AECL--10638

CA9200398

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DEVELOPING THE MAPLE MATERIALS TEST REACTOR CONCEPT

DÉVELOPPEMENT DU CONCEPT DE RÉACTEUR MAPLE D'ESSAIS DE MATÉRIAUX

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May 1992 mai

AECL RESEARCH

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RÉSUMÉ

MAPLE-MTR est une installation nouvelle polyvalente de recherches projetée par EACL Recherche pour remplacer éventuellement le réacteur NRU âgé de 35 ans. En développant le concept de MAPLE-MTR, EACL part de l'expérience récente en conception et en obtention de permis avec le réacteur MAPLE-X10. En partant de la technique mise au point pour le soutien de la conception de MAPLE-X10 et en l'adaptant pour produire un concept qui satisfait aux conditions des essais de matériaux de canaux de combustible et des programmes d'irradiation du combustible, EACL prévoit minimiser le besoin de grands progrès en technique nucléaire (par exemple: le combustible, le transfert de chaleur). La formation du concept de MAPLE-MTR est au stade initial. Dans ce rapport, on décrit les besoins d'irradiation des secteurs de recherche, la façon dont ces besoins se traduisent en critères de conception pour le projet et en éléments du concept préliminaire de réalisation.

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ABSTRACT

MAPLE-MTR is a new multipurpose research facility being planned by AECL Research as a possible replacement for the 35-year-old NRU reactor. In developing the MAPLE-MTR concept, AECL is starting from the recent design and licensing experience with the MAPLE-X10 reactor. By starting from technology developed to support the MAPLE-X10 design and adapting it to produce a concept that satisfies the requirements of fuel channel materials testing and fuel irradiation programs, AECL expects to minimize the need for major advances in nuclear technology (e.g., fuel, heat transfer). Formulation of the MAPLE-MTR concept is at an early stage. This report describes the irradiation requirements of the research areas, how these needs are translated into design criteria for the project and elements of the preliminary design concept.

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1. INTRODUCTION

The MAPLE Materials Test Reactor (MAPLE-MTR) is a new multipurpose research facility being planned by AECL Research as a possible replacement for the NRU reactor. Although the primary uses of the MAPLE-MTR will be CANDU* fuel irradiations and fuel channel materials testing, condensed matter science research will also be an important function for the facility. AECL is also considering using the MAPLE-MTR as a back-up radioisotope production facility.

At present, AECL operates two research reactors, NRX and NRU, at its Chalk River Laboratories and has one new reactor, MAPLE-X10 [1], under construction. The 45-year-old NRX reactor is maintained in a "hot" standby mode and is only operated to produce radioisotopes when the NRU reactor is out of service.

The NRU reactor provides irradiation facilities to carry out research programs in fuel channel materials, fuel and severe fuel damage behaviour in support of the development of the CANDU reactor. The NRU reactor also produces all of the radioisotopes for medical and industrial applications and provides access to beam tubes for the condensed matter science program.

The MAPLE-X10 reactor is being designed to operate as a dedicated commercial-scale producer of radioisotopes. Design of the MAPLE-X10 reactor [1] is in an advanced stage and construction is in progress. Once the MAPLE-X10 reactor is operating, the radioisotope production function will be transferred from the NRU reactor. The NRU reactor will then assume the backup radioisotope production role. The NRX reactor will be shut down when the MAPLE-X10 reactor is operating.

AECL is examining its options for future research reactor facilities because the NRU reactor is 35 years old and will need refurbishing if it is to operate into the twenty-first century. The NRU reactor has been a versatile facility for proof testing CANDU components and fuel designs because it approximated many conditions in the CANDU reactor reasonably well. However, the irradiation requirements to support future advancements in the CANDU reactor and to investigate phenomena associated with ageing of reactor components have changed as the CANDU design matured. The NRU reactor needs significant refurbishment if it is to continue as the primary irradiation facility. This option is being studied, but the potentially large costs and regulatory uncertainties make this option very challenging.

The MAPLE-MTR concept represents one alternative to continued reliance on the NRU reactor. In pursuing this option, AECL expects to draw on the recent design [1] and licensing [2,3] experience from the MAPLE-X10 project. By starting from technology developed to support the MAPLE-X10 design and adapting it to produce a concept that satisfies the requirements of fuel channel materials testing and fuel irradiation programs, AECL expects to minimize the need for major advances in nuclear technology

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* CANada Deuterium Uranium, registered trademark of AECL

(e.g., fuel, heat transfer). If the MAPLE-MTR concept can be shown to meet AECL's irradiation requirements at a reasonable cost, it is expected that a new reactor facility could be put into operation by the late 1990s.

Formulation of the MAPLE-MTR concept is at an early stage. This report describes the irradiation requirements of the research areas, how these needs are translated into design criteria for the project and elements of the preliminary design concept.

2. RESEARCH REACTOR IRRADIATION REQUIREMENTS

The major programs in AECL that require a reactor-based irradiation facility are CANDU reactor support, condensed matter science and radioisotope production. There are several other programs (e.g., neutron radiography and fusion breeder blanket fuel development) that will also require a neutron source; however, their requirements are captured by the major programs.

A common requirement from all of the programs is a high availability factor for the reactor. A goal of 90% availability has been set.

2.1 REQUIREMENTS FOR CANDU SUPPORT

The design of the CANDU reactor is supported by three programs: fuel channel materials research, fuel development and reactor safety research. Fuel development and reactor safety research have largely the same irradiation requirements.

2.1.1 Fuel Development and Reactor Safety Research

The CANDU fuel bundle consists of relatively short (0.5 m) lengths of fuel elements that are held together by thin end plates. The fuel development program supports this design through irradiation testing, which includes investigating the interactions between reactor coolant, reactor physics, materials properties, heat transfer, and fabrication variables. In addition to studying the performance of individual aspects (i.e., fuel elements) of the fuel bundle, the overall performance is studied under conditions that closely approximate the CANDU environment.

The reactor safety program involves establishing the limits of performance, and the behaviour and consequences if the fuel is exposed to extreme conditions. This program requires the capability to operate fuel beyond the performance limits in a controlled environment where the consequences of fuel failure can be managed safely and studied to provide data for normal plant operation.

2.1.1.1 Fuel Element Test Requirements

For fuel element tests, the requirements are the ability to irradiate from one to seven elements to thermal neutron fluxes of sufficient intensity to produce peak linear power ratings of about 70 kW/m. The fuel test loop must be able to operate at representative CANDU temperature (e.g., 300°C), pressure (e.g., 10 MPa), flow, and coolant chemistry conditions. H_2O will be the normal coolant used in these small diameter loops, but other coolants, such as D_2O, may also be required.

The reactor safety research program also requires the use of small-diameter fuel test loops with the above mentioned irradiation conditions. The additional requirement is the ability to induce rapid loss of coolant and loss of flow transients in a selected test loop.

2.1.1.2 Fuel Bundle Test Requirements

For fuel bundle tests, the irradiation requirements include 0.5-m length of relatively uniform flux and thermal neutron fluxes of sufficient intensity to produce peak linear power ratings of 70 kW/m in some elements. These fuel test loops must also operate at representative CANDU temperature, pressure, flow and coolant chemistry conditions. The normal coolant used in these loops will be H_2O.

Although the current reactor safety research program relies on use of small multi-element assemblies, future programs may require off-normal tests to be performed on full-diameter CANDU bundles. Since the fuel channels in a CANDU reactor are oriented horizontally, the capability of testing multi-element assemblies and CANDU bundles in a horizontal orientation is also desirable.

2.1.2 Fuel Channel Materials Requirements

The CANDU reactor design features an array of horizontal fuel channels, each containing a series of short fuel bundles. The fuel channel (i.e., pressure tube and calandria tube combination) is the main pressure retaining boundary and separates the high-temperature coolant from the low-temperature moderator. The fuel channel materials program involves gaining an understanding of the ongoing and end-of-life behaviour of the pressure tubes and calandria tubes. This understanding requires exposing fuel channel materials to conditions that both match and significantly exceed the fast-neutron fluxes of CANDU reactors.

The fuel channel materials program has several types of irradiation requirements. To define the life of fuel channel components, small (~30-mm diameter) samples of fuel channel materials need to be exposed to high fast ($E > 1.0$ MeV) neutron fluxes (i.e., 2 to 3 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$) and need to accumulate annual fast-neutron fluences of 3 to 4 x 10^{25} $n \cdot m^{-2}$. These material samples need to be maintained at typical CANDU temperatures.

The fuel channel materials program also irradiates sections of full diameter pressure tubes for proof testing of new materials and for gaining further information on the life of the pressure tubes. These need to be maintained at typical CANDU temperatures, pressures and fast-neutron fluxes (i.e., 0.2 to 0.3 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$).

Samples used in corrosion studies need to be maintained at typical CANDU temperatures and pressures in a controlled D_2O water-chemistry environment and a typical CANDU irradiation environment (i.e., fast-neutron fluxes of 0.6 to 0.7 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$).

2.2 NEUTRON BEAM REQUIREMENTS

The condensed matter science program at AECL involves performing neutron scattering studies such as investigations of residual stress and texture in components. In addition, active programs in neutron radiography and the application of neutron scattering to industrial research are pursued. The users of neutron beams, for neutron scattering and neutron radiography, acknowledge that the primary uses for the MAPLE-MTR will be for fuel and materials irradiations. It is intended to attempt to match the beam-tube capabilities of the NRU reactor in any new reactor. This would require six to eight beam tubes with ~2 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$ for the thermal-neutron fluxes. Provisions will be made to add a cold neutron source at some future date if it is not included in the initial design.

2.3 RADIOISOTOPE PRODUCTION REQUIREMENTS

Although the MAPLE-X10 reactor has been designated as the primary producer of radioisotopes, AECL considers it prudent to have a backup production facility available. Molybdenum-99 as a fission product and ^{125}I dominate backup radioisotope production considerations. Production of ^{99}Mo requires at least matching the power density (i.e., ~160 kW/L) in the MAPLE-X10 ^{99}Mo target assemblies. For ^{125}I production, a thermal neutron flux of about 1 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$ is needed.

3. SAFETY PRINCIPLES AND CRITERIA

The successful development of the MAPLE-MTR concept requires not only satisfying the irradiation requirements of the research programs but also satisfying the safety and licensing requirements of the regulatory authorities. To ensure that safety and licensing considerations are adequately addressed, a set of safety principles and criteria are being prepared. These safety principles and criteria will provide the safety basis for the design of the MAPLE-MTR and for assessing the design.

For the design of the neutron source, it is proposed to minimize the consequences of abnormal or accident conditions by using inherent safety features such as:

- negative fuel temperature coefficient,
- negative coolant temperature coefficient,
- negative coolant void coefficient,
- negative D_2O temperature coefficient, and
- negative D_2O void coefficient.

Other proposed safety principles and criteria for the reactor design include:

- the ability to shut down the reactor and maintain it in a subcritical state for all operational states and accident conditions;

- the withdrawal of any single control rod or largest worth experimental assembly in the shutdown reactor will not make the reactor core critical;

- the inadvertent dropping of a control rod will shut down the reactor;

- the maximum permissible design limits for fuel elements, reactivity control mechanisms, experimental assemblies, etc., are not exceeded;

- significant fuel damage is prevented during severe accident conditions; and

- the maximum positive reactivity worth of an experimental assembly will be 5 mk.

4. MAPLE-MTR CONCEPT

The MAPLE-MTR concept starts with the MAPLE-X10 design and adapts the technology to develop a multipurpose research reactor. The MAPLE-X10 reactor has 19 core sites surrounded by a D_2O reflector. Each site accommodates a hexagonal 36-rod fuel assembly, a cylindrical 18-rod fuel assembly or various target assemblies. At 10 MW, the MAPLE-X10 reactor has an average power density of 159 kW/L.

The power output of the MAPLE-MTR must be sufficient to provide the neutron fluxes required by the research programs (see Table 1). As a starting point for the concept development, a core power output of 15 MW has been chosen. This power output is based on several considerations. At 15 MW, the average power density in the core will be 250 kW/L. This is very similar to the power densities of the HFR-Petten (45 MW) and OSIRIS (70 MW) reactors, which provide fast-neutron fluxes of 2 to 3 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ at power densities of about 210 and 280 kW/L, respectively. Since the MAPLE-MTR core is similar in composition to HFR-Petten, similar fast-neutron fluxes can be expected. Preliminary physics calculations indicate the fast-neutron fluxes are about 2 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$. Also 15 MW is considered to be a modest increase in power over the MAPLE-X10 reactor and is not expected to result in linear power ratings beyond AECL's operating experience. Hence, no advances in fuel technology would be required. However, adjustments can be made to the reference power output if the concept assessment indicates higher powers are needed.

4.1 FUEL

The reference fuel is the low-enrichment (about 19.7 wt% ^{235}U in total uranium) U_3Si-Al that AECL developed for use in the NRU and MAPLE-X10 reactors. The fuel meat is composed of U_3Si particles dispersed in an aluminum matrix and coextrusion-clad with aluminum to form finned rods. This fuel has demonstrated excellent performance with up to 93% burnup of initial fissile material and with linear power ratings up to ~120 kW/m without any defects. Further information about the fuel can be found in Reference 4.

TABLE 1

SUMMARY OF NEUTRON SOURCE CRITERIA

	Design Criterion
Fuel Development	
Location	D_2O
Power rating	peak 70 kW/m
Thermal-neutron flux	~4 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$
Axial average to peak ratio	0.9
Fuel Channel Materials (Small sample)	
Location	Core
Fast-neutron flux	1.8-3 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$
Location	FN-site
Fast-neutron flux	0.6-0.7 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$
Fuel Channel Materials (Large sample)	
Location	Fuel test loop
Fast-neutron flux	0.2-0.3 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$
Beam Tubes	
Location	D_2O
Thermal-neutron flux	~2 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$
Thermal/fast-neutron ratio	~80
Backup Radioisotope Production (^{99}Mo)	
Location	Core
Average power density	250-300 kW/L
Backup Radioisotope Production (^{125}I)	
Location	D_2O
Thermal-neutron flux	~1 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$

4.2 CORE DESIGN

For the MAPLE-MTR, the reference 19-site core (Figure 1) will consist of six cylindrical 18-element fuel assemblies in the control and shutdown sites, two experimental assemblies for materials testing and eleven hexagonal 36-element fuel assemblies. Cylinders of hafnium surround the circular flow tubes holding the 18-element fuel assemblies. Three of these

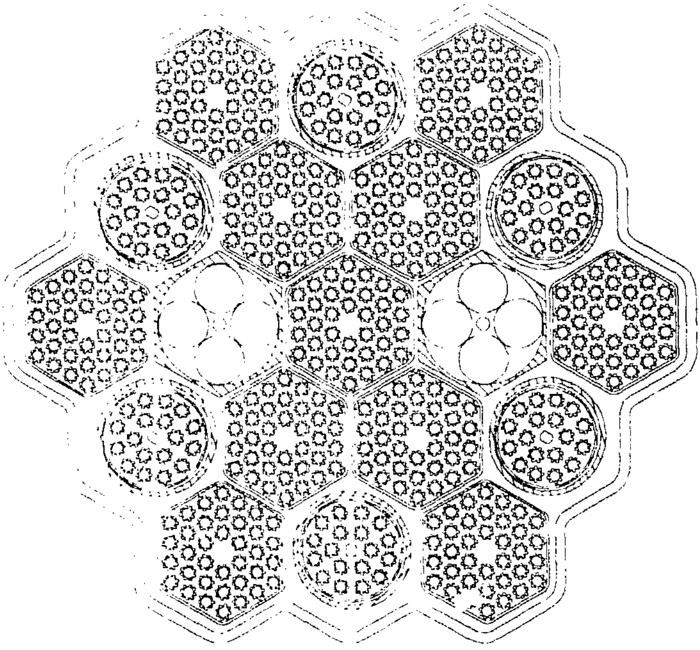

FIGURE 1: Schematic Representation Of The MAPLE-MTR Core

hafnium cylinders provide reactivity control, the other three are maintained as a poised safety bank. All six cylinders are inserted into the core upon detection of a trip signal to shut down the reactor.

With a core volume of 63 L, the MAPLE-MTR is considerably smaller than that other materials test reactors, such as HFR-Petten at 210 L, OSIRIS at 250 L and SILOE at 113 L, and has fewer in-core sites for experiments. This small core volume represents a compromise between in-core space for high fast-neutron flux irradiations and thermal-neutron fluxes in the D_2O reflector. However, since the power densities are similar (i.e., 250 kW/L for MAPLE-MTR, 210 kW/L for HFR-Petten and 280 kW/L for OSIRIS), the MAPLE-MTR is expected to have similar unperturbed fast-neutron fluxes in the range from 2 to 3 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$. Preliminary physics calculations indicate that the MAPLE-MTR has perturbed fast-neutron fluxes of ~1.4 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$ in the samples.

The thermal-neutron flux in the D_2O reflector will determine the value of the MAPLE-MTR for the fuel development program and for beam-tube applications. The basic requirements for high thermal-neutron fluxes in the D_2O reflector are a high power level and a small external surface area to the core. With a core volume of 63 L, the MAPLE-MTR core is about 10% larger than the ORPHEE core (56 L) and has about 10% greater external surface area. Since the power densities are the same, it is expected that the thermal neutron fluxes in the D_2O reflector would be similar at ~3 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$. Preliminary calculations confirm these peak thermal-neutron fluxes.

4.3 FN-ROD DESIGN

With the small core volume, the in-core space for materials testing is limited to two or three core sites. Additional fast-neutron irradiation space is provided by introducing fast-neutron rods (FN-rods) in the D_2O reflector. These FN-rods consist of annular fuel assemblies placed in the D_2O reflector to locally convert thermal-neutron fluxes into medium fast-neutron fluxes. Such FN-rods have been used in the NRU and DIDO reactors for many years to provide fast neutron irradiation facilities with fluxes of ~0.6 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$.

A FN-rod concept for the MAPLE-MTR is under development and assumes use of the same fuel element as the driver fuel. The development of the FN-rod concept must account for the compromises between the volume of irradiation space in the centre of the assembly and the magnitude of the fast-neutron fluxes. As well the physical location of the FN-rods with respect to the core will determine how much power and fast-neutron flux can be produced. Figure 2 shows a schematic representation of four FN-rods and the core. Preliminary calculations indicate that with an inner diameter of 74 mm for the FN-rod to hold the experiment assembly, the average power in each FN-rod is about 1.2 MW and the peak fast-neutron fluxes in the experiment assembly is ~0.6 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$. The medium fast-neutron fluxes will satisfy the irradiation requirements for corrosion studies. Although initial studies have used four FN-rods, additional FN-rods may be considered if more irradiation space is required.

The presence of the FN-rods in the D_2O reflector has several effects on the overall performance of the reactor. Depending on the amount of ^{235}U in the FN-rods, the available excess reactivity of the reactor can be increased by as much as 100 mk. The FN-rods decrease the local thermal-neutron fluxes and increase the local fast-neutron fluxes. The fast neutrons escaping from FN-rods are thermalized elsewhere in the D_2O reflector and contribute to higher thermal-neutron fluxes in other regions of the D_2O reflector.

4.4 FUEL TEST LOOP CONCEPTS

Several fuel test loops will be included in the D_2O tank for the MAPLE-MTR. The irradiation requirements from the fuel development and reactor safety research programs have identified fuel test loops to hold small multi-element (up to 7) assemblies and loops to hold full-diameter CANDU bundles.

To achieve peak linear power ratings of 70 kW/m requires thermal-neutron fluxes of 3-4 x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$. Preliminary calculations indicate that the regions between each pair of FN-rods have the requisite thermal-neutron fluxes. However, it is expected that the performance of the small-diameter test loops will differ, depending on the number of fuel elements. Preliminary scoping calculations have been performed to determine the fuel performance as a function of distance from the core. In these calculations, a four-element assembly with natural uranium UO_2 fuel was modelled. For a test loop centred about 100 mm outside of the core, the peak linear

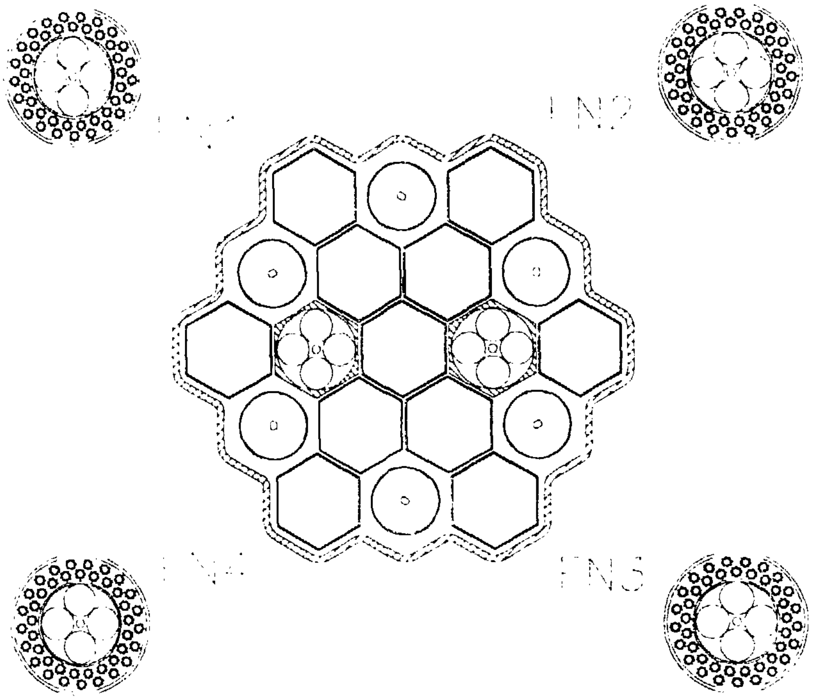

FIGURE 2: Schematic Representation Of FN-Rods Around The MAPLE-MTR Core

ratings in each of the fuel elements was ~67 kW/m, which is in the upper range of CANDU fuel performance. When the same test loop was centred about 270 mm outside the core, the peak linear ratings in each fuel element was about 47 kW/m, which represents the normal operating range. The peak linear ratings for the fuel test loop located 270 mm outside the core can be increased by enriching the uranium, thereby enabling the locations nearer the core to be occupied by the full-diameter test loops.

As CANDU fuel bundles represent much stronger thermal-neutron absorbers, some enrichment will be needed to achieve the desired linear power ratings. Scoping calculations to determine the effect of enrichment on the power distributions through the bundles are in progress. To meet the needs of the fuel development program at least four test loop positions will be needed. These test loops will be located between pairs of FN-rods to take advantage of the prime thermal fluxes. In addition to providing the facilities for fuel irradiations, the local fast fluxes produced by the test fuel will provide the appropriate conditions for proof testing pressure tubes.

4.5 D_2O TANK

The D_2O tank for the MAPLE-MTR is adapted from the design of the MAPLE-X10 tank. At present, the reference diameter is 1.6 m, but the demand for many fuel test loop positions, four or more FN-rods and the beam tubes may require the diameter to be increased. The reference height for the

MAPLE-MTR D_2O tank is 1.5 m, which is taller than the MAPLE-X10 tank. The tank height has been increased to increase the axial thermal flux region for the fuel test loops and to accommodate the fast D_2O dump system, which provides a second diverse shutdown system. Although placement of the beam tubes awaits finalizing the positions for the fuel test loops, it is expected that 6-8 beam tubes and a cold neutron source position can be accommodated.

The second shutdown system, which provides rapid removal of the D_2O is based on the shutdown system for tne WR-1 reactor. The D_2O tank consists of two parts, the upper D_2O reflector region and the lower dump region, separated by a weir. When the upper region is filled with D_2O, the lower region is pressurized with helium to hold up the D_2O. In response to a trip signal, the pressure in the upper and lower regions is equalized and the D_2O spills over the weir.

5. SUMMARY

The research programs that require reactor-based irradiation facilities have been identified and include fuel channel materials research, fuel development, reactor safety research, condensed matter science and radioisotope production. Table 1 summarizes the neutron flux requirements associated with these programs.

To provide the requisite neutron fluxes, the MAPLE-MTR would have a compact (63 L) H_2O-cooled, H_2O-moderated core with several high fast-neutron flux irradiation sites and a relatively high core power density (i.e., at least 250 kW/L). The in-core irradiation sites would provide the high fast-neutron fluxes needed for accelerated ageing studies on fuel channel materials. To provide medium fast-neutron flux irradiation sites, it is proposed to add at least four FN-rods in the D_2O reflector. To achieve the desired fast-neutron flux performance, each FN-rod will need to contribute about 1.25 MW to the reactor. Hence the total fission power of the reactor, excluding the power contributed by the fuel test loops will be at least 20 MW. To provide irradiation facilities for fuel development, reactor safety research and fuel channel proof testing, at least four fuel test loop positions for full-diameter CANDU bundles will be positioned in the D_2O tank. To complete the complement of fuel test facilities, several small-diameter multi-element test loops will be included. Sites will be chosen for these test loops once locations for the full-diameter test loops have been selected. Beam tubes will be placed in the remaining space in the D_2O tank. This forms the starting point for developing the MAPLE-MTR concept. Studies in physics, thermalhydraulics and engineering are in progress to develop a feasible concept.

REFERENCES

1. Lee, A.G., Bishop, W.E. and Heeds, W., "Safety Features of the MAPLE-X10 Design," Proceedings of The Safety, Status and Future of Non-Commercial Reactors and Irradiation Facilities, Boise, Idaho, 1990 September 30 to October 4, 1990.

2. Cotnam, K.D., "Safety Assessment of the MAPLE-X10 Reactor," Proceedings of the International Symposium on Research Reactor Safety, Operations and Modifications, IAEA-SM-310/96, Chalk River, Ontario, 1989 October 23 to 27, 1989.

3. Cotnam, K.D., Proceedings of The Safety, Status and Future of Non-Commercial Reactors and Irradiation Facilities, Boise, Idaho, 1990 September 30 to October 4, 1990.

4. Heeds, W., Lee, A.G., Carlson, P.A., McIlwain, H., Lebenhaft, J.R. and Lidstone, R.F., "The Nuclear Design of the MAPLE-X10 Reactor," Presented at the 14^{th} International Meeting on Reduced Enrichment for Research and Test Reactors, Jakarta, Indonesia, 1991 November 4 to 7. Also Atomic Energy of Canada Limited Report, RC-720.

ISSN 0067-0367

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