MAPLE-X10 REACTOR FULL-SCALE HYDRAULIC TEST RIG

INSTALLATION D'ESSAI HYDRAULIQUE EN VRAIE GRANDEUR DU RÉACTEUR MAPLE-X10

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RÉSUMÉ

Le réacteur MAPLE-X10 de 10 MW(t) en cours de construction aux Laboratoires de Chalk River d'EACL Recherche est un nouveau type de réacteur piscine. On a construit une installation d'essai hydraulique en vraie grandeur qui utilise des composantes du réacteur et des ensembles prototypes; elle servira à vérifier la conception des composants et des systèmes et à valider les programmes de calcul utilisés à l'étape de la conception. Le programme d'essai réalisé a déjà permis d'apporter des modifications qui ont amélioré les performances du modèle et de démontrer l'acceptabilité de concepts liés à la sûreté qui sont à la base du modèle.

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ABSTRACT

The 10 MW MAPLE-X10 reactor being constructed at the Chalk River Laboratories of AECL Research is a new concept in pool-type reactors. To verify the design of components and systems and to validate computer codes used in the design, a full-scale hydraulic test rig has been constructed utilizing reactor components and prototype assemblies. The testing program completed so far has resulted in significant design changes to improve performance and has also demonstrated the acceptability of safety-related, underlying concepts.

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1. **INTRODUCTION**

The MAPLE-X10 reactor is presently under construction at the Chalk River Laboratories of AECL Research. It is a 10 MW thermal pool-type reactor with a compact core and heavy-water reflector. Although dedicated to the production of radiopharmaceuticals and industrial isotopes, the reactor is a prototype of the Maple research reactor concept.

To meet safety and reliability requirements, the many unique components of the reactor must be tested to confirm that the required performance is met, and the underlying concepts described below must be demonstrated.

To carry out the testing program, a full-scale hydraulic test rig has been constructed utilizing actual reactor components and prototype assemblies. This paper describes the reactor, the rig and the testing program, and reports the results of the tests completed so far.

2. **THE REACTOR**

The reactor is illustrated in Figure 1. The assembly is located at the bottom of a 9.5 m deep, light-water filled pool. The core assembly consists of nineteen vertical flow tubes mounted in a grid plate assembly which in turn is mounted on an open-top tank referred to as the inlet plenum. Ten of the flow tubes are hexagonal in cross section and contain a single 36-pin fuel-bundle assembly. The remaining nine tubes are cylindrical and contain either an 18-pin fuel-bundle assembly or an isotope target. The core assembly is surrounded by an annular reflector tank containing heavy water. The primary coolant enters the inlet plenum, flows upward through the closed central area of the grid plate and hence through the flow tubes. Upon emerging from the core the coolant enters an open-top chimney assembly and leaves via two outlet arms. From here it passes through the pool wall and to the circulation pump and heat exchanger located in an adjacent shielded process room. A fraction of the flow into the plenum is directed to the bottom of the pool, where it rises and returns down the open top of the chimney to join the coolant exiting the core. This downward flow suppress the core outlet flow to the lower part of the chimney.

Reactivity control is achieved with six rods, which are actually hafnium metal tubes that surround six of the cylindrical flow tubes, as shown in section in Figure 2. Three of the rods are normally held out of the core by individual hydraulic cylinders pressurized with pool water. These three shut-off rods drop into the core under gravity when the cylinders are depressurized. The other three control rods move into and out of the core under computer control, but also drop into the core under gravity when electromagnets connecting them to their drive system are de-energized. The six rods thereby constitute two separate and equally capable shut-down systems, each with its own trip instrumentation. A typical rod assembly is shown in Figure 3.
3. UNDERLYING CONCEPTS

3.1 Upward Flow

The reactor utilizes upward flow of coolant with high channel velocities. This ensures that the transition from forced to thermosyphoning flow requires no flow reversal. The high flow results in low-temperature operation, 35°C inlet, 45°C outlet and a large operating margin from critical heat flux for the fuel.

3.2 Open-top Chimney

The flow down the chimney, described as the bypass flow, constrains the core outlet flow (which contains high levels of $^{16}\text{N}$) to the chimney. This permits normal operator activities at the top of the pool without the use of a thermal blanket.

A cooling circuit for thermosyphoning of pool water through the core is provided.

The open-top chimney allows rapid manual changing of fuel with the reactor shut down. This is particularly important as it is shut down daily and excess reactivity limits shut-down to about one hour before poison-out occurs. Recovery requires 72 hours if fresh fuel is not added to the core.

3.3 Shut-off Rod Protection

The shut-off rods and their cylinders are located within the chimney, as shown in Figure 4, thereby reducing their susceptibility to damage from above-pool activities.

3.4 Shrouded Rods

The shut-off and control rods are located within the highly turbulent flow above the core, but are surrounded by shroud assemblies. These shrouds prevent vibration of the control rods and ensure that no side loadings from the turbulent flow prevent the rods from dropping into the core. The arrangement is shown in Figure 4.

4. THE FULL-SCALE HYDRAULIC TEST RIG

A computer program was developed to predict the flow patterns in the pool and chimney to confirm the core jet confinement concept. A fifth-scale rig was built to validate this computer program and to examine the performance of the control and shut-off rods in the turbulent flow within the chimney. Given that the uncertainties in the scaling presented an unacceptable risk to demonstrating the performance of the final design, a decision was made to construct a full-scale hydraulic test rig.
The rig, shown in Figure 5, is essentially the reactor outside of the pool. The inlet plenum and grid plate were built to the reactor specifications so that they could be used in the reactor, should the design be acceptable. There was adequate certainty in the physics codes used to predict core and fuel performance, so the core assembly components for reactor installation were fabricated. Fuel bundles without uranium were also fabricated.

The shape of the outlet chimney was determined by the reactivity mechanism mounting and access to irradiation sites in the reflector tank. The arrangement is shown in Figure 2. The experimental chimney was built in three sections to allow changing the elevation of the outlet arms. Windows and glands were provided to observe component performance and flow distribution.

To achieve the full static hydraulic head, the chimney was extended with a larger diameter spool piece to the full pool depth. Not only does this provide the correct hydraulic condition, it also allows testing of fuelling and other assembly tools and operator training. To round out the hydraulic simulation, the bypass flow was introduced high in the chimney extension and a reactor primary cooling pump was installed to provide flow. A prototype of each of the shut-off and control-rod assemblies was installed and dummy assemblies in the chimney ensured the correct hydraulic geometry.

5. TEST PROGRAM AND RESULTS

5.1 Control and Shut-off Rods

The first test program carried out after commissioning was to demonstrate the performance of the control and shut-off rods.

A measurement was required of the position of the rods as a function of time after the rod drop was initiated. This allowed not only the drop time to be measured, but the performance of the hydraulic arrestor to be assessed. Knowing the position, it was also possible to determine the time at which the operating reactor would go sub-critical, a time of importance as the rods do not have to be fully into the core to achieve shut-down.

Measuring the position of the control rod after de-energizing of the electromagnet was straightforward, as the control rod was accessible for attachment of a linear transducer. An accelerometer was also attached to the rod, to allow assessment of the effectiveness of the hydraulic arrestor.

Measuring the position of the shut-off rod, however, presented more of a challenge, as the installed system has only an up or down position indicator, and the closest point on the rod is some 5 m below the water
surface. A lightweight cable was attached to the top of the piston head and extended above the surface to a rotary potentiometer. The cable was lightly tensioned using rubber tubing.

A storage recorder was used to record the position measurements and was triggered either by the de-energizing relay for the electromagnets or the switch contacts that opened the depressurizing valves.

The position of the shut-off rods during a drop was measured both with and without cooling flow through the core. The results are presented in Figure 6; no appreciable change is evident. The position of the control rod during a drop was only measured without cooling flow, as the hydraulic geometry of importance is the same for both rods. The test program did result in significant modifications to the hydraulic arrestors, the hydraulic cylinder and the pressurizing system, to achieve the required less than 1 second drop time.

The shut-off rod has been cycled using time-delay relays for the equivalent of 40 years of reactor operation. After 15000 cycles, the cylinder was dismantled for inspection. A rotary profilometer was used to plot the wear profiles, as shown in Figure 7. The excessive wear of the lower sleeve bearing and the piston head has been traced to a misalignment error that occurred during installation. The material combination was Wakesha 88 and 17.4 pH 1100 stainless steel. The cylinder design has been modified to make it more tolerant to misalignment.

The control rod has been driven the equivalent of 15 km, with reversal of direction occurring every five minutes. To simulate more closely the operation of the reactor, the drive has also been operated with a change in direction every two seconds. As the reactor control computer system was not available, a stepping motor drive system was assembled to simulate the computer output. It uses a 200 ms cycle time similar to that of the computer. The system allows reversal in direction after full 630 mm rod travel or after as little as one step, or 0.013 mm.

No excessive wear has been observed in the mechanical components of the control-rod drive, but damage of instrument cabling has occurred. All modifications made to the prototype are now being incorporated into the reactor units. These will also be tested in the rig.

5.2 Core Flow Distribution

The flow through each of the 19 flow-tubes in the core is affected by the inlet and outlet geometry of the reactor structure.

The flow distribution to the central region of the grid plate, which is the common header for the flow-tubes, is affected by the geometry of the inlet pipe, plenum and grid plate. The "10 inch" diameter inlet pipe connects to the inlet plenum, which has a diameter of 1.6 m but is only 0.5 m in height. The central region of the grid plate is 0.4 m in diameter and
0.3 m long. No attempt was made to develop a three-dimensional computer model to predict flow patterns through the expansion and contractions or through the short lengths. Baffling or other modifications would be made if testing in the rig showed that the distribution through the flow-tubes was unacceptable.

The flow through a hexagonal flow-tube is set by a fixed orifice located at the bottom of the tube. The orifice was sized experimentally in a single channel test rig. As there was the possibility of interaction of flows in adjacent flow-tubes, both at the inlet and outlet, flow distribution measurements in the rig were required.

A paddlewheel-type flowmeter was mounted in an assembly that could be inserted into the top of each flow tube in turn. The assembly and display are shown in Figure 8.

The flow measured in each flow tube was within ±7% of the average. This distribution is better than the ±10% specified. There is an apparent regional bias in the distribution with flows higher in the flow-tubes opposite the inlet pipe. This is illustrated in Figure 9.

There will be no modifications made to inlet-orifices and no baffling will be added.

5.3 Core Jet Confinement

The purpose of this test was to show that with the bypass flow specified by the computer model and confirmed by the fifth-scale model, the outlet flow from the core is confined to the chimney. The bypass flow was varied and the elevation of the top of the turbulent zone was determined.

The tests did not include measurement of flow velocities in the chimney, but consisted of visually examining the flow distribution. The assembly shown in Figure 10 was used. The reaction of the streamers in terms of direction and fluttering was observed. The elevation of the top of the turbulent zone was recorded as bypass flow was varied; it is plotted along with a computer prediction in Figure 11. Particular attention was paid to the periphery of the chimney, to ensure that no streaming was occurring. None was observed.

5.4 Pump Rundown

The loss of power to the primary cooling pump is considered an accident-initiating event in the Safety Analysis, and the thermalhydraulic behaviour of the reactor during this event is analyzed. An important parameter required for the analysis is the pump or flow rundown characteristic. As the reactor hydraulic conditions are simulated and a reactor pump is used in the rig, the rundown was measured; the results are shown in Figure 12.
Pump shaftspeed was measured with an optical tachometer, while flow was measured with both an annubar and two differential pressure transducers with square-root extractors. Two transducers were used to give adequate range.

The rundown time measured was considerably shorter than that used in the preliminary analysis of the accident. Although the shut-down systems are sufficiently fast to prevent high fuel temperatures, the frequent loss of pump power makes the dependence on the shut-down system unacceptable. An auxiliary cooling system supplied by uninterruptible power is now being incorporated into the design.

5.5 Corrosion

As some components of the rig a.e to be used in the reactor, the chemistry of the water in the rig is controlled to reactor conditions. This provides an opportunity to assess the corrosion behaviour of components both singly and in combination with each other, without, of course, any effects of irradiation. Components examined are in as-new condition after immersion for up to two years.

5.6 Temperature Effects

The core assembly is not heated and therefore thermosyphoning flows are not examined. However, pump heat does allow the rig to be heated to above-reactor temperatures, up to 60°C. Changes in performance of the hydraulic cylinder have been noted, but are still within specification. The control-rod drive utilized a polyethylene sleeve bearing, which was immersed in water at the top of the pool. It expanded to the point of seizure as the water temperature increased. The bearing has now been modified to eliminate this problem.

5.7 Wear

In addition to the wear of hydraulic cylinder components noted above, premature fretting wear has been noted in fuel-bundle locking components. The components are now being modified prior to resumption of testing.

6. QUALITY ASSURANCE

Testing is directed at demonstrating the performance of safety-related systems, and the availability and operability of the reactor. Test activities are therefore controlled by a Quality Assurance Program, to assure that they are properly managed and that the results are valid and auditable.

This has been the first application of Quality Assurance to an extensive research and development (R&D) program within AECL Research. Although
implementation has presented some difficulties, there is now a general acceptance of the necessity of R&D Quality Assurance by those carrying out and reporting the testing.

7. CONCLUSION

To verify the design of the MAPLE-X10 reactor, particularly the underlying concepts, a full-scale hydraulic test rig was built at the Chalk River Laboratories. Although the rig and the testing program have been costly, they have been cost effective. Safety features have or will be adequately demonstrated to the licensing authorities, predictive computer codes for future reactors have been validated, operability has been confirmed without activation of components and the commissioning period is predicted to be significantly reduced; these are significant factors for a commercial-production-oriented reactor.
Figure 1: MAPLE-X10 Reactor Structure
Figure 2: Core Arrangement Showing Location Of Control Rods
Figure 3: Control Rod Assembly
Figure 4: Control And Shut-Off Rod Arrangement
Figure 5: Full-Scale Hydraulic Test
Figure 6: Shut-Off Rod Drop
Figure 7: Wear Profile Of Hydraulic Cylinder

Wear Profile of Lower Bearing

Wear Profile of Piston
Figure 8: Meter Used To Measure Flow In Individual Flow-Tubes
Figure 9: Regional Bias In Core Flow Distribution
Figure 10: Device Used To Locate Turbulent Zone
Figure 11: Height of Turbulent Zone
Figure 12: Rundown Of Primary Cooling Pump

Flow rate (L/m x 1000)

Pump shaft speed (RPM x 100)

TIME (s)

0 2 4 6 8 10 12 14 16 18 20

10 12 14 16 18 20

18 16 14 12 10 8 6 4 2 0

20
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