proposed exercises for the transient calculations:

1) Depressurized Conduction Cooldown (DCC) without reactor trip.
2) Pressurized Conduction Cooldown (PCC) with reactor trip.
3) Water ingress with reactor trip.
4) Power 100-80-100 load follow.

Phase III: Lattice Depletion Case

The depletion benchmark phase is intended to examine the variation in lattice calculation results between benchmark participants. The calculation will include depletion and will be performed on a single reflected fuel block. The objective of this benchmark is essentially an extension of the VHTR benchmark reported in [6].

CONCLUSION

A coupled neutronics-thermal fluids benchmark problem is being defined for assessment of prismatic core HTGR analysis capabilities. With an anticipated call for participants in 2011, the exercise will be available to interested parties in a timeframe compatible with reactor design and safety evaluation efforts.

ACKNOWLEDGEMENT

Work partially supported by the U.S. Department of Energy, Assistant Secretary for the Office of Nuclear Energy, under DOE Idaho Operations Office Contract DE-AC07-05ID14517.

REFERENCES

1. "OECD/NEA/NSC PBMR Coupled Neutronic/Thermal Hydraulics Transient Benchmark: the PBMR-400 Core Design," Draft 07, June (2007).
2. "Preliminary Safety Information Document for the Standard MHTGR", MHTGR-86-024, Rev. 13, Bechtel, GA Technologies, September (1992).
3. "Berechnung der Nachzerfallsleistung der Kernbrennstoffe von Hochtemperatur- reaktoren mit kugelförmigen Brennelementen" DIN 25485, Deutsches Institut für Normung eV, (1990).
4. G. Marleau, A. Hébert, and R. Roy, "A User Guide for Dragon Version4," Technical Report IGE–294, École Polytechnique de Montréal (2010).
5. "Probabilistic Risk Assessment of the Modular HTGR Plant", HTGR-86-011, Rev. 1 Draft, GA Technologies, June (1986).
6. M. D. DeHart and A. P. Ulses, Benchmark Specification for HTGR Fuel Element Depletion, NEA/NSC/DOC(2009)13, Nuclear Energy Agency, Nuclear Science Committee, Organisation for Economic Co-operation and Development, Paris, France. (June 2009).