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THERMAL HYDRAULIC MODEL VALIDATION FOR HOR MIXED CORE FUEL MANAGEMENT

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INTRODUCTION

A thermal-hydraulic core model has been developed for the Hoger Onderwijsreactor (HOR), a 2 MW pool-type university research reactor. The model was adopted for safety analysis purposes in the framework of HEU/LEU core conversion studies. It is applied in the thermal-hydraulic computer code SHORT (Steady-state HOR Thermal-hydraulics) which is presently in use in designing core configurations and for in-core fuel management. An elaborate measurement program was performed for establishing the core hydraulic characteristics for a variety of conditions. The hydraulic data were obtained with a dummy fuel element with special equipment allowing a.o. direct measurement of the true core coolant flow rate. Using these data the thermal-hydraulic model was validated experimentally. The model, experimental tests, and model validation are discussed.

STEADY-STATE HOR THERMAL-HYDRAULICS (SHORT)

thermal hydraulic model

The HOR is cooled by forced convection downward flow of pool water sucked into the core region and circulated by the primary pump through the heat exchanger. During forced flow conditions a vertically movable suction header is seated to the bottom of the grid plate (Fig. 1). The core hydraulics are modelled in the SHORT code system.

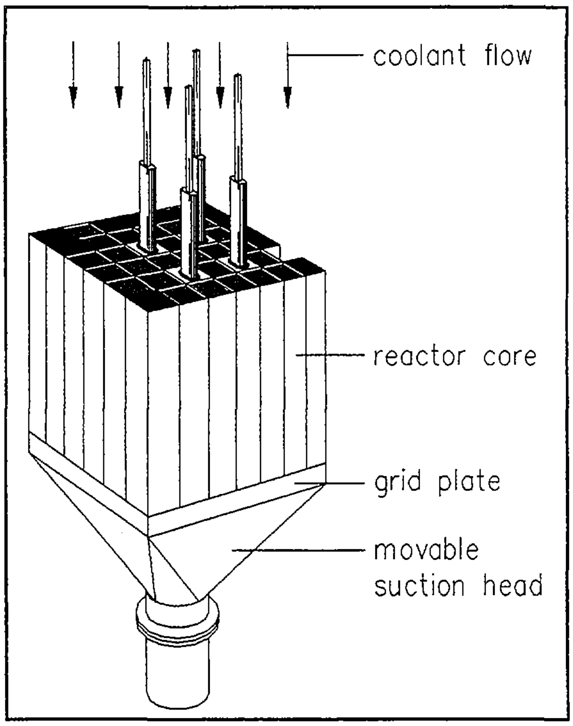

Figure 1. HOR core cooling system

The SHORT program [1] is composed of the two established computer program modules FLAC [2] and COBRA-IIIC [3]. FLAC solves the equations for the flow and pressure distribution in arbitrarily arranged hydraulic resistance networks and COBRA-IIIC carries out thermal-hydraulic calculations in an array of heated channels with or without links for cross-flow. To make the application for the HOR user-friendly, FLAC and COBRA-IIIC are coupled in SHORT. Appropriate empirical functions for heat tranfer and fluid friction are used on a preselected basis, as well as basic geometry data. Only core operating conditions and the core configuration are to be specified as input data by the user. From these the SHORT program then calculates the data required for running FLAC and COBRA-IIIC.

Once the input data are provided SHORT starts to generate a flow resistance network which consists of resistances in the axial and transverse direction simulating the flow of pool water into the interconnected system of gaps between core components which is then sucked through the small holes in the grid plate. The flow through the core components is also modelled. Leakage flow of pool water into the suction head plenum through small gaps is accounted for by an additional resistance connecting the plenum below the grid plate with the pool. FLAC then iteratively calculates the pressure and flow distribution in the network and gives a breakdown of the flow through the small holes in the grid plate, the flow through the interior of the core components and the leakage flow.

For the thermal-hydraulic calculations to be performed by COBRA-IIIC only the relevant flow in the heated section of the fuel element cooling channels is taken from the FLAC analysis. On the basis of the channel axial power profiles that follow from the core neutronic calculations, COBRA-IIIC then evaluates the flow distribution in the array of heated cooling channels. These axial power profiles are calculated with the 3D Monte Carlo code KENO V.a [4]. If hot channels are specified, hot channel and hot spot factors are applied to the temperature rise in the coolant, the velocity and the heat flux. These modified values are then used to calculate the safety margin with respect to the occurence of flow instabilities.

Finally SHORT allows for an analysis of the outer fuel plate temperatures at the fuel element boundary. For an unshrouded core like the HOR, the heat removal conditions of such outer fuel plates are quite different from those of the inner plates. This is mainly due to the deviating coolant velocity profile for the channels in between fuel assemblies. For these channels there is a significant increase in coolant velocity downwards from top to bottom.

Code installation and verification
The SHORT code system was developed in the framework of safety analysis studies performed for the HOR [5]. It had been designed to run on the developer's platform for performing this kind of computer calculations. After completion the code system was ported to IRI's computing environment, so adequate testing and verification of the installed modules was necessary. Test input and output was supplied by the authors of the code system. For managing the programming environment different software tools are in use at IRI. First: for quality asssurance purposes the QA FORTRAN package is used for checking the source code. It is a toolset for analyzing, improving and maintaining the quality of FORTRAN programs. Second: a software engineering tool (DECset) is available. It can be used to develop, install, and to maintain a code system in a systematic way.

To verify the correct installation of SHORT these tools were applied to the system and a number of test runs were performed. Some minor problems were detected and subsequently corrections were made. Finally for validating purposes, the results of test cases which had been run on the designers platform were reproduced successfully.

EXPERIMENTAL TESTS

Method
The hydraulic data were obtained with a special device, designed for the purpose of incore measurements, e.i. a dummy fuel element assembly was equipped with a turbine-type flow meter in the lower end fitting as shown in Figure 2. The device was calibrated and certified [6] independently off-site in a dedi-

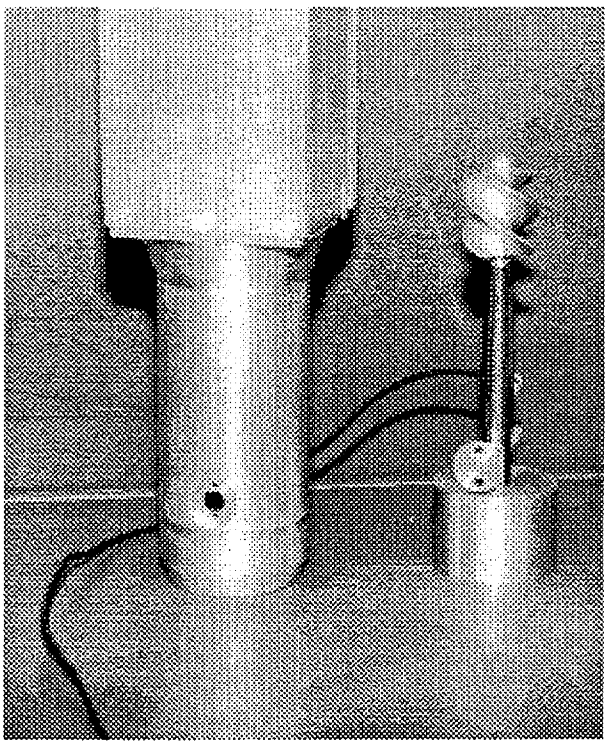
Figure 2. Dummy fuel element with flow meter dismounted from bottom nozzle

cated test and calibration loop, owned and operated by the Dutch national calibration institute responsible for maintaining the national measurement standards. The influence of the turbine flow meter was assessed separately by taking pressure difference data of the dummy fuel assembly with and without the turbine.

Measurement program

With the reactor shutdown, in-core measurements were performed under steady-state conditions for two different core types at a large number of grid positions for nominal settings of 67, 80 and 89 dm^3/s for the primary loop flow rate. For determining the influence of the suction head gap bypass flow on incore coolant velocity, measurements were taken with and without temporarily sealing of the suction head gap. Additional to these steady-state measurements transient measurements have been performed in the framework of contributions to the safety analysis report [5]. They consisted of determining the influence of deliberately and instantaneously forcing down the suction head while the primary pump kept running and recording flow coast down after shutting-off the primary pump.

Results

From the measurement data, a.o. the core flow rate distribution and the true core coolant flow rate were determined. Figure 3 displays the measured in-core coolant velocity distribution for a nominal primary flow rate of 80 dm^3/s for the (mixed) compact core. The average coolant velocity was 0.961 m/s. It can be seen that in general, the coolant velocity is highest in the central core region, whereas at the core boundary velocities are somewhat lower. The spread of the relative flow rate is from 0.978 to 1.025. Figure 3 also displays the relative increase of the incore flow rate when sealing of the suction head gap. It can be seen that the influence is only marginal.

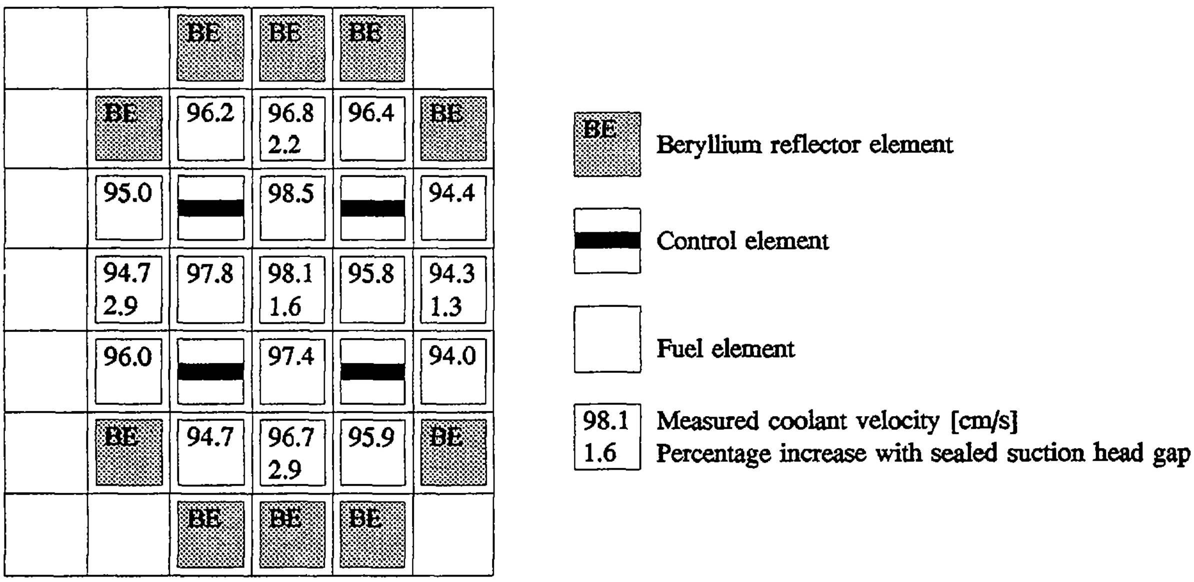

Figure 3. Coolant velocity distribution

EVALUATION OF MEASUREMENTS AND IMPACT ON MODEL

Fuel element flow rate

To evaluate the validity of the SHORT program, calculations were performed for the experimental test conditions of the simulated compact core. Compared to the experimental test results, the suction head bypass flow rate was overpredicted substantially with underprediction of the active core flow. According to this an adjustment of the flow network in SHORT was made. The suction head bypass of originally 5.5% of total flow for the compact core model was reduced by adjusting the flow resistance of the specific flow path of the resistance network to meet the measured bypass. No other changes in the input or modelling were made. The calculated fuel element active flow rate increased due to the reduction of the suction head bypass by 3.4 %. It is concluded that after the adjustment the true active coolant velocity is still conservatively underpredicted by SHORT by 3.9 %. The results are presented in Table 1.

Table 1. Comparison between test results and apriori and posteriori SHORT-calculation for the flow paths in the simulated compact core.

Flow path	Flow [kg/s]		
	Test	SHORT apriori	SHORT posteriori
Active cooling channels	68.43 (86.2%)	63.57 (80.1 %)	65.73 (82.8 %)
Absorbers and small holes in grid plate	9.26 (11.7 %)	11.46 (14.4 %)	11.85 (14.9 %)
Suction head bypass	1.7 (2.1 %)	4.37 (5.5 %)	1.80 (2.3 %)

Flow distribution across the core

The fuel element flow rate was measured at 17 grid positions in the simulated mixed core. These results were compared to an apriori assumed design value of 1.03 for a nuclear hot channel subfactor used in the SHORT program. This subfactor relates to the nonuniform mass velocity at the core inlet affecting individual fuel elements. A value of 1.03 corresponds to an assumed flow reduction of 3% at the inlet of the fuel element containing the hot channel. Since the radial nuclear hot channel factor occurs in the central region of the core the apriori design value is conservative for the planned core configurations and loading patterns. Thus this factor could be set to 1.0 thus increasing the design value of the fuel element flow rate by 3 %.

CONCLUSIONS

The true core coolant flow rate for different core conditions and flow distribution was assessed by experimental methods for validating the thermal-hydraulic code SHORT. This code is used for core design and in-core fuel management purposes for the HOR. The in-core fuel management of mixed HEU/LEU cores requires special attention with respect to power peaking constraints. Based on the results mentioned above and the experiences so far, the code SHORT is considered to be a valuable asset as a design tool for in-core fuel management, serving proper guidance during the HOR conversion process.

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