

**THE IMPORTANCE OF THE CANADIAN NEUTRON FACILITY
TO
THE FUTURE DEVELOPMENT OF CANDU REACTORS**

**RESEARCH AND DEVELOPMENT ADVISORY PANEL
TO THE BOARD OF DIRECTORS OF AECL**

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THE IMPORTANCE OF THE CANADIAN NEUTRON FACILITY TO THE FUTURE DEVELOPMENT OF CANDU REACTORS

1.0 INTRODUCTION

During the 1990-91 cabinet review of Atomic Energy of Canada Limited, a consensus was developed on the need for an independent, arms-length review of AECL's research and development program. The Board of Directors of AECL subsequently approved the formation of the Research and Development Advisory Panel for this purpose.

The mandate of the Panel, as spelled out in its current terms of reference, is:

The Research and Development Advisory Panel shall advise the Board of Directors of AECL respecting the strategic needs, alliances and direction of the research and development activities of AECL. The Panel shall provide advice to the Board as to whether or not these programs have the appropriate scope, composition and balance between short- and long-term activities to sustain AECL's nuclear program, nationally and internationally.

The Panel is composed of independent experts in the various scientific and engineering disciplines involved in the R&D programs undertaken by AECL. Its members have considerable experience in both undertaking research and managing research programs.

The Panel prepares and submits an Annual Report to the AECL Board of Directors and undertakes other activities on matters relevant to its mandate.

In view of the present joint undertaking by the National Research Council and AECL to propose to the Government of Canada that a new Canadian Neutron Facility for Materials Research (CNF) be funded and built, it appeared appropriate, because of the Panel's long-standing interest in and support for a new research reactor for Canada, for the Panel to prepare a statement of its views on the importance of the CNF to the future development of CANDU reactors. This statement is provided in this special report.

2.0 THE NEEDS FOR A NEW RESEARCH REACTOR IN CANADA

Since its inception, the Panel has focused considerable attention on the needs for, and the provision of, a new research reactor for Canada. In its first Annual Report in 1992, the Panel recommended that the replacement of AECL's major research facility, the NRU reactor, with an improved R&D reactor be given an urgent and high priority. Based on further reviews of the requirements and options for a new R&D reactor, the Panel has made a number of detailed recommendations on a new research reactor in each of its subsequent Annual Reports including its forthcoming Annual Report for 1998.

The Panel has found that there are two major reasons for a new research reactor in Canada:

- * The compelling need for an engineering-scale research reactor with adequately high thermal and

fast fluxes to provide the essential support required for AECL to fulfil its mission of securing the maximum economic benefit for Canada from the CANDU business. This need also encompasses the strategic need to ensure long-term international competitiveness of the CANDU reactor.

- * The need for a high-flux neutron beam facility for basic and applied research in materials technologies, as part of an essential suite of materials probes, to which Canada, as an advanced industrial economy, must have access. Materials technologies are universally recognized as strategic priorities for future economic growth.

As noted above, the Panel is providing in this special report a statement of its views on the need for a new research reactor, the proposed CNF, as an essential element in support of the CANDU business. It leaves it to others to make the arguments for the CNF as an essential element in basic and applied materials research in Canada under the Neutron Program for Materials Research (NPMR) of the National Research Council.

3.0 THE NEED FOR A NEW RESEARCH REACTOR TO SUPPORT CANDU R&D

In this section, the Panel presents its main arguments for the general need for a new research reactor for the support of the future development of the CANDU reactor, as well as for the ongoing support of existing CANDU reactors, and reviews the design features of the proposed CNF and its R&D facilities to meet these needs.

3.1 AECL Marketing Goal and CANDU Cost Targets

AECL has set a goal of capturing 25% of the emerging global market for nuclear power for CANDU reactors. Achieving this ambitious goal will require a product that will appeal to potential customers in the long term by matching or surpassing the offerings of competitors, both nuclear and non-nuclear. To help ensure that this goal can be achieved, AECL has established long-term stretch targets of reductions OF 50% in both unit capital and unit operating costs of future CANDU reactors. In addition, future CANDU designs will incorporate greater use of passive features to enhance the already high level of safety in current designs.

In considering this ambitious market goal and the challenging cost targets, it is important to recognize the following points:

- * All current competing reactor vendors have access to indigenous engineering-scale research reactors to support the in-reactor R&D essential for their reactor designs,
- * Current CANDU owners and potential customers for CANDU reactors expect a long-term commitment by AECL to maintain the R&D necessary to ensure the continuing viability of operating CANDU reactors and the development of advanced CANDU designs.

3.2 Key Characteristics of CANDU Reactors

As part of its long-term strategy to achieve its market goal, AECL has identified the key characteristics of the CANDU reactor design that underlie its successes and that have attracted customers in the past. These key characteristics are to be retained in all future CANDU designs. They are:

- * Heavy-Water Moderator, Separate from the Coolant
- * Horizontal Fuel Channels in Pressure Tubes
- * On-Power Fuelling with Short Fuel Bundles

The rationale for the retention of these key characteristics is summarized in Appendix 1. The Panel strongly supports the retention of these characteristics in all future CANDU reactor designs as an important part of the AECL long-term strategy for achieving its market goal. The need to retain these key characteristics has a major effect on the design of the CNF to support new CANDU designs and of the facilities needed for the R&D to support these designs.

3.3 Research and Development Areas for Future CANDU Designs

To meet the cost-reduction targets and AECL's overall marketing goal, considerable research and development will continue to be necessary in areas such as;

- a) fuel bundle design including further development of the new 43-element CANFLEX fuel bundle,
- b) advanced fuel cycles using low-enriched uranium including recycled uranium from LWRs, mixed oxides (uranium and plutonium) and eventually thorium,
- c) pressure tubes with lifetimes of 40 to 60 years, improved methods of fast re-tubing and an internally insulated pressure tube (CANTHERM),
- d) new coolants to permit higher operating temperatures and reduced limitations on channel power, with resulting reduced unit operating and capital costs,
- e) enhanced safety through greater use of passive features such as additional passive elements in emergency coolant injection systems and passive heat removal from the moderator and from containment, as well as ongoing resolution of generic safety issues with the AECSB and further computer code validations,
- f) improved systems and components, including steam generators,
- g) more efficient and economical methods of nuclear power plant construction and improved plant life management

- f) more economical methods of heavy water production and moderator and coolant detritiation
- g) increased applications of information technology in the design, construction and operation of CANDU reactors
- i) further research in radiobiology areas of particular concern to the CANDU design, tritium and carbon-14.

The availability of an engineering-scale research reactor is an essential requirement for effective R&D programs in the first five of these areas.

3.4 Historical Role of Engineering-Scale Research Reactors in CANDU Development

The development of CANDU to its current status would not have been possible without the use of AECL's high-flux engineering-scale research reactors NRX, WR-1 AND NRU. By the use of self-contained loops and other facilities installed in these reactors, fuel elements and fuel bundles, fuel channel sections and other components as well as different coolants have been irradiated under realistic conditions to provide the data and experience necessary for the past and ongoing evolution of the CANDU design. Examples of key R&D programs undertaken using these reactors include:

- * CANDU fuel elements and fuel bundles have undergone hundreds of irradiations in research reactor loops over the years to investigate phenomena such as sheath corrosion and hydriding, fuel pellet cracking and distortion, fission-product gas release and diffusion rates, bundle end-plate behavior, bundle flow and temperature distributions and critical heat fluxes. As a recent example, the CANFLEX fuel bundle design, the result of some ten years of research and development by AECL, could not be at its current threshold of commercialization without the many and lengthy irradiations in research reactor loops that contributed in a key manner to its development.
- * The development of the CANDU pressure tube has relied considerably on irradiations in NRX and NRU loops over the years to investigate, under reactor conditions of temperature, pressure and neutron flux, such phenomena as delayed hydride cracking and fracture, irradiation damage and deformation, corrosion and deuterium ingress.
- * The knowledge required to permit proper control of coolant chemistry under reactor conditions has been developed to a large degree from in-reactor experiments.
- * In the area of reactor safety, important knowledge of the release of fission products from fuel bundles and their transport through reactor systems under accident conditions has been gained from experiments run in the Blowdown Test Facility in NRU.

From this experience, it is concluded that appropriate and adequate engineering-scale irradiation facilities must continue to be readily available for the future development of the CANDU reactor, in at

least the first five of the areas listed in section 3.3, to meet the cost targets and marketing goal established by AECL.

3.5 Current Availability of Engineering-Scale Research Reactors for CANDU R&D Programs

The NRU reactor at Chalk River is the only AECL engineering-scale research reactor remaining in operation now. NRU is a 135 MW (thermal) heavy-water-moderated and -cooled multi-purpose reactor that has been in operation since 1957. As Canada's primary source of neutrons, it is used for the support of CANDU technology, for basic and applied materials research using neutron beams and, currently, for radio-isotope production.

Maintenance and upkeep of the NRU is becoming more difficult with time and many of the parts and components are difficult to replace because of obsolescence. This is particularly true in the areas of instrumentation and control. Its operating cost is very high compared to that projected for new CNF described in Appendix 2. At present, part of the operating cost is being borne by MDS-Nordion since NRU is continuing to provide molybdenum-99 and other medical radioisotopes for this organization. Following the start-up of the second of the two MDS Medical Isotope Reactors (MMIR) scheduled to occur in 2000, the full cost of NRU operation will fall on AECL. The AECB has concerns about the continuing licensability of NRU and AECL has assured the AECB that NRU will not operate beyond 2005.

Thus, while NRU continues, for now, to provide the key irradiation research facilities required for the ongoing support of the CANDU R&D program, it will no longer do so after 2005, at the latest. If NRU does operate through 2005 and the CNF and its reactor R&D facilities are constructed and installed on the current schedule, as given in Appendix 2, there would be little or no "neutron gap", the period between the shutdown of NRU and the start-up of CNF, when AECL would be without its own engineering-scale irradiation research facility. There remains also the possibility that the NRU may be shutdown before 2005, because of component or equipment failures or because of additional AECB licensing requirements. The premature shutdown of NRU would obviously result in the occurrence or lengthening of a neutron gap. AECL has estimated that a neutron gap of about two years could be tolerated without serious impacts on CANDU R&D programs but that a gap significantly longer than that would have serious implications for the overall program.

Engineering-scale research reactors in other countries have been used in the past and are continuing to be used for certain CANDU research projects, generally because of the need for higher fast neutron fluxes than NRU can provide. Reactors such as ATR in the USA, OSIRIS in France, HFR-Petten in the Netherlands and HBWR in Norway have been and are being used to supplement NRU. For example, about 40% of the 1998/99 budget for fuel-channel research has been used to fund experiments in four offshore reactors. An early shutdown of NRU would add significantly to the annual cost of offshore fuel-channel research. There would be a much more serious impact on budgets, and schedules, for fuel and fuel-cycle R&D since, for a neutron gap exceeding two years, the design, installation and operation of a test section and loop for testing full-scale CANDU fuel bundles in an offshore research reactor would be necessary for the program to continue. The need to design and install a new test section in this case reflects the fact that foreign research reactors are not well adapted

to R&D for CANDU in general because of its unique horizontal configuration and its use of pressure tubes.

There are other drawbacks to significant reliance on foreign engineering-scale research reactors. While there are a few under construction or planned, the number of such reactors is limited and most existing ones are old (except for the HANARO reactor supplied to Korea by AECL) and may be shutdown in the next few years. As pointed out in the Panel's 1994 Annual Report, a major use of foreign reactors for the CANDU R&D program involves serious risks of:

- * loss of the significant financial investment required to mount certain programs in the event of premature shutdown of ageing facilities,
- * loss of security of experimental data, considering that many foreign facilities are owned or used by AECL competitors,
- * low priorities given to AECL programs,

Considering the foregoing discussion, it is evident that AECL cannot rely on the availability of NRU beyond 2005, and perhaps earlier, and that the use of foreign research reactors to support the CANDU program may not be possible in the long run and in any case would involve significant additional costs, schedule delays and other risks.

3.6 Summary of the Case for the CNF to Support the CANDU R&D Program

The case for a new engineering-scale research reactor to support the CANDU R&D program is based on the arguments presented above and is summarized below:

- * The AECL marketing goal and cost reduction targets require a vigorous on-going CANDU R&D program.
- * The key characteristics to be retained in all future CANDU designs play a major role in defining the design of the CNF and those of the CANDU R&D facilities.
- * Improvements and developments in certain key areas of the CANDU design require experiments and tests in an engineering-scale research reactor
- * The development of the CANDU reactor to its present status as one of the three commercially successful power reactor types in the world would not have been possible without AECL's indigenous engineering-scale research reactors.
- * The one remaining indigenous engineering-scale research reactor, NRU, will not operate beyond 2005, and may be shutdown even earlier, and significant reliance on foreign reactors for essential CANDU research programs would be very costly, would delay programs and would have other risks.

From these arguments, it is evident that a new engineering-scale research reactor, the proposed CNF, with appropriate facilities to support the CANDU R&D programs, as described in Appendix 2, is vital to the AECL marketing goal and cost-reduction targets for CANDU and that the CNF must be committed as soon as possible to avoid major disruptions to the CANDU R&D programs.

4.0 CONCLUSIONS

The Panel strongly supports the collaboration between the National Research Council of Canada and Atomic Energy of Canada Limited in proposing, in partnership with universities and industry, the Canadian Neutron Facility for Materials Research. The Panel is convinced that the CNF and its R&D facilities will provide an essential, effective and economic testing facility to advance the CANDU power reactor design and ensure the future competitiveness of the Canadian nuclear industry as well as providing an advanced materials research capability to meet the needs of Canadian universities and industry.

The Panel also strongly endorses the joint efforts of NRC and AECL, under the leadership of the CNF Steering Committee, to obtain funding for the CNF from public and private sources and urges that every effort be made to start construction of the CNF in 1999 so as to ensure that the CNF is operational by 2005, the latest date at which NRU will continue to operate, thus avoiding a neutron gap in the

CANDU R&D program.

APPENDIX 1. RATIONALE FOR RETENTION OF KEY CANDU CHARACTERISTICS IN ALL FUTURE CANDU DESIGNS

* **Heavy-Water Moderator, Separate from the Coolant**

The heavy-water moderator is the essential feature of the CANDU reactor, providing the excellent neutron economy that distinguishes CANDU from other reactor types. Keeping the moderator separate from the coolant enables other coolants than heavy water to be considered, enables moderator pressure and temperature to be kept low and also retains the safety feature of the inherent heat sink thus provided for severe accident conditions.

* **Horizontal Fuel Channels in Pressure Tubes**

Horizontal fuel channels permit the extensive technology developed by AECL for this design to be retained, together with the neutronic and consequent operational benefits of double-ended fuelling. The use of pressure tubes avoids the need for developing a design for a large pressure vessel, which would be considerably larger than that for a PWR of the same thermal power, and capitalizes on the major AECL investment in pressure-tube technology.

* **On-Power Fuelling with Short Fuel Bundles**

On-power fuelling permits high life-time capacity factors to be achieved with consequent economic benefits, provides flexibility in operational fuel management and in exploiting advanced fuel cycles and has the safety advantage of keeping the excess reactivity of the core low at all times. The use of short fuel bundles permits the major AECL investments in fuel-bundle and fuelling-machine technology to be retained as well as providing flexibility in fuel management, enabling fuel burn-up to be maximized with resulting economic benefits.

APPENDIX 2. THE CANADIAN NEUTRON FACILITY AND CANDU RESEARCH AND DEVELOPMENT FACILITIES

The CNF reactor, which will be located at the Chalk River Laboratories of AECL, is a 40 MW pool-type reactor based on AECL's well-established MAPLE technology. The first MAPLE-type reactor to operate was the HANARO research reactor supplied by AECL to the Korea Atomic Energy Research Institute (KAERI) which started up in 1995. Two MAPLE reactors for the production of radioisotopes are under construction by AECL at Chalk River Laboratories for MDS-Nordion.

The reactor assembly is located at the bottom of a 15.6 metre deep, light-water-filled pool. The compact light-water-cooled and -moderated core uses low-enriched uranium fuel and produces the fast and thermal neutron fluxes needed for R&D purposes. The maximum unperturbed thermal neutron flux is 4×10^{18} n/m²s.

A unique split-core design is proposed for the CNF. In this design, the core consists of two MAPLE-type core segments, separated by a heavy-water-filled tank which also surrounds the core segments and acts as a neutron reflector. Each core segment generates 20 MW for a total core power of 40 MW. Each segment consists of 16 fuel sites plus two fast-neutron sites. Twelve of the fuel sites accommodate 36-element fuel bundles and four accommodate 18-element bundles. Special annular fuel bundles are used in the fast-neutron sites. The 18-element fuel bundle sites also accommodate hafnium absorbers to provide reactivity control and a shutdown system. The heavy-water vessel can be rapidly dumped to provide a diverse, independent shutdown system.

The need for the CNF to meet the requirements of both the CANDU research and development programs and those of basic and applied materials research under NPMR presented a major design challenge. AECL has met this challenge very well with the unique split-core design of the CNF. This design enables the major objectives of both main functions of the CNF to be achieved in an economic and efficient manner. The design permits the irradiation of full-scale CANDU fuel bundles and fuel-channel sections at high thermal-neutron fluxes in the region between the two core segments and the irradiation of reactor materials at high fast-neutron flux sites. The design also enables the inner ends of the neutron-beam tubes and neutron guides leading to the materials research facilities to be located at high flux sites near the outer perimeter of the core.

To support evolving and advanced CANDU designs and advanced fuel cycles, as well as existing CANDU stations, irradiation facilities are provided for fuel and fuel cycle technology, fuel channel technology, reactor chemistry research and reactor safety research. The major CANDU R&D facilities consist of three horizontal channels located in the heavy-water-filled tank between the core segments, two vertical test sections and four fast-neutron sites. The three horizontal test sections are connected to two loops and the two vertical test sections are connected to one loop. Each of the horizontal channels permits irradiation of two to three full-size CANDU fuel bundles, at thermal neutron fluxes and spectra characteristic of CANDU reactors, as well as full-diameter fuel-channel irradiations. The horizontal test sections also have the capability of providing test sites for the CANTHERM advanced fuel-channel design. The vertical test sections accommodate irradiation of multi-element partial bundles and the fast neutron sites provide for reactor materials research. The bottom horizontal test section is replaceable with a high-integrity test section for future severe fuel damage tests, i.e. to serve as a blowdown test facility (BTF). One of the loops connected to the horizontal test sections is designed as a high-pressure,

high-temperature loop for supercritical pressure steam, which is being considered as a potential coolant for an advanced CANDU design.

Facilities provided in the CNF design for basic and applied materials research include six thermal-neutron beam tubes, one cold neutron source feeding seven neutron guides and one thermal-neutron source feeding two neutron guides.

In addition to the reactor facilities themselves, a general-purpose hot cell for the examination of irradiated components and samples will be provided at the CNF site at Chalk River. Also, the R&D infrastructure at the Chalk River Laboratories will be accessible for support of the key CANDU R&D programs.

The CNF project is planned to begin in 1999, with the projected start-up of the reactor in 2005. The total estimated cost of the reactor and the CANDU R&D facilities is \$298 million with the cost of the basic and applied materials research facilities being \$90 million, for a total cost of \$388 million.

A high-level Steering Committee is leading the efforts to obtain the funding from public and private sources to enable the CNF project to begin in 1999.

To enable the project to start in 1999, AECL has been pursuing an up-front approach with the Atomic Energy Control Board for the licensing of CNF. The objective of this approach is to focus on the resolution of all safety and licensing issues at an early stage of the design when any necessary changes are relatively easily made, thus avoiding delays due to licensing issues arising in the later stages of design and construction. AECL has already prepared and submitted to the AECB a licensing-basis document for the CNF which describes the basic approach to safety and the licensing criteria to be met. AECL has also submitted the quality assurance manual and documents on the shutdown systems and the containment to the AECB.

The CNF will require an environmental assessment, in which public participation is mandatory, under the Canadian Environmental Assessment Act. The AECB will be acting as the responsible authority under the Act, so that it will have a dual regulatory responsibility for the CNF. Although no difficulties are foreseen in this area, allowance has been made in the CNF capital cost estimates for uncertainties arising from the environmental assessment process.