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DEVELOPMENT OF THE NEW CANADIAN IRRADIATION-RESEARCH FACILITY

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ABSTRACT

To replace the aging NRU reactor, AECL has developed the concept for a dual-purpose national Irradiation Research Facility (IRF) that tests fuel and materials for CANDU® (Canada Deuterium Uranium) reactors and performs materials research using extracted neutron beams. The IRF includes a MAPLE reactor in a containment building, experimental facilities, and support facilities. The reactor concept was developed to provide a realistic environment for irradiating up to nine natural- or enriched-uranium CANDU bundles at powers up to 1 MW_t, to generate fast-neutron fluxes up to 1.4×10^{18} $n \cdot m^{-2} \cdot s^{-1}$ in materials-damage and corrosion specimens, and to match the thermal-neutron fluxes available in NRU for a set of eight thermal beam tubes plus two cold sources equipped with neutron guides.

1. INTRODUCTION

Since 1957, the NRU reactor at the Chalk River Laboratories of Atomic Energy of Canada Limited (AECL) has been the cornerstone for the development of CANDU® (Canada Deuterium Uranium) reactor technology and the national source of neutrons for basic and applied materials research. However, NRU is unlikely to operate much beyond the year 2000. Accordingly, as reported at previous IGORR meetings [1,2], AECL has been conducting an ongoing assessment of the future requirements for irradiation facilities to support continued development of the CANDU reactor and developing a new Materials-Testing Reactor (MTR) concept to meet these requirements. Furthermore, the Committee on Materials Research Facilities (CMRF), which was sponsored by the NSERC (Natural Sciences and Engineering Research Council), has recognized that the development of new materials is a key component of a competitive economy and recommended that Canada give priority to funding and building a new Canadian neutron beam facility for materials research [3]. AECL has responded to national priorities by ensuring that the emerging MTR concept is a fully dual purpose Irradiation-Research Facility (IRF) that provides:

<u>**Irradiation facilities for CANDU fuel and materials testing**</u>: Advanced CANDU concepts include more passive safety systems, shorter construction times, easier more reliable operation and maintenance, higher load factors, longer plant lifetimes, and a variety of advanced fuel cycles (including thorium fuels and the burning of actinide wastes and spent fuel from light-water reactors). Therefore, the IRF must be able to test new reactor fuels and materials under representative CANDU reactor conditions.

<u>**A national facility for materials research**</u>: Neutrons provided by NRX and NRU have facilitated world-class materials research using neutrons (which culminated in the 1994 Nobel Prize for physics given to B.N. Brockhouse for his work on determining the excitation properties (phonons and magnons) of materials, and developing inelastic scattering techniques and the triple-axis spectrometer). As an indigenous source of neutrons, the IRF is essential for continuing neutron-based materials science in Canada and thus for gaining reciprocal access for Canadian scientists to foreign materials-research facilities.

2. EXPERIMENTAL REQUIREMENTS FOR THE IRF

To form a consensus on experimental requirements, AECL established a user review committee with representation from all CANDU and basic R&D programs. The following detailed requirements reflect the dual nature of the IRF.

2.1 Experimental Requirements to Support CANDU R&D Programs

Three major CANDU research and development programs require irradiation facilities:

- **Fuel and fuel-cycle technology** which investigates the behaviour of existing and future fuel designs both under normal operating conditions and at extreme limits;
- **Fuel channel technology** which involves long-term research to study end-of-life behaviour in fuel-channel materials, to improve the fundamental understanding of in-reactor material behaviour, to further develop predictive models for materials behaviour, and to develop improved materials and components;
- **Reactor safety research** which will improve the understanding of fuel and fuel-channel behaviour in the event of loss-of-coolant accidents and under severe-fuel-damage conditions by providing data that validates computer codes and models used for safety assessments and characterizes fission-product release, transport and deposition.

The corresponding CANDU experimental requirements are presented in Tables 1 and 2. Reactor-safety-research requirements are included with those of the fuel technology program under multi-element partial bundles.

TABLE 1: EXPERIMENTAL REQUIREMENTS FOR THE FUEL TECHNOLOGY PROGRAM

CAPABILITY	EXPERIMENTAL REQUIREMENTS
CANDU Bundles	**Capacity:** four or more bundles **Flux length:** 1.0-1.5 m per test section **Coolant pressure:** 10 MPa **Coolant temperature:** 300°C **Linear element ratings:** 50-70 kW/m **Power:** up to 1 000 kW per bundle
Multi-element Partial Bundles	**Capacity:** several test sections with 1 to 8 fuel elements per test section **Flux length:** 1.0-1.5 m per test section **Coolant pressure:** 10 MPa **Coolant temperature:** 300°C **Linear element ratings:** 50-70 kW/m
Diagnostic Capability	**Type:** in-pool neutron radiography of irradiated fuel **Thermal-neutron flux:** $\sim 0.7 \times 10^{18}$ $n \cdot m^{-2} \cdot s^{-1}$ **Type:** neutron radiography of unirradiated fuel **Thermal-neutron flux:** $\sim 2 \times 10^{18}$ $n \cdot m^{-2} \cdot s^{-1}$

TABLE 2: EXPERIMENTAL REQUIREMENTS FOR THE FUEL CHANNEL TECHNOLOGY PROGRAM

CAPABILITY	EXPERIMENTAL REQUIREMENTS
Full-diameter CANDU Fuel Channel Sections	**Capacity:** four or more m of test section **Flux length:** 1.0-1.5 m per test section **Coolant pressure:** 10 MPa **Coolant temperature:** 300°C **Fast Flux:** 0.3 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$
Deformation and Fracture	**Medium fast flux:** 0.7 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ **Capacity:** 4-5 capsules **High fast flux:** 1.8 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ **Capacity:** 2 capsules **Ultra-high fast flux:** 3.0 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ **Capacity:** 2-3 capsules
Corrosion Testing	**Type:** a stainless-steel loop with standard CANDU coolant chemistry, a stainless-steel loop with variable coolant chemistry, and a recirculating gas loop
Diagnostic Capability	**Spectrometers:** one for residual strain determination, one for texture determination and one for chemical phase and annealing studies

2.2 Requirements of the Neutron Beam Research Community

The Canadian neutron beam-research community has described its requirements in several CINS (Canadian Institute of Neutron Scattering) publications [4,5,6] and in the interim report [3] by the NSERC-sponsored CMRF. Although perturbed thermal-neutron fluxes of 6 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ at the noses of the beam tubes are desirable, lower fluxes of ~2 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ (i.e., comparable to the peak thermal-neutron flux at the beam tubes of NRU) are acceptable. The minimum complement of beam tubes includes: seven thermal-neutron beam tubes, one cold-neutron beam tube looking directly at the cold-neutron source plus a cold-neutron guide fan leading to an adjacent guide hall, one thermal-neutron beam tube for neutron radiography, and one in-pool short beam tube for neutron radiography. To allow for future growth, provision should be made for a second cold-neutron source with neutron guides leading to a second guide hall.

3. DESCRIPTION OF THE IRF

Although the IRF concept was developed to be non-site specific, suitable locations are available at AECL's Chalk River Laboratories (CRL) and Whiteshell Laboratories (WL). A representative location at CRL was used to develop the reference cost estimate of 500 million (1994) Canadian dollars. Although certain new support facilities (e.g., process water supply and heating) are included, the estimate assumes an existing nuclear infrastructure (e.g., hot cells, cafeteria, waste treatment centre, waste storage, etc.) at the IRF site.

3.1 The IRF Complex

The IRF complex consists of the reactor containment building, an adjacent guide hall, a mock-up building, and adjoining buildings for operations, administration, and utilities.

The reactor containment building, which houses the reactor and service pools and equipment rooms for the reactor process systems, is a cylindrical reinforced concrete structure (40 m diameter by 40 m high) with a hemispherical dome. It is designed to provide shielding for fission-product releases and to withstand any internal pressurization arising from postulated severe accidents. The lowest level of the building provides an array of instrument stations clustered around the beam tubes as well as access to the horizontal fuel test sections. Neutron guides extend from the outer face of the reactor pool through the building wall to the guide hall. Air locks provide normal access to the building at the reactor-operations and beam-research-facility levels. Removable wall panels allow the infrequent movement of large components to and from the building.

The guide hall houses the cold- and thermal-neutron guides outside the containment building plus various instrument stations. Laboratories, offices and other supporting beam-research facilities are adjacent to the guide hall. The operations building contains control rooms for the reactor and the experimental process facilities plus offices and laboratories and a hot cell for handling experimental equipment. The utilities building contains the electrical power distribution switchgear, compressors, refrigeration units, a de-ionized water plant, the ventilation systems and other utilities needed for reactor operation and the various experimental facilities. Located between the operations and utilities buildings is a shipping and receiving area with a pool for storing spent fuel and other radioactive components and for assembling and inspecting experimental equipment. The administration building contains offices, conference rooms, lecture rooms, and a small self-serve cafeteria. Adjacent to the administration building is a separate building that houses a full-scale mock-up of the reactor and the reactor pool; it will be used for testing reactor components, developing tools and procedures, and training operations and maintenance staff.

3.2 The IRF Reactor Assembly

TABLE 3: MAJOR FEATURES OF THE IRF

FEATURE	DESCRIPTION
Reactor Type	open tank-in-pool reactor assembly with split core
Fuel	19.7 wt% ^{235}U as U_3Si_2-Al 18-, 36-, and 58-rod assemblies with 0.7 m fuelled length
Coolant	H_2O
Reflector	D_2O
Reactor Regulation System	hollow-cylindrical hafnium absorbers inserted into the core from above
Shutdown System 1	de-energize electromagnets to drop hafnium absorbers (overriding regulation system)
Shutdown System 2	D_2O dump from fuelled portion of reactor vessel
Total Power (MW_t)	40 (nominal)

The IRF reactor assembly (major features listed in Table 3) employs a split-core concept that places three horizontal CANDU-fuel-channel test loops between two cores each of which consists of an 18-site MAPLE-type core segment plus two fast-neutron (FN) sites. The reactor assembly is located in a 15.6-m deep, light-water-filled pool and consists of four main components (shown in Figures 1 and 2):

- **Inlet plenum:** The inlet plenum supports the core assembly and reactor vessel and provides H_2O from the primary cooling system.

- **Reactor vessel and Core assembly**: The reactor vessel, which rests on the inlet plenum, is a complex D_2O-filled tank with two corrugated inner walls that define the H_2O-cooled MAPLE-type core regions. Each core segment contains 18 flow tubes that accommodate 16 fuel bundles and two irradiation sites; the flow tubes are mounted into a grid plate that directs cooling water from the inlet plenum past the fuel and the irradiation rigs The vessel has horizontal penetrations for three fuel-bundle test sections and ten beam tubes, plus vertical penetrations for the four FN sites, two vertical U-shaped fuel test sections, and tubes for irradiation assemblies (e.g., hydraulic and pneumatic rabbits). As Figure 1 shows, the reactor vessel extends down and around the upper portion of the inlet plenum When the reactor is operating, the upper (core) portion of the vessel is filled with D_2O, which is held in place by differential pressure of helium gas relative to the lower portion. The D_2O may be rapidly drained into the lower portion (to shut down the reactor) by equalizing the helium pressure in the upper and lower portions of the vessel.

- **Chimney:** The chimney which rests on top of the reactor vessel collects the water exiting the two core segments and directs it through two outlet nozzles back to the primary cooling system/ The chimney is open at the top to the pool which provides a natural-circulation path for cooling the fuel when the reactor and primary cooling system are both shut down. The chimney also supports and locates the eight control/shut-off absorbers.

The fuel elements contain a core of U_3Si_2 dispersed in aluminum and surrounded by a co-extruded aluminum sheath. The LEU (Low-Enrichment Uranium) is enriched to 19.75 wt% ^{235}U. The fuel element design is based on the LEU fuel developed for use in NRU, and is very similar to that supplied for use in HANARO. There are three types of driver fuel bundles:

- **36-element driver bundle:** The main type of driver fuel bundle contains a hexagonal array of 36 elements. The elements are held by a top and bottom end plate mounted on a central support shaft which is locked into a receptacle in the bottom of the flow tube. There are 24 of these 36-element bundles in the core.

- **18-element driver bundle:** Fuel bundles for the eight reactivity-control sites contains 18 elements. The flow tubes in these positions have circular exteriors to accommodate the circular sections of the hafnium control absorbers that surround them.

- **58-element FN bundle:** The four FN sites, located just outside the 18-site core segments, each contain 58 elements in two rings surrounding a central irradiation thimble.

3.3 Reactor Process Systems

The **Primary cooling system** cools the driver fuel and the FN fuel with two circuits that supply H_2O to the two nozzles of the inlet plenum. After passing over the fuel, the water is drawn from the two outlets of the chimney and discharged through the heat exchangers and back to the inlet plenum. To ensure that core coolant is not discharged directly to the pool through the open top of the chimney, a fraction of the coolant entering the inlet plenum is discharged to the pool which results in a flow down the chimney that confines the core-exit flow to the lower part of the chimney. Each circuit has a single plate-type heat exchanger two parallel pumps equipped with high inertia rotors to provide a slow pump rundown. Each inlet pipe contains a venturi-type flow diode that limits the reverse flow through the circuit in the event of an inlet piping failure and ensures adequate cooling flow to the core. At low decay powers, heat is removed by natural circulation path out the top of the chimney through the inlet-plenum flow diodes.

The **Reflector cooling system** provides circulation of D_2O through the upper portion of the reactor vessel over a dump-ring weir to the lower portion, and thence through a cooling circuit that removes the heat deposited in the D_2O and the reactor vessel components. A catalytic recombiner is provided to compensate for the formation of D_2 and O_2 gas that occurs as the D_2O passes through the reactor vessel.

3.4 Reactor Control and Safety Systems

The reactor control system consists of:

- **Control rod and drive:** Eight control rods (four in each of the two core segments) are used to adjust the reactor power. Each control rod consists of a hollow cylindrical hafnium metal absorber attached to a shaft that extends up through the reactor chimney to a drive unit mounted on a support structure located at the top of the pool. The drive unit consists of a stepping motor driven by the control computer, an electromagnet that magnetically couples the connecting shaft to the motor drive, and a hydraulic damper section that arrests the fall of the rod at the end of its travel when the electromagnet is de-energized.

- **Reactor control computer system:** The Digital Control System (DCS) provides computerized control and monitoring for all reactor systems and experimental facilities. Two main components, the Digital Control Computer (DCC) for control functions and data acquisition, and the Plant Display System (PDS), which is the interface between the Reactor Operator and the DCC, make up the DCS. The DCS uses fault-tolerant, dual-redundant, computer hardware to automate operator activities, where possible, during normal operation. The PDS generates the operator displays, processes operator commands and transmits these control commands to the DCC, provides alarm annunciation and acknowledgement, and controls the data logging necessary to support historical data/trend displays and event logs. The display information will also be routed to a remote monitoring and shutdown facility.

Two diverse, independent safety systems are provided:

- **Shutdown system 1:** Shutdown system 1 (SS1) rapidly shuts the reactor down by interrupting the power to the electromagnets of the eight control rods and allowing the absorbers to fall into the core. The parameters monitored include those of the reactor and also those of the various irradiation facilities whose failure without reactor shutdown could result in fuel damage and the release of fission products. All sensing instruments are triplicated.

- **Shutdown system 2:** Shutdown system 2 (SS2) achieves shutdown by rapidly draining the D_2O out of the top part of the reactor vessel that surrounds the core. During normal operation, the D_2O is held up by the pressure of helium gas in the lower part of the vessel. Different types of detectors from SS1 are used, where practical, to avoid failure of both safety systems due to a common failure.

3.7 Experimental Facilities

Table 4 lists the IRF's experimental facilities. The **Horizontal Fuel-Test Facilities** comprise three in-reactor horizontal test sections stacked vertically between the two core segments plus their respective out-reactor process systems. Each test section consists of a calandria tube and a pressure tube that accepts up to three CANDU fuel bundles. Provision is also made for controlling test-section power by adjusting the level of either ^{10}B or ^{3}He poison in a thin annulus outside the pressure tube. Coolant supply piping connects the end fittings to process systems located in shielded rooms where an arrangement of pumps, heat exchangers, tanks and other equipment provides representative CANDU fuel-channel conditions and removes the heat generated by test fuel bundles.

There are two vertical multielement fuel-test facilities. Coolant flows down an inlet leg and then upwards past the fuel assembly located in the outlet leg of a U-shaped test section. A process system located in a shielded room on the reactor process systems level provides the desired temperature, pressure, flow and chemistry conditions in the test section and removes the heat generated by the test assembly.

TABLE 4: SUMMARY OF EXPERIMENTAL FACILITIES

TYPE OF FACILITY	DESCRIPTION
Horizontal Fuel-Test Facilities	3 test sections with several CANDU bundles/section Bottom test section replaceable with a high-integrity test section for BTF tests 3 test loops, 1 per test section
Vertical Fuel-Test Facilities	2 test loops, 1 per test section for multi-element partial bundles
BTF Loop	1 BTF loop system to connect to bottom horizontal test section
Materials-Irradiation Facilities	4 in-core sites with 3 or 4 inserts/site 4 FN-sites with 4 inserts/site or 1 corrosion loop/site
Hot Cells	1 three-compartment cell 1 handling cell for horizontal test sections
Service Irradiation Facilities	10 vertical tubes including: 2 hydraulic rabbit systems 1 pneumatic rabbit system
Neutron Beam Research Facilities	10 beam tubes, 2 of these for cold neutron sources 1 liquid hydrogen cold neutron source 5 cold-neutron guides 2 thermal-neutron guides

The bottom horizontal test section can be configured such that after the reactor is shut down the test section can be depressurized or blown down into the BTF (Blowdown Test Facility) loop. The transport of fission products from the fuel can be monitored by gamma spectrometers mounted on the downstream piping and in the BTF loop room at the reactor process systems level. The loop provides for steam and helium cooling of the assembly after the test. The initial water and steam discharged from the test assembly and the post-accident coolant will be directed to a large blowdown tank.

Each core segment has two locations for **Materials-Irradiation Facilities** in which material specimens are irradiated at high fast-neutron flux conditions. The devices (compatible with the QUATTRO rigs employed at the HFR-Petten facility) will consist of four cylindrical inserts in which material specimens are mounted.

In the four FN-sites, the fast-neutron flux is locally increased by surrounding a central irradiation thimble with a 58-element fuel bundle. Different types of devices may be installed in the thimble, including the QUATTRO-type rigs, and assemblies of cylinders containing material specimens that are cooled by water or gas, whose chemistry and temperature can be varied to examine the effect on the corrosion properties of the material specimens. The irradiation effect on the coolant chemistry, such as radiolysis, can also be examined in these devices. Two D_2O loops and one gas corrosion loop will be provided to supply D_2O or gas to the corrosion specimens.

A hot cell on the main floor level is divided into three compartments. The general purpose compartment will contain equipment for assembly and disassembly of the irradiation facilities, such as the QUATTRO-type rigs and the vertical fuel-test assemblies. The other two compartments will be used for sample examination. The rabbit transfer system will be contained in one of these compartments. Rabbit capsules may be transferred from the cell to a laboratory located outside the Reactor Containment Building in the operations area. A hot cell is also located on the beam research facility level, for installing and removing assemblies from the horizontal test sections (i.e., fuel bundles, pressure tubes and BTF assemblies).

Two vertical tubes provided in the reactor vessel will contain assemblies into which material specimens can be installed and removed using a hydraulic rabbit. A pneumatic rabbit will also be provided. Other vertical tubes are provided for general purpose irradiations and future facilities.

Various experimental facilities are provided for the national and international neutron beam research community. There are eight thermal-neutron beam tubes in the reactor vessel to deliver beams of neutrons to instrument stations outside of the reactor. Two of these beam tubes will accommodate thermal-neutron guides to transmit neutrons to instrument stations in the Guide Hall. Two additional beam tubes can accommodate liquid hydrogen cold neutron sources, although only one cold neutron source is included in the initial installation. The second beam tube can be used as a thermal-neutron beam tube until a second cold neutron source is installed. A liquid hydrogen cold neutron source and a set of cold-neutron guides will allow cold neutrons to be delivered to instrument stations in the Guide Hall. It is planned to move three existing triple-axis spectrometers, a high-resolution powder diffractometer (one-half of DUALSPEC), and a polarized neutron triple-axis spectrometer (the other half of DUALSPEC) from NRU to the new facility. These instruments will be attached to the thermal-neutron beam tubes. Six new instrument stations for use on the cold-neutron guides will be supplied as part of the IRF project. The specifications for these instruments will be developed in consultation with CINS.

4. PERFORMANCE ASSESSMENT

The neutronic performance of the reactor and its experimental facilities analyzed using the physics computer codes WIMS-AECL/3DDT [7,8] and MCNP [9]. A total power of 40 MW_t was assumed to be produced by the two core segments (~33 MW_t) and the four FN-sites (~7 MW_t). The design power, and hence the available flux levels, will be optimized during formal design phases of the IRF project.

4.1 Concept Development to Meet CANDU Bundle Testing Requirements

The experimental requirement that has most strongly governed the evolution of the IRF concept has been the capability for irradiating at least four (and preferably eight or more) CANDU bundles under realistic power-reactor conditions. The primary requirement is to operate natural CANDU bundles under the very uniform high-power conditions listed in the second column of Table 5. Additionally, it must be feasible to irradiate the same bundles at lower power and element ratings with a substantial axial power gradient that represents end-bundle conditions, but without introducing power tilts or changing the relative element-to-outer-element powers.

In the NRU facility (as shown in Table 5), it has been necessary to enrich prototype CANDU-6 fuel bundles to ~1.7% to attain a power history that conservatively represents a natural UO_2 bundle that operates at 1000 kW when fresh; the somewhat higher initial power for the enriched test bundle compensates for the slight initial power rise of a natural UO_2 bundle at low burnup. As the NRU loops are vertical, it has been normal practice to replace the centre fuel element with a support shaft that holds up to six bundles per test section. Although NRU's large size enables very uniform irradiation conditions, the inner elements run somewhat cooler at the outer elements somewhat hotter than desired as a consequence of the use of enrichment.

Early MAPLE-MTR studies [2] that considered the vertical irradiation of single CANDU bundles in the heavy-water tank that surrounds a MAPLE-X10-type core showed that power levels of interest (800-1000 kW) could be obtained with 5% enrichment (column 4 of Table 5); however, the relative element powers are quite atypical and the power tilt across the bundle (in the direction away from the core) is relatively large. The use of four FN fuel assemblies interspersed with four vertical CANDU test sections results in a reduced need for enrichment (to ~2%) and improvements in the power tilt (column 5 of Table 5), but the element power distribution remains atypical of natural CANDU bundles.

By placing the CANDU bundle-test sections (horizontally) in the centre of the IRF core, the capability of uniformly irradiating several natural UO_2 bundles at up to 1000 kW is attained with the required element power distribution, especially if D_2O is employed as the coolant (column 6 of Table 5). These IRF results were obtained using MCNP with allowance for fission-product decay heating.

TABLE 5: MEETING CANDU BUNDLE IRRADIATION REQUIREMENTS

Parameter	CANDU*	NRU	Early MAPLE-MTR		IRF
			no FN Sites	with FN Sites	
Number of Fuel Elements	37	36	37	36	37
Enrichment (wt% ^{235}U)	0.7	1.7	5.0	2.0	0.7
Bundle Power (kW)	1000	1046	840	890	~1000
Average Element Rating (kW/m)	56	61	47	52	56
Ave. Outer Element Rating (kW/m)	63	74	60	65	65 63*
Peak Outer Element Rating (kW/m)	64	78	87	78	71 69*
Centre vs. Outer Element Power	0.69	-	0.28	-	0.63 0.69*
Inner vs. Outer Element Power	0.72	0.56	0.35	0.50	0.67 0.72*
Middle vs. Outer Element Power	0.81	0.68	0.50	0.63	0.77 0.81*
Maximum vs. Average Element Power	1.13	1.22	1.40	1.26	1.16 1.13*
Axial Gradient (max./ave.)	1.01	1.02	1.10	1.09	1.07
Axial Gradient (min./ave.)	0.99	0.97	0.80	0.80	0.90
Outer Element Power Tilt (max./ave.)	~1.0	1.01	1.19	1.10	1.02
Outer Element Power Tilt (min./ave.)	~1.0	0.99	0.82	0.90	0.98

* Heavy-Water coolant

The power output predicted by WIMS-AECL/3DDT for the horizontal test sections with two natural uranium CANDU bundles per test section and H_2O coolant is about 600 kW per bundle in the bottom test section, 900 kW per bundle in the middle test section, and 650 kW per bundle in the top test section. Using D_2O coolant in place of H_2O coolant increases the power per bundle by about 5%. With three bundles per test

2 wt% ^{235}U, the power output from each test section would approximately double. To avoid derating the reactor during the irradiation of enriched CANDU bundles, studies have been performed that establish the feasibility of controlling test section power using either ^3He in the gas gap between the pressure tubes and the calandria tubes or soluble ^{10}B in a D_2O annulus outside the calandria tubes.

4.2 Performance of Other Experimental Facilities

The average linear element rating for a seven-element assembly and H_2O coolant, estimated using WIMS-AECL/3DDT is 37 kW/m at natural uranium enrichment and 76 kW/m if enrichment is 2 wt% ^{235}U. The extrapolated flux length was calculated to be 1.2 m.

The performance of the in-core materials-irradiation devices was estimated by modelling representative QUATTRO assemblies in two sites in each core segment. The calculations were performed with WIMS-AECL and 3DDT. The fast-neutron (E > 1 MeV) flux exceeds 1.3 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ (i.e., 8.8 displacements per atom per year at 90% reactor availability) for a 150 mm length of zirconium alloy, and is greater than 1.0 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ (i.e., 6.7 displacements per atom per year at 90% reactor availability) for a 450 mm length of zirconium alloy. For comparison, the pressure tube material in a typical CANDU reactor experiences one to two displacements per atom per year. Hence, the irradiation assemblies will permit accelerated aging studies to be conducted on pressure tube materials.

The performance of FN-irradiation devices was also estimated by modelling representative QUATTRO rigs. The fast-neutron (E > 1 MeV) flux exceeds 0.42 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ (i.e., 3.0 displacements per atom per year at 90% reactor availability) for a 94 mm length of zirconium alloy, and is greater than 0.33 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ (i.e., 2.3 displacements per atom per year at 90% reactor availability) for a 460 mm length of zirconium alloy.

The peak unperturbed thermal-neutron flux is estimated to exceed 4 x 10^{18} $n{\cdot}m^{-2}{\cdot}s^{-1}$ in the D_2O region outside of the core segments. Table 6 lists the unperturbed and perturbed thermal-neutron fluxes at the entrances to the beam tubes, as calculated with WIMS-AECL/3DDT and MCNP. For the unperturbed case, the beam tubes were replaced with D_2O. In Table 6, the entries for BT9/10 in the cold source vessel refer to modelling the beam tubes with a cold neutron source vessel installed but without including the liquid hydrogen in the vessel. There is good agreement between the WIMS-AECL/3DDT and MCNP results.

5. SUMMARY

AECL has responded to the need to replace the NRU reactor by developing the concept for a national dual-purpose IRF to test CANDU fuels and materials and to perform materials research using neutrons. The proposed IRF would meet the Canadian nuclear industry's needs with various CANDU-specific experimental facilities, and would satisfy a very broad spectrum of national and international academic and industrial research requirements with a national neutron-beam research facility.

TABLE 6: UNPERTURBED AND PERTURBED THERMAL-NEUTRON FLUXES FOR THE BEAM TUBES

	WIMS-AECL/3DDT		MCNP	
	Unperturbed (x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$)	Perturbed (x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$)	Unperturbed (x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$)	Perturbed (x 10^{18} $n \cdot m^{-2} \cdot s^{-1}$)
BT1/2	3.3	2.9	3.2	2.4
BT3/4	3.8	3.0	3.6	2.5
BT5/6	2.9	2.2	3.1	1.8
BT7/8	2.7	1.9	3.0	1.8
BT9/10 (at the entrance)	3.0	2.3		
BT9/10 (in cold source vessel)		2.2		1.8

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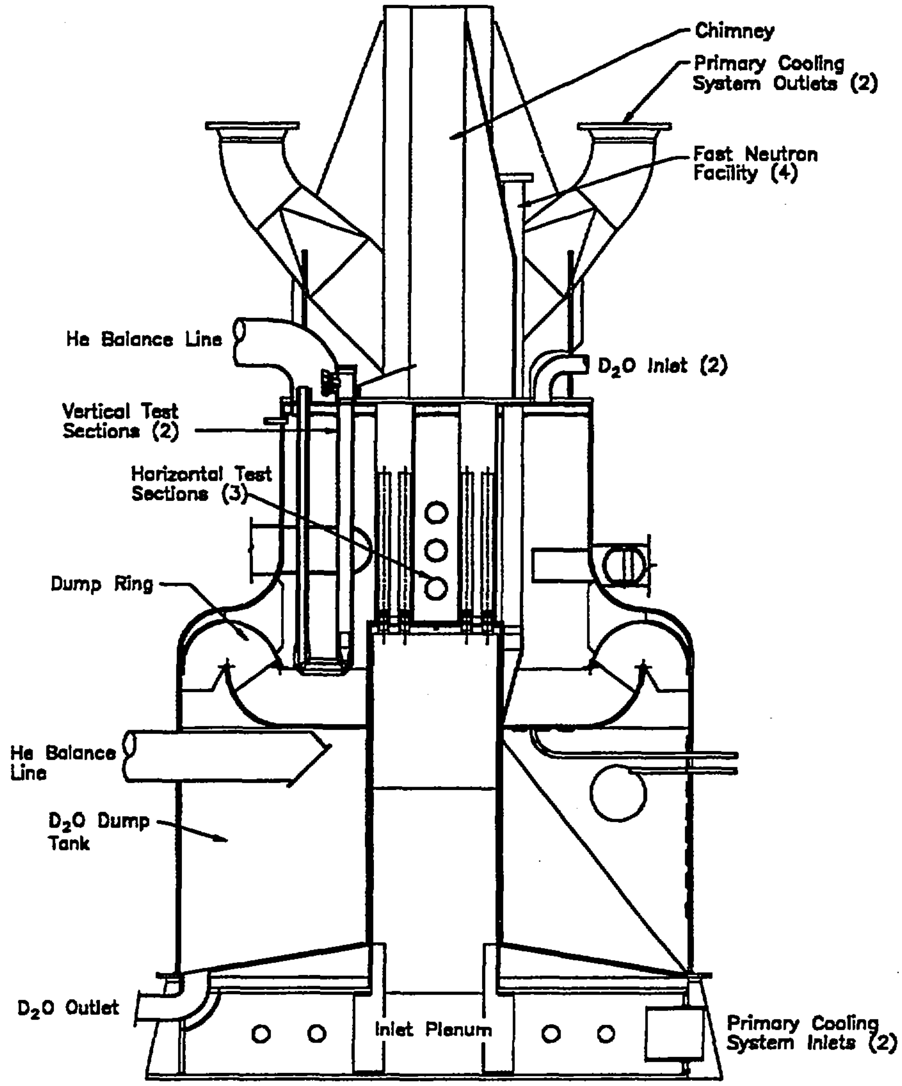

FIGURE 1: IRF REACTOR ASSEMBLY VERTICAL SECTION

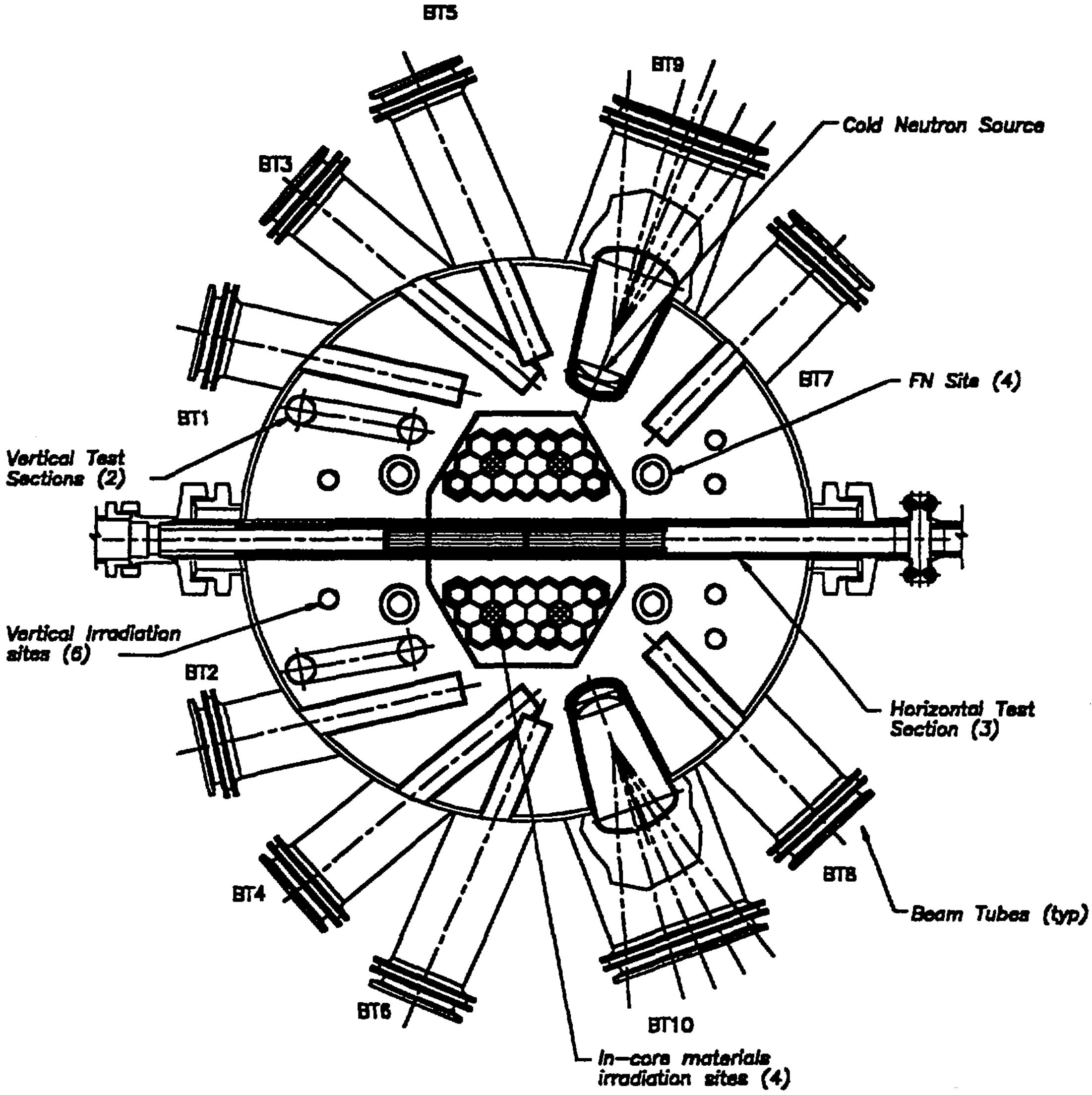

FIGURE 2: IRF REACTOR PLAN VIEW