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COMPARISON OF PRESSURE DROP MEASUREMENTS AND CALCULATIONS FOR HEU AND LEU FUEL ASSEMBLIES FOR MARIA REACTOR

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ABSTRACT

In preparation for testing 2 low-enriched uranium (LEU) lead test fuel assemblies (LTFA) in MARIA reactor (located at the Institute of Atomic Energy in Poland), measurements of pressure drop versus coolant flow rate at range of temperature were made for proposed LEU and current HEU fuel assemblies (FA) in special out-of-reactor test stand. The FA and experiment stand were modeled using RELAP5 computer code. Good agreement was obtained between calculations and measurements. Results of this analysis were used to support application for approval for irradiation testing of the LTFAs (which has begun).

1. Introduction

A common task in analyzing reactor core fuel conversions is establishing the relationship between pressure drop and coolant flow rate for each fuel assembly design. In many cases this is done on a preliminary basis using calculational models. Whenever possible this is later evaluated and adjusted based on experimental data. These types of relationships are needed in order to establish coolant flow distributions in cores having multiple fuel assembly types and to assess the capabilities of the existing pumps to work with the introduction of new fuel assembly types into a reactor core. The comparisons of calculational and experimental results for fuel assemblies for the MARIA reactor are presented here.

2. Fuel Assembly Geometry and Tests

The multipurpose high flux research reactor MARIA [1] is a water and beryllium moderated reactor of a pool type with graphite reflector and pressurized channels containing concentric six-tube assemblies of fuel elements. The reactor achieved criticality in 1974 and is perated by the Institute of Atomic Energy (IEA) in Swierk, Poland.

The MARIA reactor is currently fueled with MR-6-430 type fuel assemblies (FA). The fuel material is UO_2-Al clad in Al with 36% enrichment in U-235; there are 430 g of U-235 per FA. The fuel is contained in the central 1 m axial length of 6 concentric circular tubes as shown in Figure 1. The tube numbering convention is from inner (=1) to outer (=6) in this paper. The coolant gap between tubes is 2.5 mm. Coolant flow is downward outside of tube 4, turns below the fuel tubes, and is upward inside of tube 4. A non-fueled extension above tube 4 separates down- from up-flow. [Extracted from Reference 2.] Nominal coolant flow rate is 25 m^3/h per FA.

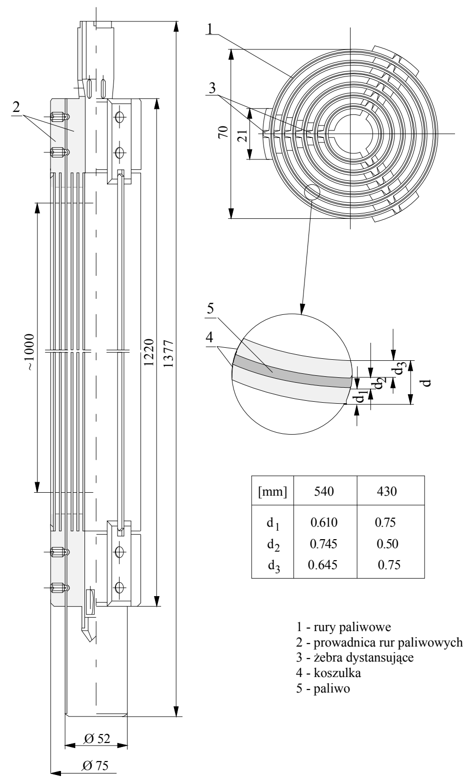

Figure 1 HEU Fuel Assembly (Legend: 1: fuel tubes, 2: fuel tubes guide bar, 3: spacer ribs, 4: clad, 5: fuel. The bottom of the FA is at the top of the figure.)

The IEA is considering converting MARIA from HEU to LEU fuel. As part of the decision process IEA is irradiating 2 LEU lead test fuel assemblies (LTFAs) designed and fabricated by CERCA. These LEU LTFAs are similar to the current HEU FA with the following notable exceptions. (a) Fuel enrichment will be 20% in U-235; there are 485 g of U-235 per FA; tube 1 will have no fuel; the fuel meat is U_3Si_2 and is thicker than in the HEU; the cladding is thinner than in the HEU. (b) Each fuel tube consists of 3 azimuthal segments of somewhat less than 120 degrees each; the segments are joined together using an aluminum spacer (which is bigger than the rib in the HEU design) which also helps maintain tube-to-tube separation. (c) Nominal coolant flow rate is expected to be 30 m^3/h per FA. [Extracted from Reference [3]. More exact details of the FA design have been presented by CERCA [4].]

Prior to irradiation, IEA performed hydraulic measurements [3] of HEU and LEU fuel assemblies in an out-of-reactor test stand. Pressure drop was measured at water flow rates up to 30 m^3/h for water temperature in range 20-80°C.

3. RELAP5 Model

For comparison with the experiment data, steady-state calculations have been performed using the RELAP5 code [5].

The noding for a single HEU FA will be described using the component numbers in the left portion of the noding diagram in Figure 2. The fuel element tubes 1 through 6 are represented by heat structures 2801, 2701, 2201, 1801, 1701, and 1201, respectively; the 1 m fueled length is divided into 20 axial nodes. (The heat source and heat transfer aspects of these components were ignored in the present constant-temperature calculations.) The central unheated tube 0 is represented by heat structure 2901. Coolant flows downward toward the fuel tubes using pipe-type component 115. The coolant flow splits and continues downward adjacent to tubes 4 (outside), 5, and 6 using pipe components 180, 170, and 120, respectively. At the bottom of the fuel, the flow continues downward using branches 190 and 130, turns inward using branch 194, and flows upward using branches 209, 289, and 200. The flow continues upward adjacent to tubes 0 through 4 (inside) using pipe components 210, 290, 280, 270, and 220, respectively. The flow streams rejoin at various axial levels and continue upward flow using pipe component 295. Heat structure 1151 allows for energy transfer between the inlet and outlet components. There is no azimuthal variation modeled within any of these components.

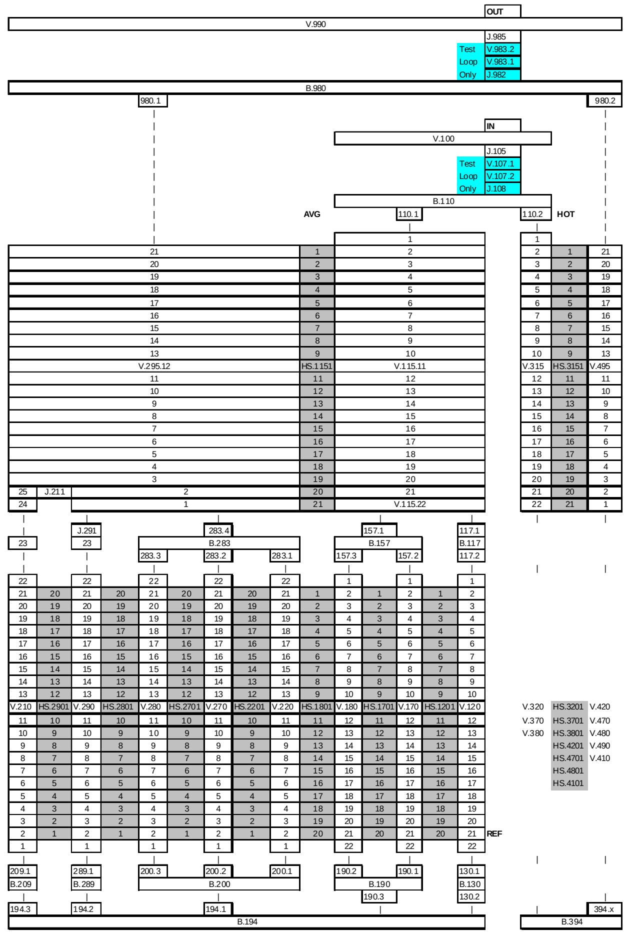

Figure 2 RELAP5 Noding for HEU Core

Noding for a single LEU FA is similar to the HEU FA noding except tube 0 (i.e., 2901) and the pipe component (i.e., 210) for coolant interior to it are deleted and tube 1 (i.e., 2801) has no fuel. All flow areas, hydraulic diameters, fuel and clad thickness, and fuel tube azimuthal extents are different between the HEU and LEU models.

Volume 100 is the coolant source; the inlet temperature is specified here. Junction 105 specifies the coolant flow rate for the total FA. (If modeling an entire core, Branch 110 allows the total core flow to be spread across multiple FAs, and branch 980 collects the outlet flow from all FAs.) Volume 900 is the coolant sink; the pressure specified here is the reference for other pressures in the calculation. Volumes 107 and 983 are the inlet and outlet piping connecting the FA channel to the test stand; there is a horizontal-plane bend of approximately 75 degrees in each of these pipes plus the turn from horizontal to vertical; the inlet (i.e., p1) and outlet pressure (i.e., p3) transducers are located in Volume 107.1 and 983.2, respectively. The bottom (i.e., p2) pressure transducer is located in Branch 194.

Past experience has shown that effort must be made to include in the RELAP5 model as much of the geometry as possible, in particular flow area changes and locations where the coolant flow splits into (and rejoins from) multiple paths. Hydraulic losses at area changes were treated using the abrupt area change junction option in RELAP5. The one-dimensional RELAP5 code does not automatically account for hydraulic loss associates with a change in coolant flow direction, such as what occurs between inlet pipe and fuel channel, at the ends (primarily bottom) of the fuel tubes, and between fuel channel and outlet pipe; therefore, a K-type constant loss coefficient was user input at each of these locations, and the loss was computed as this value times velocity squared. The present study found that a non-zero value for surface roughness was appropriate.

4. Comparison Between Calculations and Experiments

Representative results for the two FA types are shown in this section. The style used for the results is as follows. Experiment data are denoted by small solid markers; large open-center markers are used for RELAP5 results (denoted by "R5" prefix in legend). The pressure drops are identified as "p1-p2" for inlet to bottom, "p2-p3" for bottom to outlet, and "p1-p3" for inlet to outlet. The experiment data and RELAP5 calculated values have been adjusted to remove the static gravity head; therefore, the expectation is that there is no pressure drop when there is no coolant flow.

Results for the HEU FA are shown in Figures 3 (for 42°C) and 4 (for 84°C). The RELAP5 results were obtained using a K-type loss factor of 1 at flow-direction change locations and the surface roughness was assumed to be 1 μm. There is excellent agreement between RELAP5 and the experiment values for downward, upward, and total pressure drop, for all flow rates, and for both temperatures. The pressure drop increases with coolant flow rate. The pressure drop decreases as temperature increases (due to the decrease in water viscosity). The pressure drop across the downward flow path (i.e., p1-p2) is less than the pressure drop across the upward flow path (i.e., p2-p3) (due to the smaller flow area and lower hydraulic diameter of the upward flow path relative to the downward flow path).

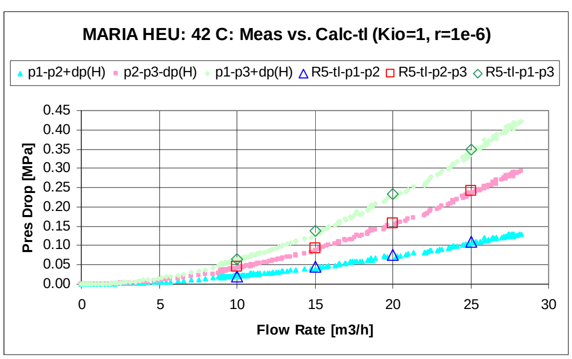

Figure 3 Pressure Drop vs. Flow Rate for HEU Fuel Assembly at 42°C

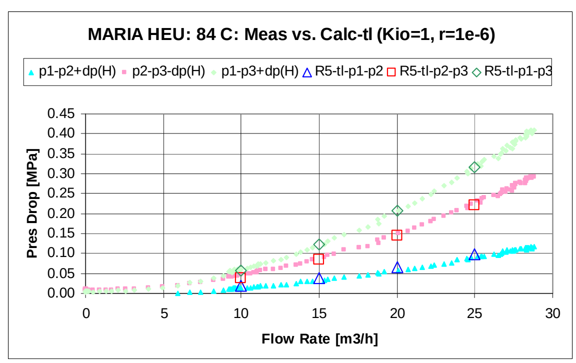

Figure 4 Pressure Drop vs. Flow Rate for HEU Fuel Assembly at 84°C

Results for the LEU dummy FA are shown in Figures 5 (for 20°C) and 6 (for 75°C). The RELAP5 results were obtained using a K-type loss factor of 1 (same as for HEU) at flow-direction change locations and the surface roughness was assumed to be 5 μm (rougher than the HEU). The higher roughness may be consistent with the fact that the LEU FA for which data are shown is a non-nuclear dummy for which the fuel tube surfaces may have been subjected to lesser efforts at achieving surface smoothness. There is excellent agreement between RELAP5 and the experiment values for downward, upward, and total pressure drop, for all flow rates, and for both temperatures. All trends are the same as seen for the HEU FA.

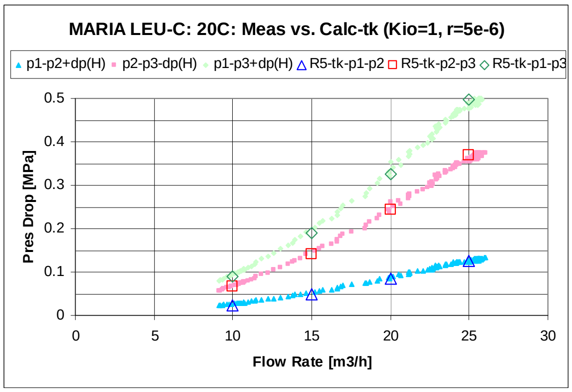

Figure 5 Pressure Drop vs. Flow Rate for LEU Fuel Assembly at 20°C

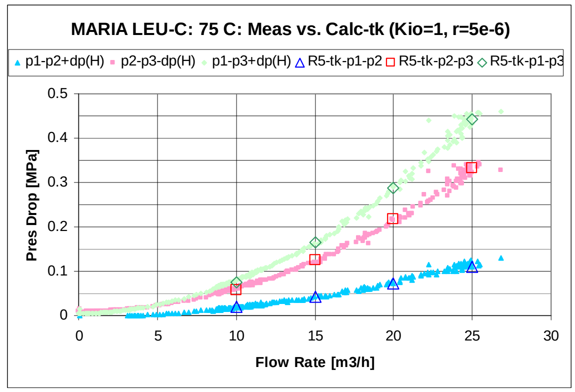

Figure 6 Pressure Drop vs. Flow Rate for LEU Fuel Assembly at 75°C

5. Conclusions

Calculations of pressure-drop versus coolant flow rate have been performed using RELAP5. The calculated results are in excellent agreement with those measured in out-of-reactor test stand adjacent to MARIA reactor at IEA in Poland. These results give confidence that RELAP5 could be used for other aspects of the design analysis, including changes in the geometry.

6. References

[1] "MARIA Reactor Operations", Chapter 2 in *Annual Report 2007*, http://www.iea.cyf.gov.pl/pdf/ar_2007/reactor_maria/Chp_2_Maria%20Reactor.pdf, Institute of Atomic Energy, Swierk, Poland (2007).

[2] "Reactor Construction and Characteristics", Chapter 5 in MARIA Safety Analysis Report, Institute of Atomic Energy, Swierk, Poland (2003).

[3] W. Mieleszczenko and A. Moldysz, "Experimentally Determined Hydraulic Characteristics of HEU and LEU Fuel Assemblies for MARIA Reactor", paper S14-1, *2008 International Meeting on Reduced Enrichment for Research and Test Reactors* (Washington, DC, USA), http://www.rertr.anl.gov/RERTR30/index.html, Argonne National Laboratory, Argonne, Illinois, USA (October 5-9, 2008).

[4] P. Colomb, L. Halle, G. Krzysztoszek, W. Mieleszczenko, F. J. Blom, F. Roelofs, and C. J. J. Beemsterboe, "LEU U_3Si_2 Fuel Manufacturing for MARIA Reactor (Poland)", paper S13-3, *2008 International Meeting on Reduced Enrichment for Research and Test Reactors* (Washington, DC, USA), http://www.rertr.anl.gov/RERTR30/index.html, Argonne National Laboratory, Argonne, Illinois, USA (October 5-9, 2008).

[5] "RELAP5-3D© Code Manual", INEEL-EXT-98-000834, Revision 2.3, Idaho National Laboratory, Idaho Falls, Idaho (April 2005).