Report of the AECL Research & Development Advisory Panel for 2002

Cover Photo: "Proven international experience: Qinshan Phase III, two 728 MWe CANDU reactors in-service 2002 and 2003; on budget, on schedule."

Preface

The Board of Directors of Atomic Energy of Canada (AECL) is advised by a Research and Development Advisory Panel (the Panel), a body of independent scientists, engineers and physicians, which provides counsel on the strategic needs, alliances, and direction of the R&D activities at AECL. The Panel provides advice to the Board as to whether these activities have the appropriate scope, composition, and balance between short- and long-term activities, to sustain AECL's nuclear program, nationally and internationally.

On behalf of the Board of Directors and at the request of the Panel, this document comprises the eleventh report of the Panel, for the year 2002.

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Report of the AECL

R&D Advisory Panel for 2002

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CHAPTER 1: OVERVIEW

1.1 INTRODUCTION

The Research and Development Advisory Panel is pleased to submit its 2002 annual Report to the Board of Directors of AECL. In preparation for the writing of this report, the Panel met four times for a total of eleven days for discussions with AECL staff members and other invited experts. In addition, sub-committees and individual members of the Panel met on a number of other occasions with AECL staff to discuss particular issues and to visit the Chalk River Laboratories and the Sheridan Park site to gather the information necessary for the review and assessment of AECL's research and development (R&D) activities mandated by the Panel's terms of reference.

As in the last few years, the procedure used by the Panel in 2002 was to develop position papers on certain key aspects of the AECL R&D programs from which the findings and recommendations provided in this Report were distilled.

As discussed in previous annual Reports of the Panel, AECL undertakes R&D in support of the Nuclear Platform in Canada as well as in direct support of commercial activities, such as the marketing of CANDU reactors. As described in last year's Panel report [1], the Nuclear Platform consists of the knowledge base and associated facilities that Canada must maintain to support current nuclear activities, such as the operation of existing CANDU nuclear power stations and other ongoing applications of nuclear science and technology, as well as activities needed to deal with legacy issues, such as the management and disposal of nuclear wastes. Of course, the Nuclear Platform also provides the base upon which AECL commercial activities are built. The Panel has examined and assessed AECL R&D activities in both of these areas during the year, as reflected in the contents of this Report.

This is the eleventh annual Report of the Research and Development Advisory Panel. The terms of reference of the Panel are given in Appendix A and the members of the Panel and their affiliations are given in Appendix B. Publications and submissions of the Panel are listed in Appendix C. Appendix D provides a list of frequently used abbreviations and acronyms while Appendix E lists Panel activities throughout the year.

1.2 PANEL ACTIVITIES

1.2.1 Preparation of Annual Report

The major focus of the Panel's activities in 2002 was on the Advanced CANDU Reactor (ACR), formerly known as the Next-Generation CANDU (NG CANDU), which is key to AECL's future as a reactor vendor. Chapter 2 provides the Panel's assessment of the R&D program supporting the ACR.

While the specific R&D supporting the ACR is obviously commercially oriented, much of it grows out of the Nuclear Platform R&D base. Similarly, much of the other R&D reviewed and assessed by the Panel this year also combines commercially oriented and Nuclear Platform type activities. For example, while R&D on feeder and pressure tube behavior in existing CANDU reactors, as discussed in Chapter 3, is basically a Nuclear Platform activity, results obtained may also contribute to the ACR design commercial activity.

Following the terrorist attacks in the USA on September 11, 2001, AECL, like many other nuclear organizations, re-assessed security requirements for nuclear facilities and the Canadian Nuclear Safety Commission (CNSC) issued new security guidelines and regulations for nuclear materials and facilities. The Panel studied these issues with the objectives of identifying any R&D that might be needed to deal with such threats and of assessing any impacts on AECL's research activities resulting from new regulations and guidelines. The Panel's assessment is summarized in Chapter 4.

As another example of an R&D program that combines commercial and Nuclear Platform activities, AECL strategy on R&D on waste management and disposal, as discussed in Chapter 5, is to leverage the work needed to deal with legacy issues to provide future commercial opportunities. Another area where AECL is planning to leverage legacy-oriented research to provide potential commercial opportunities is radiobiology, as discussed in Chapter 6. See also section 1.2.2 below.

The issue of global warming and ratification of the Kyoto Protocol on reduction of greenhouse gas emissions has been much in the public eye in 2002. The Panel prepared a position paper on the importance of nuclear energy and, in the long-term, the nuclear-hydrogen economy, to the reduction of CO_2 emissions, which is summarized in Chapter 7. This topic is covered further in section 1.2.2 below.

While the Panel did not devote much time this year to the CANDU X reactor concept, AECL's vision of a long-term future CANDU reactor, it did keep up-to-date on AECL work on this concept, as discussed in Chapter 8, because of its importance not only for leveraging international support for this concept through the Generation-IV initiative [2], but also in stimulating the type of innovative thinking that led to the ACR design.

An issue of considerable concern to AECL as well as to other organizations in the nuclear field in Canada is that of human resources. The Panel addressed this issue most recently in its annual reports for 1999 and 2000 and addresses it again in Chapter 9, as well as in specific recommendations in Chapters 2, 5 and 6. This issue is another that spans both the Nuclear Platform and commercial activities.

1.2.2 Other Panel Activities

1.2.2.1 W.B. Lewis Lecture

The terms of reference for the Panel, as given in Appendix A, now make it officially responsible for organizing the annual W.B. Lewis Lecture, having done so unofficially for the last two years. The lecture this year was presented on October 23 by Joe F. Colvin, President and CEO of the Nuclear Energy Institute, Washington, D.C. and was entitled "*Nuclear Energy: Fulfilling the Promise*". Mr. Colvin described a renaissance for nuclear power in the USA, based on the outstanding improvement in the performance of U.S. power reactors over the last decade, equivalent to the addition of 24 new units of 1,000 MW capacity each, and on the recent approval by Congress of the Yucca Mountain fuel waste disposal facility (see Chapter 5). He foresees an increase of nuclear capacity in the USA of some 50,000 to 60,000 MW by 2020. Those attending the lecture were very encouraged by Mr. Colvin's view that the ACR was one of only two designs that could be technically and economically suitable to meet the demands of this potential market beginning about 2010.

1.2.2.2 Visit to Bruce Power

In accordance with one of the responsibilities of its terms of reference, the Panel visited the Bruce Power site during its September meeting. Bruce Power personnel described the company's activities, including the R&D program in support of the Bruce-A and -B plants and organized a tour of the site, in particular of the Bruce-B plant, for the Panel. The Panel learned that AECL and Bruce Power have developed a strategic alliance, which recognizes AECL as the preferred supplier of CANDU reactor technology and fuel design. Bruce Power is participating in various CANDU Owners Group (COG) R&D programs, including feeder-thinning behavior (see Chapter 3). Of particular interest is an agreement between Bruce Power and AECL on the design, qualification and licensing of Low Void Reactivity CANFLEX fuel for the Bruce-B reactor for implementation by 2006.

1.2.2.3 Panel Response to Federal Government Discussion Paper on Climate Change

The terms of reference of the Panel authorize it, after consultation with AECL, to make public statements on all matters relevant to its mandate. Past activity of this nature by the Panel is evident from the list in Appendix C. One such activity this year was a written response to the Federal Government's discussion paper on climate change. The Panel was disturbed to find that the discussion paper completely ignored the important current role of nuclear energy in reducing CO_2 emissions and the even more significant role of the nuclear-hydrogen economy to do so in the future. The Panel's response, which pointed out these deficiencies in the discussion paper, also served as the basis for Chapter 7 of this Report. Now that Parliament has ratified the Kyoto Protocol, it is vital that the Federal Government recognize that nuclear energy is the only large-scale energy technology capable of providing significant reductions in greenhouse gas emissions as well as reductions in emissions of atmospheric pollutants, such as particulate matter, sulfur oxides and nitrogen oxides, which lead to smog and acid rain.

1.2.2.4 Revision of Publication "CANADA – Vision 2020 and Beyond"

In 1998, the Panel prepared a publication with the above title that focused on the need for nuclear R&D in the 21st Century. This publication has proven very useful to AECL with 1,100 copies being distributed to decision makers and the public. At the request of AECL, the Panel undertook to produce an update of this document. An updated version has been prepared and it is anticipated that it will be ready for distribution by AECL early in 2003. The current version of this document is available on the AECL website: www.aecl.ca. The revised version will replace the current one on the AECL website as soon as it is ready.

1.2.2.5 Special Report on Radiobiology

The Panel produced a special report on radiobiology in June 2002, since AECL was then beginning to re-assess its role in this field. As summarized below in Chapter 6, the special report recommended that AECL undertake a strategic planning exercise, using external as well as internal expertise, on the scope, priorities and directions of its radiobiology research program.

1.2.3 Key Overall Finding

The Panel's key overall finding in its 2002 review of AECL R&D is that those programs examined by the Panel are generally appropriate, well managed and well planned. Recommendations on specific issues are provided in the Report.

REFERENCES

1. Report of the AECL Research and Development Advisory Panel for 2001

2. Generation-IV International Forum; Tokyo, September 30, 2002

CHAPTER 2: ADVANCED CANDU REACTOR (ACR) RESEARCH AND DEVELOPMENT REQUIREMENTS

2.1 INTRODUCTION

This chapter is an update of Chapter 6 of the 2001 Panel Report [1] on The Next-Generation CANDU Design. The Next-Generation CANDU (NG CANDU) has now been renamed the Advanced CANDU Reactor (ACR). This chapter reviews the development of the ACR design over the last year and assesses the changing needs of the supporting R&D program. In particular, this position paper reviews progress on the priority issues and actions, which the Panel identified as needing particular attention last year [1] as well as identifying some new priority issues and actions.

2.2 DEVELOPMENT OF THE ACR CONCEPTUAL DESIGN

2.2.1 Potential Markets and ACR Development

Important steps in the development of the ACR in the last year included approval by the AECL Board of Directors of the funding for a three-year development program, start of the basic engineering work scheduled for completion by March 2005, and development of a construction strategy and schedule. Hitachi continued to contribute to the design and optimization of the balance of plant. Progress on design and R&D continues to give confidence that the design will be market-ready by 2006.

In Canada, work is underway on an up-front licensing process with the CNSC and a project implementation study has begun for an ACR at a potential utility site, based on the assumption that a two-unit ACR-700 could be in service in Canada by 2010/2011.

A joint study with British Energy (BE) started in November 2001, to assess the feasibility of building twin ACR-700 units on existing BE sites, with a possible 10,000 MW of capacity to be replaced. Excellent progress has been made on this study and a preliminary licensing review with the Nuclear Installations Inspectorate (NII), the nuclear regulatory body in the UK, has begun that is intended to be coordinated with the up-front licensing process in Canada. The Government White Paper on energy, expected early in 2003, is expected to define the future role for nuclear energy in the UK, which should help to clarify the potential for ACR in that market.

In June 2002, AECL launched an ACR marketing program in the USA, through its subsidiary AECL Technologies Inc [2], working with GF Energy and Bechtel, a large architect-engineering firm. In July 2002, a public pre-application licensing review was held at the head office of the U.S. Nuclear Regulatory Commission (NRC) and a two-day NRC public workshop was held in September 2002. Coordination of the licensing process between the two regulators, NRC and CNSC, is being pursued and is also being coordinated with the Canada/UK licensing activities. NRC personnel visited the Chalk River Laboratories in December 2002, for presentations and discussions on ACR safety and licensing issues. Three U.S. utilities, Dominion, Entergy and Exelon, have included ACR-700 as a candidate design for new reactors in the Early Site Permit (ESP) process with the NRC. In addition, a technical familiarization program began in September 2002 with the U.S. Department of Energy. An important milestone has been reached with an agreement, signed on December 4, 2002, between AECL and Bechtel for the two companies to work together on the deployment of the ACR in the USA.

Last year, GF Energy identified China as a potential market for the ACR. AECL has initiated cooperative studies on the ACR with Chinese institutions.

2.2.2 Completion of the ACR-700 Design Concept

As discussed in reference [1], the primary objective of the ACR design is to reduce overnight capital costs to about $1,000/kW[1] from the current costs of about $1,650/kW for the Qinshan CANDU reactors, while ensuring low operating costs, enhancing passive safety, improving operability and reducing construction time. Achieving these goals will enable the ACR to compete against the combined-cycle gas turbine (CCGT) design in most markets for the expected range of future natural gas prices.

As explained in reference [1], at the heart of the ACR design is the use of slightly enriched uranium (SEU) instead of natural uranium, as used in conventional CANDU reactors, made possible by the development by AECL of the CANFLEX fuel bundle. This key design change, together with other design changes flowing from it, leads to the significant reduction in capital costs of the ACR compared to a conventional CANDU.

Over the past year, the conceptual design of a 700 MW ACR has been completed. Some of the important parameters of this design concept differ from those of the preliminary concept [1], partly as a result of the feedback from potential customers.

2.2.3 Modification of Design Parameters from the Preliminary Conceptual Design

2.2.3.1 Fuel Bundle and Fuel Channel

In the final conceptual design of the ACR-700, the fuel bundle enrichment has been increased to 2.00% from 1.65% in the preliminary design and dysprosium, a burnable poison[2], has been added to the centre element at a concentration of 4.6%. In addition, the gas gap between the pressure tube and the calandria tube in the ACR has been increased to 20 mm, compared to 10 mm in a conventional CANDU and the lattice-pitch has been reduced to 220 mm, compared to 286 mm in a conventional CANDU. The reason for these changes is to ensure that the coolant void reactivity (CVR) coefficient for the ACR is slightly negative under all operating conditions. This will ensure that there is no power surge in a loss-of-coolant accident, as occurs in a conventional CANDU reactor with its positive CVR coefficient, but actually a power decrease. While the power surge in a conventional CANDU is limited by the two independent shutdown systems, thus preventing fuel damage, the regulatory authorities in the USA and the UK demand a negative CVR coefficient. The overall effect of the foregoing changes results in the ACR being undermoderated, like an LWR, rather than overmoderated like a conventional CANDU, and being inherently stable under all operating conditions.

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[1] All costs are expressed in U.S. dollars.

[2] As the fuel is irradiated, the dysprosium absorbs neutrons and gradually disappears as neutron-absorbing fission products build up. This behavior limits parasitic neutron absorption in the fuel while ensuring a negative CVR.

2.2.3.2 Reactor Core Conditions

The core inlet pressure has been reduced to 12 MPa in the final conceptual design from 13 MPa in the preliminary design and the core outlet temperature has been reduced to 325^{o}C from 331^{o}C. For an ACR pressure tube thickness in the range of 6.0 to 6.5 mm, these changes were found to be necessary to ensure that a 30-year pressure-tube life could be achieved. The Panel endorses these changes, having suggested last year that such reductions might be advisable.

2.2.3.3 Core Thermal Power and Gross Electrical Power

The number of fuel channels in the final conceptual design has been increased to 284 from 256 in the initial design to raise the reactor thermal power to 1,980 MW from 1,790 MW. The increased core size resulting from the additional channels has caused a small increase in the calandria diameter from 5.06 m to 5.20 m. Optimization of the steam cycle conditions, using the methodology described in [3], has enabled the thermodynamic cycle efficiency to be slightly increased in the final conceptual design to 36.9% from 36.1 % in the preliminary design, resulting in an increase of gross electrical power from 647 MW in the preliminary design to 731 MW in the final design, essentially the same as that in a conventional CANDU 6.

2.3 ACR R&D PROGRAM

This section of the chapter will focus on progress on the priority R&D issues identified in reference [1] as well as on new priority issues that have arisen over the year.

2.3.1 Progress on Priority Issues and Actions Identified Last Year

Last year [1], the Panel identified a set of R&D issues and actions associated with the NG CANDU reactor that needed particular attention by AECL. These are listed below.

- Procurement of test fuel bundles and pressure tube sections;
- Modification of RD-14M for CATHENA code validation;
- Modifications to NRU for fuel bundle and pressure tube section irradiations;
- Modifications to the critical heat flux facility at Stern Laboratories;
- Fracture toughness of thicker pressure tube materials;
- Continued development of methods for more rapid identification of a leaking pressure tube;
- A pressurized water loop for chemistry and materials R&D for the ACR;
- Decisions on safety R&D programs for licensing submissions;
- New R&D facilities to ensure AECL's long-term R&D capability;
- A decision on pressure tube burst tests;
- Inspection and maintenance procedures for end-fittings and feeders;
- Fuelling machine development;
- Assessment of the need for a multi-group version of the RFSP code;
- An up-front licensing process with CNSC for the ACR; and
- Collaborative work by other organizations with AECL.

The Panel reviewed AECL progress on all of these ACR-related issues and actions during the year and arrived at the following conclusions.

Panel Finding 1

Recognizing that work is ongoing on most of the actions and issues concerning the Advanced CANDU Reactor identified by the Panel as requiring particular attention in its 2001 Report and that a few are long-term ones that did not need specific work this year, the Panel finds that AECL has responded appropriately in general to these issues and actions.

Recommendation 1

The Panel recommends that AECL continue to pay particular attention to those actions and issues concerning the Advanced CANDU Reactor identified by the Panel in its 2001 Report that are ongoing.

The review of these priority issues and actions identified last year also touched on many other aspects of the current and future ACR R&D programs. An overview of these aspects with a discussion of some additional priority issues and actions is given in the next section.

2.3.2 Overview of Current and Future ACR R&D Programs

2.3.2.1 ACR R&D Program Personnel Requirements

As the ACR conceptual design has evolved, the scope of the needed R&D activities has increased. This increase in scope as well as ongoing modifications to meet design requirements has resulted in some slippage of the R&D program. This slippage should be regained in an accelerated schedule developed in cooperation with potential customers. The Panel notes the potential difficulty in securing appropriately skilled and experienced R&D personnel to meet the needs and that hiring of new graduates, even those with advanced degrees, may not alone solve this problem.

Recommendation 2

As the design of the ACR has matured, the scope of the associated R&D has increased and its schedule has slipped. While noting the accelerated schedule adopted with input from potential customers, the Panel suggests that AECL consider an approach to existing and potential partners and other entities for additional funding and assignment of skilled personnel to help meet R&D needs on a timely basis.

2.3.2.2 Recent Feedback from Potential Customers and Partners and Possible Effects on the R&D Program

As discussed earlier, licensing requirements in both the USA and the UK resulted in the major modification in the ACR fuel bundle and fuel channel design needed to provide a negative coefficient of coolant void reactivity. The ongoing assessments with British Energy and the American utilities have resulted in a number of other issues being identified that could affect the

ACR design and, possibly, the R&D program. These issues are discussed in the following paragraphs and potential impacts on the R&D program are identified.

Some potential customers have expressed interest in a larger version of the ACR with a capacity of 1,000 MW, (ACR-1000), rather than 700 MW (ACR-700), to achieve a further reduction of capital costs, based on the economy of scale. In response, earlier this year AECL began the development of a conceptual design for the ACR-1000, in parallel with the work on that for the ACR-700, which has delayed the start of detailed design for the ACR. A decision as to which detailed design to proceed with will be made in January 2003. In AECL's judgment, there should be no significant changes in the ACR R&D program if the emphasis should shift from the ACR-700 design to the ACR-1000 design.

Other issues raised by British Energy that are not expected to have any significant effects on the ACR R&D program are the possible need for a double containment, the potential effects of a single-channel flow blockage accident and an adequate lifetime for the ACR steam generators. Also, AECL believes that the British Energy design objective of a 30-year pressure tube life can be demonstrated by the current pressure-tube R&D program, assisted by probabilistic analysis.

A longer-term issue is the interest of British Energy in the use of MOX fuel in the ACR, which is also one of the long-term objectives for ACR, partly as a contribution to the international Generation-IV activities [4,5], but it is not an issue for market readiness, so that no impact is foreseen on the present R&D program. Another long-term issue arising out of the Generation-IV activities is the potential for going to even longer fuel burnup, up to 40,000 MWD/t., to increase fuel supply sustainability and to reduce waste management requirements. Again, no impact on the present ACR R&D program is foreseen.

Panel Finding 2

The Panel is very satisfied that AECL is keeping well aware of the needs and preferences of potential partners, customers and regulatory bodies and is responding expeditiously to these needs and preferences.

2.3.2.3 Recent Assessment of ACR Design Focus and Potential R&D Activities

The Panel understands that there are at present three main areas in which the development of the ACR design is currently focused: the pressure tubes, the calandria tube-sheet and the steam generators.

Concerning pressure tubes, the Panel believes that it would be worthwhile to undertake a small-scale pressure tube burst test program to enable large-scale burst tests to serve simply as confirmatory tests, thus reducing the cost and duration of the latter.

Recommendation 3

The Panel recommends that AECL undertake a small-scale burst test program of simulated ACR pressure tubes to provide early data on this important parameter and to reduce the cost and duration of later full-scale pressure tube burst tests, which would then be confirmatory in nature.

The calandria tube-sheet design and manufacture require special attention because of the much reduced lattice pitch in the ACR from that in a conventional CANDU. It is not clear at this time whether this represents a design problem only or whether any R&D may be required for its resolution.

AECL believes that life limitations on steam generators under the ACR conditions can be avoided by the choice of appropriate materials, good control of coolant chemistry and adequate inspection and maintenance, as well as fabrication of the entire lengths of the outlet feeder tubes from stainless steel. Control of coolant chemistry will be enhanced by the application of the ChemAND technology, the on-line monitoring and plant condition prediction methodology under development by AECL [1]. This technology is being tested at the Gentilly-2 reactor, but on the secondary side, i.e., the steam-cycle side, only. To assist in prolonging steam generator life, among other benefits, the technology should be demonstrated on the primary side of a CANDU also.

Recommendation 4

The Panel recommends that AECL develop the ChemAND technology for application to CANDU reactor primary-side coolant systems, in particular for ACR primary-side conditions, and that AECL arrange for the demonstration of the ChemAND technology on the primary side of an operating CANDU reactor.

2.3.2.4 ACR Reactor Physics Codes

As pointed out in section 2.2.3.1, the final conceptual design of the ACR core results in the neutronic behavior of the ACR, including spectral shift effects, being significantly different from that of a conventional CANDU, approaching that of a pressurized water reactor (PWR). Therefore, with the unique neutronic characteristics of the ACR, it must be demonstrated that the reactor physics codes used for core design and safety analysis for the ACR can adequately represent its neutronic behavior under all operating and accident conditions.

As mentioned in section 2.3.1, AECL has been assessing the need for developing a multi-energy group version of the RFSP diffusion-theory reactor code, instead of the current two-group version, to represent adequately the ACR neutronic behavior. Comparisons with other multigroup codes (such as DONJON) have confirmed that the two-group approach is adequate. Other issues concerning the RFSP code that need to be addressed include the discretization used to represent the ACR lattice, the core-reflector interface where very large flux gradients will occur and the influence of thermalhydraulic feedback on reactor physics calculations.

The transport-theory cell code, WIMS, must also be validated for the significantly different composition of the ACR fuel from that in a conventional CANDU and its variation with time as the fuel burns up and the burnable poison burns out. In particular, considering the major role played by resonance absorption in determining the void reactivity and the difficulties involved in self-shielding calculations, particular attention has to be given to the resonance treatment in WIMS and to the cross-section data base used for the ACR conditions. Detailed benchmark comparisons have been made with MCNP, and for various experimental lattices similar to ACR for which data is available. These comparisons, and preliminary ZED-2 measurements carried out in 2002 confirm the validity of WIMS-AECL (with the current version of ENDF-B VI cross-sections) for application to the ACR.

Thus, detailed comparisons with MCNP and other codes such as DRAGON/DONJON have confirmed that the WIMS/RFSP codes are valid for the analysis of the ACR and that no major reactor-physics modelling effort will be required to achieve the pre-licensing objectives and to satisfy design requirements. An anticipatory approach has been adopted by AECL to deal with the issues noted above, and the main thrust of the proposed experimental program in ZED-2 with CANFLEX SEU fuel in an ACR lattice will be to confirm the validity of the standard toolset WIMS/RFSP, in order to quantify the biases and uncertainties of the codes in relation to clearly identified physical phenomena.

The Panel approves the approach taken by AECL. In view of the importance of establishing a solid theoretical basis for the reactor-physics toolset as applied to ACR, inter-code comparisons will play a significant role. In particular, the availability of an alternate set of codes for comparison is viewed favourably by the Panel. A partnership or collaborative effort with the university developers of the DRAGON/DONJON codes therefore appears to be advisable. This partnership would provide a complementary confirmation of the applicability of the standard toolset to the design and safety analysis of ACR. The Panel emphasizes that such an approach represents a "defence-in-depth" or insurance policy to ensure that issues that create regulatory uncertainty are addressed early and resolutely so that a delay in the ACR market-ready date beyond 2006 due to unresolved uncertainties in the reactor-physics modeling will be avoided.

Recommendation 5

Considering the need to quantify the uncertainties in the predictions of the neutronic behavior of the ACR using the current AECL codes WIMS/RFSP because of the significantly different behavior ACR compared to that of a conventional CANDU, the Panel recommends that AECL undertake an early collaborative effort with Canadian universities to support the development of an alternate toolset for comparison with AECL codes.

2.3.2.5 Probabilistic Methodology Applied to ACR

AECL is employing probabilistic methodology for the design of the pressure-tube leak detection system and the prediction of pressure-tube life for the ACR. The Panel has become aware recently that AECL's existing capability in developing and applying probabilistic methodology has been enhanced by the addition of former Kinectrics personnel with considerable experience in this field. The Panel has strongly supported the use of probabilistic methodology in general and particularly in the development of the ACR [4].

Recommendation 6

The Panel recommends that AECL explore possibilities for greater use of probabilistic methodology in the R&D program in support of the ACR, including the utilization of the capabilities of the Reactor Engineering Services Department and the Computational Mechanics Development Group.

2.3.2.6 Handling of Spent ACR Fuel

The handling of the enriched ACR fuel bundles after discharge from the reactor is different from the handling of natural uranium fuel bundles because of the higher radioactivity and heat generation rate and the need to avoid criticality under certain conditions. ACR spent fuel will be stored in the short term in water pools and, in the longer term, in the dry-storage MACSTOR modules developed by AECL (see Chapter 5). The Panel notes that the ACR R&D program calls for work on the handling and storage of ACR spent fuel in the 2003/2004 fiscal year and is aware that planning has started for this work.

Panel Finding 3

The Panel finds that the handling and storage of ACR spent fuel in water pools and in MACSTOR facilities is adequately covered in the ACR R&D program.

2.4 CONCLUSION

The Panel remains impressed with the initiative of AECL in developing the innovative ACR design and the progress of the R&D programs needed to support it. The Panel emphasizes again, as in reference [1] that the R&D program for the ACR is tightly coupled to the development of the design and that R&D requirements are still subject to change as the detailed design evolves.

The Panel is encouraged by the progress that has been made in the vital area of potential markets for the ACR and by the positive reactions of potential customers. These attest to the attractive design of the ACR and the solid CANDU platform from which it is being developed.

The Panel is also encouraged by the active development of partnerships by AECL to ensure that the challenging ACR design and R&D programs are successfully completed to achieve market readiness by 2006.

The Panel's main concerns with respect to the ACR R&D program are the need for skilled personnel in the next two years to support an accelerated program and the initiation of a collaborative effort with the university developers of the DRAGON/DONJON codes. These concerns have led to Panel recommendations 2 and 5.

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CHAPTER 3: FEEDER PIPE R&D

3.1 FEEDER THINNING

Inlet and outlet headers in the Primary Heat Transport (PHT) system of a CANDU power reactor are connected to the fuel channels by feeder pipes made of grade SA106-B carbon steel. Ultrasonic measurement of the wall thickness of feeders, to detect corrosion thinning, has always been part of the inspection strategy. Prior to 1996 these measurements were made at locations close to the headers. In 1996 some measurements were made at Point Lepreau at locations close to the Grayloc seal connecting feeders to the end fittings of the fuel channels; substantial wall thinning was detected in the first bend of some outlet feeders.

This degradation mechanism has been identified as flow-accelerated corrosion (FAC). Although wall thinning has been observed along the entire length of some outlet feeders, the rate of wall loss is highest in the region of the close radius bends nearest to the outlet end fitting of the fuel channel. Some differences in site fabrication procedures for these bends have been identified but it is known that the extrados of the first bend, which can be particularly thin initially, is usually the limiting spot on a feeder; recently, however, the intrados of the second bend of some feeders has been identified as the limiting spot. This fabrication thinning, plus wall loss due to FAC, may lead to an in-service profile and minimum wall thickness that necessitates a shutdown to replace this part of a feeder.

R&D programs to identify the key factors affecting FAC rates and to develop mitigation strategies have been underway for some time. Other programs have focussed on development of on-line monitoring of changes in wall thickness in bends. Inspection campaigns at CANDU sites in Canada and overseas have shown that feeder thinning is a generic issue but some plants are much more susceptible than others. Differences in FAC rate in bends have been attributed to differences in flow velocity, outlet water chemistry and temperature.

For new plants, the specification of the composition of the carbon steel feeder pipes has been altered to include a minimum concentration of chromium of 0.2%; e.g., Qinshan feeder material contains 0.3% chromium. For existing plants, control of water chemistry, including use of special additives, has been a focal point for R&D. Models have been developed for prediction of FAC rates [1,2], and an early correlation of FAC is used in Fitness for Service guidelines submitted for review to the regulator (CNSC).

3.2 FEEDER CRACKING

At Point Lepreau, detection of through-thickness cracking in two of the aforementioned first bends and part-through thickness cracking in two other “first” bends led to the replacement of four outlet feeders. Examination of these cracked bends and subsequent research has led to the conclusion that the degradation mechanism is stress corrosion cracking (SCC). Neutron diffraction measurements of residual stress fields in the zone where SCC cracks developed have shown that there are high residual tensile stresses. These residual stresses were induced during the fabrication (bending) process used to produce the Point Lepreau “first” bends. These tensile residual stresses and local electrochemical potential (the latter determined by coolant chemistry, especially the concentration of added hydrogen) are considered to be the key factors influencing the initiation and propagation of SCC cracks. However, these SCC cracks are inter-granular, which is exceptional, and the cracks occurred in the same area where wall thinning (FAC) is significant.

The bend fabrication procedure used for Point Lepreau bends was not used for all CANDU 6 plants. Differences in fabrication procedure, including stress relieving in some cases, means that the tensile residual stresses in bends in some plants are much lower than those in Point Lepreau bends, which reduces or eliminates the risk of SCC. Another factor that might influence SCC initiation and propagation is wall thinning due to FAC. The SCC cracks in Point Lepreau first bends were in arrays rather than singular cracks. It is possible that wall thinning due to FAC wipes away some SCC initiation sites, thus delaying the development of a dominant crack in an array of small cracks. This may explain why SCC cracking has only been detected in four outlet feeders at one plant, whereas FAC is a generic issue, albeit a particular concern for some plants and some feeder locations.

The CANDU Owners Group (COG) funds a large part of this Nuclear Platform R&D on feeder thinning and cracking. Some CANDU Owners directly fund some projects and AECL directly funds some research, including research on the material specifications for Qinshan feeders.

The overall goals of this Nuclear Platform R&D, regardless of funding source, have been summarized as:

> “Characterize outlet feeder conditions and develop a mechanistic understanding of feeder degradations.”
>
> “Develop databases, tools and procedures for effective management of the existing feeder degradations.”
>
> “Develop and demonstrate improved chemistry and materials to reduce and eliminate feeder degradations.”

3.3 PANEL FINDINGS

Semi-empirical models have been developed for predicting wall thinning rates, due to FAC, in feeder bends close to the outlet end-fittings of fuel channels. The accuracy of these predictions is likely to improve as ongoing research refines our mechanistic understanding of FAC.

Recommendation 1

Understanding of the mechanisms responsible for feeder cracking is less developed than that for feeder thinning. The research programs on feeder cracking should include some experiments that explore the possibility that feeder thinning affects the initiation of SSC crack arrays and development of a dominant part-through thickness crack.

Recommendation 2

Coolant chemistry is an important factor affecting degradation by both cracking and thinning. In light of the current understanding of pathways to H_2/D_2 build-up in the pressure tubes, the limits on hydrogen concentration in the coolant should be re-examined with a view to ensuring conditions that are optimal for reducing both degradation mechanisms.

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CHAPTER 4: THE PHYSICAL PROTECTION OF NUCLEAR MATERIALS AND FACILITIES

4.1 AECL'S CURRENT ROLE

AECL's role in the protection of nuclear materials and facilities is multifaceted. It includes a fundamentally important responsibility for ensuring that the physical protection of the nuclear materials and facilities within AECL's jurisdiction is accorded very high priority. As the design authority for existing and future reactors, AECL has an equally important role in assisting the CNSC to develop revised regulatory requirements, which address the recent significantly increased threat of international terrorism. .

4.2 ACTIONS OF THE FEDERAL GOVERNMENT FOLLOWING THE TERRORIST ATTACKS IN THE U.S. IN 2001

4.2.1 Federal Nuclear Emergency Plan and Other Emergency Preparedness Measures

The terrorist attacks in the United States last year prompted the Government of Canada to review the physical protection and emergency response measures then in effect to determine what additional measures should be implemented. An early result of the review was the reconfirmation of Health Canada as the lead agency under the Federal Nuclear Emergency Plan (FNEP). The review also led to the establishment in the Department of National Defence (DND) of a new Office of Critical Infrastructure Protection and Emergency Preparedness (OCIPEP) on February 5, 2002. The OCIPEP is now the overall coordinator of the Government's emergency preparedness and response program.

4.2.2 Chemical, Biological, Radiological and Nuclear Research and Technology Initiative

On May 10, 2002 the Government's five-year, $170 million Chemical, Biological, Radiological and Nuclear Research & Technology Initiative (known as the CBRN Research & Technology Initiative, or CRTI) was launched. Its objective is to strengthen public security coordination and cooperation among federal government, private industry and academic sectors. AECL is one of 13 government departments and agencies participating in the CRTI. The objective of AECL's involvement in the CRTI is to strengthen the Government's ability to use nuclear science and technology in efforts to counter terrorism. AECL has already submitted three R&D proposals to the CRTI.

Panel Finding 1

The Panel finds that AECL is continuing to participate in the implementation of the Government's CRTI initiative with the appropriate high priority.

4.3 DEVELOPMENT OF PHYSICAL PROTECTION REQUIREMENTS FOR NUCLEAR MATERIALS AND FACILITIES

The physical security regulatory requirements applied to licensees of the CNSC are based upon recommendations issued by the International Atomic Energy Agency (IAEA) [1]. As the threat of international terrorism became more evident, the CNSC commissioned two studies, one in late 1999 and the second in early 2000. The first study focused on potential internal and external threats to nuclear facilities and the second addressed the vulnerability of systems and equipment vital to nuclear safety at CANDU stations. These studies, enhanced after the terrorist attacks in 2001, and consultations with security, emergency and police bodies, led to a number of actions to enhance security at nuclear facilities, including:

- a requirement for developing an on-site capability for immediate armed response
- more rigorous security screening of employees and contractors
- protection against forced vehicle penetration of barriers
- improved photo identification of personnel
- increased frequency and scope of personnel and vehicle searching.

In late 2001, AECL, Ontario Power Generation, Hydro-Québec, New Brunswick Power and Bruce Power established an Inter Utility Working Group (IUWG) to provide mutual assistance, advice and coordination on physical security matters. The IUWG has extended Severe Accident Management (SAM) plans at nuclear power plants to take into account the increased threats of terrorist attacks

In June 2002, AECL received CNSC approval of its new Site Access Clearance system (the first CNSC licensee to do so) and is currently implementing major improvements to its overall physical security arrangements. These include a new Primary Security and Emergency Services Building and associated facilities for the rapid processing of personnel into and out of the inner "Vital Areas" and "Protected Places" zone at Chalk River Laboratories (CRL). These facilities were completed and commissioned recently.

The approach to the security improvements at CRL is based on a risk evaluation that recognizes, as a key factor, the R&D function of the Laboratories. The security improvements have been designed and are being implemented so as to ensure the least-possible interference with this function.

Panel Finding 2

The Panel endorses the approach being taken at the CRL to satisfy the new CNSC requirements since it recognizes that the R&D function of the Laboratories is paramount. As a consequence, the security improvements are being designed and implemented in a manner such as to impose the least-possible interference with this function.

4.4 PROTECTION OF NUCLEAR STATIONS IN CANADA

4.4.1 New Physical Security Requirements

The primary threat of a terrorist attack against nuclear stations in Canada would involve a physical assault on a station with the intent of producing a release of radioactive material by penetrating the reactor containment building and damaging reactor systems or by destroying or severely damaging safety-related systems located outside the reactor building.

It is expected that compliance with the new Design Basis Threats presently being developed by CNSC in consultation with AECL and other licensees will probably necessitate a number of changes in the design of the balance of plant for new CANDU reactors.

As the development of the new Design Basis Threats evolves, additional changes in station design and building layout may be indicated. The Panel recognizes that design changes to counter Design Basis Threats may result in some additional R&D being required.

4.4.2 Security of Fissionable Material

Unlike other nuclear stations, CANDU nuclear stations presently operating in Canada have only very minute quantities of highly-enriched uranium on-site, in specially designed, sealed sources for such purposes as instrument testing and calibration. The only plutonium on-site at a CANDU nuclear station is that contained in the irradiated fuel in the reactor core, in the spent fuel bay(s) or in the reinforced concrete, steel-lined dry storage canisters. Thus, the unavailability of fissionable material (highly enriched uranium or plutonium) in readily usable form virtually eliminates the risk of a terrorist group attacking a CANDU nuclear station in order to obtain materials to construct an improvised nuclear explosive device.

4.4.3 Aircraft Impacts on Nuclear Installations

As a consequence of the terrorist attacks in the USA in 2001, public concerns have been raised about the potential effects of a deliberate crash of an aircraft into a nuclear power plant. Following the attacks, industry organizations and regulatory bodies worldwide reviewed the structural integrity of containment buildings and other structures at nuclear installations.

An aircraft crash into a containment building or other structure at a CANDU nuclear power plant in Canada is not a “design basis event”, since the probability of such an occurrence is deemed to be so low as to exclude it from consideration in the design. Therefore, containment buildings and other structures at a CANDU nuclear power plant are not designed specifically to withstand an aircraft crash. Nevertheless, CANDU reactor containments are sturdy structures, with reinforced or pre-stressed concrete walls over one metre thick, designed and built to withstand the pressures and temperatures resulting from such postulated accidents as a large loss-of-coolant-accident (LLOCA) coupled with a loss-of-emergency-coolant-injection (LOECI) or to survive the impacts of internal missiles, as might result from massive failure of the turbine-generator. In such postulated accidents, the containment must maintain its integrity so as to ensure that the radiological doses to the public, from any consequent release of radionuclides, are below the dose limits specified by the CNSC. In addition, a thick concrete biological shield surrounds the reactor itself so that, even if the containment is penetrated, the reactor core is still protected. CANDU reactors are equipped with two independent, physically separate, functionally different shutdown systems, each of which, acting alone, can shut down the reactor automatically and rapidly in case of emergency. CANDU reactors are also equipped with two independent control centres, physically well separated from each other and from which the reactor can be controlled, shut down and monitored. While a large aircraft impact could cause significant damage, it is not clear that serious off–site consequences would result.

Experiments in the USA in the 1980s showed that most of the energy of a high-speed fighter aircraft impacting on a heavy concrete structure would be absorbed in the destruction of the aircraft rather than in damage to the structure [2,3]. Recently, a study by the Electric Power Research Institute for the Nuclear Energy Institute on the consequences of the impact of a Boeing 767 aircraft on a U.S. nuclear power plant concluded that the aircraft or its fuel would not penetrate the containment. Also, fuel storage facilities at a nuclear power plant site would survive such an aircraft impact. The study concluded that there would be no significant releases of radioactivity from the plant in such an event [4]. The Panel believes that a probabilistic assessment of such an impact on a CANDU nuclear generating station would give a clearer picture of the possible consequences and would indicate whether improvements might be necessary. This would enable AECL to identify any R&D that might be required, particularly for the ACR. The assessment should also take into account the potential impact of an aircraft on the plant switchyard, above-ground fuel storage facilities (MACSTOR), and other facilities.

Recommendation 1

The Panel recommends that AECL undertake a probabilistic assessment of the nature and consequences of the impact of a large aircraft on a CANDU reactor containment and other structures, focusing on the ACR design, to identify any improvements needed in the plant design and any resulting R&D requirements.

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CHAPTER 5: R&D ASPECTS OF AECL STRATEGY ON WASTE MANAGEMENT AND DISPOSAL

5.1 BACKGROUND

The Panel reviewed AECL R&D activities in the field of high-level nuclear waste management and disposal in its 1994, 1996 and 1998 annual reports. In its 1998 report [1], the Panel expressed concern that the long period taken by the Seaborn Panel for the environmental assessment of the AECL concept for deep geological disposal had seriously eroded the scientific and technical capabilities needed to develop and implement it. The Panel urged that Canada proceed quickly to a site selection process [1,2].

In its report for 2001, the Panel reviewed AECL's activities in the management and disposal of low- and intermediate-level nuclear waste and some of the technologies developed by AECL for these purposes. The Panel expressed its satisfaction that AECL was continuing to direct appropriate resources to the R&D needed for its site remediation program and recommended that AECL explore opportunities to exploit its expertise in this area more widely [3].

5.2 CURRENT SITUATION AND AECL STRATEGY

The Nuclear Fuels Waste Act was passed by Parliament in June 2002, and the Nuclear Waste Management Organization (NWMO) was incorporated as a separate legal entity by the nuclear utilities in the same month, fulfilling the intention of the Federal Government announced four years ago. The NWMO is to assess approaches to high-level disposal, including AECL's deep geological disposal concept, storage at the reactor sites and a centralized storage either above or below ground, and is to report back to the Federal Government on the recommended approach within three years. This further delay in implementing work on a waste disposal facility increases the risk of further erosion of AECL's scientific and technical capabilities in this area.

AECL intends to draw on its expertise to provide the NWMO with services, including R&D, on a contractual basis. This expertise, based on over 50 years of experience, includes managing radioactive wastes arising from reactor R&D, radioisotope production and historic war-time activities as well as dealing with hospital, university and industry radioactive wastes. It will use this expertise to fulfil its responsibilities and meet its liabilities at CRL and at WL and to leverage this work to develop a commercial waste management and disposal business.

To implement this strategy, AECL has set up a Decommissioning and Waste Management (DWM) organization. The DWM organization is also responsible, under a memorandum of understanding with Natural Resources Canada (NRCan), for the Low Level Radioactive Waste Office (LLRWMO), which manages Canada's historic non-AECL radioactive wastes [4].

It is important to recognize that AECL would have to maintain indefinitely an operational infrastructure, including its R&D capabilities, to deal with its own and the Canadian government nuclear legacies, even if all CANDU-related and other commercial operations were to cease today.

5.3 AECL WASTE MANAGEMENT ACTIVITIES

AECL activities produce wastes in various forms and over varying periods. These wastes must be first categorized as to physical and chemical properties, level of radioactivity and potential harm, segregated as appropriate, then processed, immobilized and packaged as needed, stored and eventually disposed of. Some wastes, both chemically toxic and radioactive, remain hazardous for lengthy periods so that long-term management is important. There are two basic options for long-term waste management: release with dilution and dispersion or concentration and confinement. The decommissioning of facilities, at both CRL and WL, produces wastes so that decommissioning and waste management are closely linked. Early waste management practices at AECL sites were based primarily on ensuring that radiation doses to the workers involved did not exceed regulatory limits and were limited according to the ALARA[3] principle. Also, questions of retrieval of wastes for future processing and eventual disposal were not thoroughly addressed in this period [4]. Increasingly, long-term impacts on the general population and on the environment [3] have to be taken into account.

5.3.1 Waste Remediation and Enhancement Projects

Decommissioning and site renewal projects and waste management improvement initiatives being undertaken by AECL, mainly at CRL, include remediation of the tile holes used for storing research reactor fuel and repackaging the fuel, upgrading the Waste Treatment Centre and the hot cells, reducing the hazards of stored liquid waste and development of a Modular Above-Ground Structure (MAGS) facility for storage of low- and intermediate-level waste, improved facilities for low-activity solid wastes, and better disposal of waste oils. Also, consideration is being given to the possible re-start of the Intrusion Resistant Underground Structure (IRUS) project for disposal of low-level and intermediate-level wastes [4]; this would be Canada's first licensed disposal facility for such wastes.

Many of these activities, as well as some of those described in section 5.3.2 below, require ongoing research support. An example of such support was discussed by the Panel last year [3]: the development over many years of the Wall and Curtain technology that has been installed in Waste Management Area C at CRL to prevent a ground-water plume of radioactive contaminants from reaching a wetland area. This technology could be applied to other cases in which contaminants in ground water plumes present a hazard, providing a commercialization opportunity for AECL.

5.3.2 Low-Level Radioactive Waste Management Office

The LLRWMO is a project management organization, separately funded and staffed by AECL for NRCan, which is responsible for dealing with non-AECL historic radioactive wastes in Canada that are the responsibility of the Government of Canada, for example, the wastes resulting from the mining, transportation, processing and use of radium and uranium from the 1930s to the 1980s. It performs work with its own staff or contracts and oversees work in all areas of low-level waste management. Over the years, the LLRWMO has cleaned up about 500 sites across Canada. It has recently been given the mandate, following many years of

[3] ALARA: As low as reasonably achievable, social and economic factors being taken into account.

discussions, to build three long-term storage facilities for the clean-up of historic wastes resulting from the early years of radium and uranium processing in the Port Hope, Ontario, area.

5.3.3 Nuclear Fuel Waste Management and Disposal

5.3.3.1 Nuclear Fuel Waste Storage

When nuclear fuel is discharged from a CANDU reactor, it is initially stored in open-top water pools at the reactor site. The water pools provide the necessary cooling and shielding of the discharged fuel as well as permitting easy monitoring and the inspections required by the IAEA under international safeguards agreements.

After about six years in these pools, the radioactivity and the resulting heat generation rate have decayed sufficiently to allow the fuel bundles to be transferred to dry storage facilities, which have the advantages over pool storage of completely passive operation, minimal maintenance and low operating costs and little or no corrosion of fuel sheaths. AECL has successfully developed several dry-storage technologies for discharged CANDU fuel, with earlier designs in use at several reactor sites. AECL's latest dry-storage technology is the MACSTOR dry storage module [4]. MACSTOR modules are monolithic concrete structures that provide the structural integrity and shielding needed and are designed to facilitate the passive natural-convection air-cooling required. Their compactness provides a relatively small land area for a given amount of fuel storage capacity compared to the earlier designs.

The MACSTOR technology is installed at Gentilly-2 in Quebec and has been selected for the Cernavoda CANDU 6 in Romania. AECL has been jointly developing, with Korean companies, a higher-capacity MACSTOR design for the Wolsong site to accommodate the lifetime discharged fuel from the four CANDU reactors there in the limited area available at the site. The MACSTOR design should be suitable for storage of discharged fuel from other reactor types as well as CANDU, i.e., PWR, BWR and VVER types. This provides an opportunity for AECL to market the MACSTOR technology on an international basis to nuclear utilities.

5.3.3.2 Nuclear Fuel Waste Disposal

As the Panel pointed out in its 1998 report [1], current nuclear fuel waste management and storage practices in Canada, as outlined in section 5.3.3.1, are adequately safe, have public acceptance and could be continued indefinitely. However, this approach would require continuous monitoring and maintenance for an indefinite period and is not consistent with government policy and CNSC regulations for ultimate passive storage. As discussed in reference [1] and noted in section 5.2 above, AECL, in cooperation with Ontario Hydro/Ontario Power Generation, has developed a technology for permanent deep geological disposal in the Canadian Shield and has spent many years and about $750 million in R&D to support this technology. There is an international consensus that deep geological disposal is the preferred approach for permanent disposal of nuclear fuel wastes, with other countries, e.g., the USA (with the recent political approval of the Yucca Mountain project), Sweden, Finland, Switzerland, France and Japan, taking this approach [4]. While the objective of permanent disposal is that there will be no need for monitoring or maintenance to ensure public safety, it is likely that society will require ongoing monitoring. In addition, in order to keep open the option of recovery of plutonium from fuel wastes for recycling as fuel, the design of the repository should not preclude access under carefully controlled conditions. To provide perspective on the size of the repository required, the total cumulative inventory of discharged fuel from Canadian power reactors up to the end of 1998 could be accommodated in three international-size hockey rinks, filled to the height of the boards.

The AECL concept for permanent disposal, burial deep in the very stable rock of the Canadian Shield, consists of isolation of the wastes from the biosphere by a series of engineered and natural barriers. With the waste in a depository below the water table, the major concern is that ground water containing radioactive materials or other contaminants could eventually reach the surface, representing a potential threat to humans or the environment. Quantitative assessments, in Canada and elsewhere, of the movement of radioactive substances to the biosphere from a deep geological depository have demonstrated that only minute quantities are ever likely to do so, even over thousands of years, and that resulting radiological doses to humans and biota would be many orders of magnitude lower than natural background doses and even further below doses that would cause harm [5].

In recent years, AECL has been working with Ontario Power Generation (OPG) to identify additional work needed for further development of the disposal concept. Much of this work has been done in the Underground Research Laboratory (URL) near Pinawa, Manitoba. The URL, in operation for many years, is composed of tunnels in rock at depths down to 420 metres below the surface, which contain equipment and instrumentation for various research programs related to waste disposal. It has also been used for collaborative studies with several other countries, including Finland, France, Japan, Sweden, the UK and the USA. A recent example of such collaboration is the Tunnel Sealing Experiment (TSX), co-sponsored by AECL, OPG, ANDRA of France, JNC of Japan and the U.S. Department of Energy. The TSX is a large-scale demonstration of the design, construction and performance of concrete- and clay-based seals of the type that would be used in an actual geological depository.

In 2000, Canada and the IAEA initiated the development of an International Training and Demonstration Facility (ITDF) to be based at the URL. The ITDF will be of particular interest to those countries with nuclear power programs that do not have an underground R&D facility. The ITDF initiative has resulted in the formation of an IAEA network of centres of excellence in training and demonstration of waste disposal technologies in underground research facilities.

The Panel has recently learned of interesting work being done in Canadian universities and other organizations, cooperatively with OPG and AECL, on the behavior of potential radioactivity releases from deep geological disposal facilities in the Canadian Shield. This work has focused on the development of highly sophisticated computer codes using advanced computers to characterize ground-water flow in three dimensions over actual regions of the Canadian Shield that could serve for the location of a fuel waste disposal facility. The Panel was particularly interested in the use of Cooperative Research and Development arrangements under the Natural Sciences and Engineering Research Council between OPG and universities for some of this work. The Panel has also learned that OPG and the University of Waterloo and Laval University are working with AECL on groundwater flow and tracer transport modelling at the URL.

5.4 PANEL ASSESSMENT

The Panel strongly supports the AECL strategy for waste management and disposal, as outlined in section 5.2, which is consistent with the recommendation of the Panel last year [3]. To implement its waste management and development strategy, AECL has formed the Decommissioning and Waste Management (DWM) organization.

Panel Finding 1

The Panel finds that the Decommissioning and Waste Management organization set up by AECL to meet its liabilities and responsibilities for site remediation and to develop a commercial waste management and disposal business appears to be an effective means towards these goals

However, the Panel has a major concern about the erosion of AECL's capabilities in waste management and disposal initiated by the reduction of COG funding and by the lengthy period taken by the Seaborn Panel for the environmental assessment of the AECL disposal concept. This concern was originally expressed in the Panel's 1998 report and is now increased by the further delay by the Federal Government in the start of site selection for a nuclear fuel waste disposal facility. This concern has been reinforced in recent discussions with AECL experts in this area.

Recommendation 1

The Panel recommends that AECL increase its efforts to retain and enhance its capabilities in R&D in the area of waste management and disposal so as to continue to meet its liabilities and responsibilities for site remediation and to develop a commercial waste management and disposal business.

As discussed in section 5.2, the Panel agrees that AECL would have to maintain an infrastructure, including R&D capabilities, to look after ongoing waste management and disposal liabilities and responsibilities even should AECL completely cease all activities as a reactor vendor and all other commercial activities.

Panel Finding 2

The Panel finds that AECL recognizes the need to maintain an infrastructure, including R&D capabilities, for waste management and disposal to meet its liabilities and responsibilities in this area, even in the absence of all commercial activities.

The Panel is pleased to note that the MACSTOR technology, as described in section 5.3.3.1, is adaptable to the storage of fuel from other types of reactors. This international business opportunity may require further R&D for the MACSTOR technology to ensure that enriched fuel bundles of different designs can be handled efficiently and safely and that international regulatory requirements can be met.

Recommendation 2

The Panel recommends that AECL assess the need for any additional R&D necessary for the MACSTOR design to handle enriched fuels of different types so as to meet international licensing requirements for such fuel storage, and implement any additional R&D deemed necessary.

As discussed in section 5.3.3.2, AECL is continuing to undertake significant R&D on its concept for the ultimate disposal of high-level radioactive waste, deep geological disposal in the Canadian Shield. The Panel strongly supports AECL's cooperative work with OPG, Canadian universities and international bodies on this concept. In particular, the Panel recognizes that the URL provides an important tool for AECL in developing a commercial waste disposal business.

Panel Finding 3

The Panel finds that AECL is continuing to develop its expertise in high-level radioactive waste disposal through cooperative work with OPG, Canadian universities and international bodies, in particular through work at the URL, which will enhance AECL's capability to develop a commercial business in the area of high-level waste disposal.

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4. Allan, C.J.; Radioactive Waste Management at Atomic Energy of Canada Limited (AECL); American Nuclear Society, Spectrum 2002, June 2002

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CHAPTER 6: RADIATION BIOLOGY

6.1 INTRODUCTION

The nuclear industry needs to be knowledgeable about the full range of biological responses to ionizing radiations for a number of reasons. For the designers and the regulatory agency, it is necessary to ensure that plant design minimizes the likelihood of radiation exposures to staff and the public during both routine operations and postulated accident conditions. The utility that proposes to build a nuclear plant must justify site selection and satisfy the environmental assessment process to its authorities. The operator of a nuclear plant must maintain a monitoring system to document that operations are safe and will also use knowledge of the biological effects of radiation to develop and justify operating policies. These needs require that entities such as AECL, COG and the CNSC have experts in radiation biology available to consult and inform their activities.

Over-arching the needs of the industry for an understanding of radiation biology is the necessity for public discussions concerning the risks and benefits of the nuclear industry, as well of the far-reaching benefits of radiation and isotopes throughout our society, to be informed and balanced, rather than driven by biases rooted in fear. Further, independent of whether there is a nuclear industry in Canada or not, the nation will continue to require a core of resident expertise in radiation biology and ecology in order to manage its legacy, to respond to external threats and in order to participate responsibly in international situations with a radiological component.

In Canada, since 1952, a large component of the nation's radiobiological expertise has been resident at AECL's nuclear laboratories. The radiobiological group was never large and it has shared in serial fiscal cutbacks over the years. At the same time, there is a renewed international effort to understand radiation biology in terms of molecular biology, rather than through epidemiological sciences.

The Panel is convinced of the ongoing importance of radiobiological sciences for the development of the nuclear industry and for Canada and it considered these issues in four of its previous reports [1,2,3,4]. The Panel strongly supported the construction of the CANDU Health Sciences Centre, which remains a unique national resource. The Centre allowed AECL scientists to focus on problems of importance to the industry, in particular, the effects of very small radiation doses. These studies are important in that they directly test, and to some degree challenge, the linear non-threshold hypothesis of radiation repair that is used by the CNSC and other regulators. Radiation injury is known to be a non-specific stress and the pathways of repair are of interest beyond the field of radiobiology. The Panel has praised the work and recommended an increased effort: however, human and other resource limitations have not permitted this to occur. The small number of scientists available for this work does not permit that full advantage can be taken of advances in molecular biology.

6.2 RECENT ORGANIZATIONAL CHANGES

Work at the CANDU Life Science Centre was, until 1998, supported by both AECL vote funds and COG. In 1998, a severe reduction in COG funding put the whole operation at risk. AECL and its scientists sought to establish working relations with others who might use the CANDU Life Science Centre. A free-standing organization, to be called the National Centre for Radiological Sciences, was proposed; through a base at CRL, it would provide avenues for the use of the facilities by all members. This laudable plan, though met with much interest, did not attract enough financial support to succeed.

The next plan was to transfer the facilities of the CANDU Life Science Centre to Health Canada; a good fit was envisaged since Health Canada has a general responsibility for radiation protection. As the option was discussed, a number of difficulties were encountered. AECL needed to retain its facilities for dosimetry and Health Physics. A transfer of the license to operate a radiation facility from AECL to Health Canada could not be accomplished without considerable effort and delay. Finally a partnership was proposed in which Health Canada would control and fund its own research at the CANDU Life Science Centre. A similar arrangement was made with COG for the support of research considered important by the utilities. AECL management found these plans attractive; they assured the continuing operation of the CANDU Life Science Centre, the integrity of Health Physics and Dosimetry and some support for research into questions important to the industry.

The COG organization is currently developing a series of strategic plans for its research program including in radiation biology. AECL is a partner in this process. The COG partners have a strong focus toward the maintenance of current plants whereas AECL, while sharing those interests, also has unique needs including maintenance of its research sites, management of Canada's nuclear legacy, development and future siting of new plants as well as obligations under international treaties. Therefore, the Panel believes that AECL needs to undertake its own strategic planning exercise.

Panel Finding 1

The programs in dosimetry and health physics must be continued. The work in basic biology is to be commended, particularly in view of the very limited facilities available for it.

Recommendation 1

The Panel recommends that the scope, priorities and directions of radiobiological research be explored through a strategic planning exercise. External advice may be required in such an exercise.

6.3 ENVIRONMENTAL PROTECTION

Under the terms of the Nuclear Safety and Control Act, the CNSC is obliged to ensure that licensing decisions will protect the major elements of the bio-environment, as well as humans. Their new focus on environmental considerations will significantly impact on the processes by which proposals for future new nuclear facilities will be assessed and licensed. While sensitivity to the fragility of the environment is a positive thing, the procedures, by which these assessments are to be made and the methodology for establishing benchmarks, remain unclear. CNSC has issued a regulatory policy document entitled "Protection of the Environment P-223". The document does not set any explicit standards but does obligate the CNSC to consult with stakeholders when "developing environmental protection programs, performance indicators and targets". Realistically, assessment and licensing procedures will become more complex, more costly and take more time to complete.

Recommendation 2

AECL should monitor the evolution of the CNSC environmental assessment process and provide input into the process whenever possible.

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2. Report of the AECL Research and Development Advisory Panel for 1996

3. Report of the AECL Research and Development Advisory Panel for 1999

4. Report of the AECL Research and Development Advisory Panel for 2000

CHAPTER 7: NUCLEAR-HYDROGEN ECONOMY AND THE ENVIRONMENT

7.1 INTRODUCTION

In its last three annual Reports the Panel has discussed the question of climate change and the role of nuclear energy and the potential for the nuclear-hydrogen economy to displace fossil fuels in such areas as transportation and oil recovery from the tar sands [1,2,3]. A description of AECL work on the nuclear-hydrogen economy and its potential impact on the reduction of greenhouse gas emissions, based on an update of reference [4], was provided to the Panel at its May meeting. The main activity of the Panel on this topic this year was to respond to the Government discussion paper on climate change, as discussed in the next section.

7.2 RESPONSE TO GOVERNMENT DISCUSSION PAPER ON CLIMATE CHANGE

The Panel was appalled to find that the Federal Government discussion paper on climate change [5] did not recognize the significant contribution that nuclear power is now making to the reduction of greenhouse gas (GHG) emissions in Canada and the more significant role that nuclear power and the nuclear-hydrogen economy can play in the future for this purpose as well as for the reduction of atmospheric pollution.

The Panel submitted a response to the discussion paper expressing its concerns about its neglect of nuclear energy in reducing GHG emissions [6]. After pointing out that nuclear power is the only proven technology that can provide base-load electricity on a large-scale without the emission of greenhouse gases, the Panel summarized the present contribution that nuclear power in Canada is making to GHG reduction and the further reduction that will be achieved when laid-up reactors at Pickering-A and Bruce-A are brought back on line. The Panel also pointed out the significant increase in CO_2 emissions, as well as the atmospheric pollutants SO_2 and NO_x, from electricity generation in Ontario as these reactors were laid up in 1997 and 1998 [7].

The Panel report goes on to criticize the focus of the discussion paper on the short term and to point out the significant potential for nuclear energy not only to displace fossil fuels in the generation of electricity for conventional purposes but also in such sectors as transportation, and oil production from the Alberta tar sands, by way of the nuclear-hydrogen economy. The report cites AECL work showing that, by 2020, current and refurbished CANDU plants, new ACR plants and nuclear-hydrogen developments in the tar sands could result in CO_2 emission reductions in Canada about two to three times those resulting from the current use of nuclear energy.

The report then points out that the Intergovernmental Panel on Climate Change (IPCC) [8], in its various scenarios for GHG emissions to 2100, seriously underestimates the potential for nuclear energy to reduce emissions by not recognizing the reduced cost of advanced reactors like the ACR and ignoring the potential of the nuclear-hydrogen economy.

The report points out that the nuclear-hydrogen economy will produce economic and environmental benefits for Canada, whether or not human activities contribute significantly to any observed global warming. This is emphasized by the fact that Canadian technology, including the ACR, is at the forefront of the technologies that comprise the nuclear-hydrogen economy.

7.3 PANEL ASSESSMENT

The Panel continues to support the AECL work on assessing the key role of nuclear energy and the nuclear-hydrogen economy in meeting the world's energy needs in the 21st Century. In particular, the Panel endorses re-assessment by AECL of the energy scenarios of the IPCC to demonstrate the much larger potential role for nuclear energy than is considered in the IPCC scenarios.

Panel Finding 1

The Panel continues to support AECL's assessments of the potential role of nuclear energy and the nuclear-hydrogen economy to meet the world's energy needs in the 21st Century and of the potential for the ACR and other advanced CANDU designs to contribute significantly to meeting these energy needs.

AECL has examined the various scenarios studied by the IPCC [8] and has concluded that nuclear energy can play a much more significant role as an energy source in this century than projected by the IPCC, as noted above. In a typical scenario assessed by AECL, over 440,000 tonnes per year of mined uranium would be needed by 2040 to meet the projected demand for nuclear energy. This quantity is a significant fraction of the known world low-cost reserves of less than 6 million tonnes. Thus, it would be prudent in the long term to develop fuel cycles that make more effective use of mined uranium. These include the DUPIC fuel cycle under development by AECL and the Korean Advanced Energy Research Institute (KAERI), which was discussed in previous Panel Reports, most recently in the 1999 Report [1], and other methods of recycling fuel such as MOX in ACRs [3]. Also, work will be required to develop thorium fuels for the ACR, which would extend fuel resources significantly [9]. While AECL has been studying advanced fuel cycles for a considerable time, the emphasis has been on their performance in CANDU reactors. The Panel believes that it would be worthwhile to look at these cycles from the viewpoint of assuring nuclear fuel supply in the long term

Recommendation 1

The Panel recommends that AECL, in its studies on alternative reactor fuels and fuel cycles for the ACR and future CANDU designs, assess the long-term availability of nuclear fuel supplies to meet the large demand resulting from the expected growth of nuclear generation and the development of the nuclear-hydrogen economy in the 21st Century.

The Federal Government has recently issued the Climate Change Plan for Canada [10]. Again, there is no emphasis on the important role of nuclear energy in reducing CO_2 emissions. Now that Parliament has ratified the Kyoto Accord, it is more important than ever that the Federal Government recognize the significant role that nuclear energy and the nuclear-hydrogen economy can play in reducing GHG emissions, in addition to its significant role in reducing air pollutants that lead to smog and acid rain.

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5. A Discussion Paper on Canada's Contribution to Addressing Climate Change; Federal Climate Change Secretariat; Ottawa, May 2002

6. Response to "A Discussion Paper on Canada's Contribution to Addressing Climate Change"; Research and Development Advisory Panel to Board of Directors, Atomic Energy of Canada Ltd.; June 20, 2002

7. The Environmental Imperative for the Return to Service of the Pickering-A NGS; Presentation to CNSC Public Hearing by the Research and Development Advisory Panel; Pickering, Ontario, December 14, 2000

8. Third Assessment Report; Intergovernmental Panel on Climate Change; 2001

9. Report of the Research and Development Advisory Panel for 1995

10. Climate Change Plan for Canada; Government of Canada, October 2002

CHAPTER 8: THE CANDU X REACTOR CONCEPT

8.1 CANDU X AND THE GENERATION-IV INTERNATIONAL FORUM

As discussed in several previous Panel Reports, most recently in reference [1], the CANDU X reactor concept represents AECL's long-term vision of a reactor concept that will achieve 50% reductions in both capital and operating costs below those of current CANDU reactors, while retaining the essential features of the CANDU design that underlie its successes to date. The Panel has strongly supported work on the CANDU X concept in these earlier reports and continues to do so.

As discussed in reference [1] as well as earlier, Canada, through AECL, is a member of the Generation–IV International Forum (GIF) which is dedicated to the development by 2030 of promising nuclear reactor and fuel cycle technologies. Recently, the GIF has selected six nuclear energy system concepts to be the focus of collaborative international R&D [2]. One of the selected concepts is the use of supercritical-pressure water (SCW) as a reactor coolant, as proposed by AECL for the CANDU X reactor concept. The selection of SCW coolant by GIF provides an opportunity for AECL to benefit from international collaborative research on SCW to support development of the CANDU X concept. As pointed out in reference [3], an SCW-cooled CANDU X design has some significant inherent advantages over the only other proposed SCW-cooled reactor design, the SCW-cooled Pressurized Water Reactor, as studied in Japan and Russia.

Panel Finding 1

The Panel continues to endorse strongly the continuation of support by AECL for CANDU X R&D, particularly now that the use of supercritical-pressure water as a coolant has been selected by the Generation-IV International Forum as one of the system concepts to be the focus for collaborative R&D.

8.2 CANDU X INTERNALLY INSULATED PRESSURE TUBE

A key issue for the CANDU X concept is the design of the internally insulated pressure tube. The purpose of the internal insulation is to protect the pressure tube, which carries the mechanical stresses imposed by the very high coolant pressure of 25 MPa, from the high temperatures (400°C to 625°C) of the supercritical water coolant envisaged for the various CANDU X conceptual designs [4]. The design of the internal insulation for an economic lifetime presents some key challenges:

- to minimize imposed mechanical stresses by minimizing any pressure difference across it,
- to keep thermal stresses low,
- to keep the temperature of the pressure tube close to the moderator temperatures of about 60°C,
- to be stable at coolant temperatures and under intense radiation over the pressure tube lifetime.

Meeting these challenges will ensure that pressure-tube creep rates are very low, will minimize the likelihood of creep-rupture, will avoid delayed-hydride-cracking and will simplify its mechanical design and will ensure that an economic lifetime for the pressure tube can be achieved.

The Panel has pointed out [5] that AECL, in co-operation with Canadian General Electric, undertook considerable R&D on internally insulated pressure tube concepts in the 1960s as part of the work on the Organic Cooled Deuterium Reactor (OCDR), an organic-cooled version of the CANDU [6,7,8]. It would appear advisable for AECL to review and assess this work for its applicability to the CANDU X concept.

Recommendation 1

The Panel recommends that AECL review and assess the applicability of the R&D by AECL and Canadian General Electric in the 1960s on internally insulated pressure tubes, for the organic-cooled version of CANDU, to the design of the internally insulated pressure tube for the CANDU X reactor concept.

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6. Ross-Ross, P.A., and K.L. Smith; Pressure-Tube Development for Canada's Power Reactors; American Society for Mechanical Engineers Paper 64-WA/NE-5, 1964

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8. Rogers, J.T.; The Insulation of Organic-Cooled Reactor Pressure Tubes Using the Flowing Coolant as an Insulant; Symposium on Nuclear Engineering Heat Transfer, 55th Annual Meeting, American Institute of Chemical Engineers, Chicago, 1962

CHAPTER 9: HUMAN RESOURCES IN THE NUCLEAR INDUSTRY

9.1 INTRODUCTION

The shrinking pool of expertise in nuclear science and engineering is causing concern in countries with nuclear power programs [1]. In its annual Reports for 1999 and 2000, the Panel addressed the situation in Canada, describing the relations between AECL and the universities and emphasising the need to continue supporting research chairs, encouraging young people to join the industry and documenting the knowledge base in CANDU-specific subjects. An important development since then has been the introduction of degrees in Nuclear Engineering and Health Physics at the newly founded University of Ontario Institute of Technology. It should also be acknowledged here that the technical colleges fulfil an important role in developing training programs for the industry.

It is clear that progress is now being made. AECL is involved in the University Network of Excellence in Nuclear Education (UNENE), spearheaded by OPG, the CANTEACH project (see Panel annual Report for 2000) is underway and COG is promoting networks of centres of excellence among universities and industry researchers in areas of CANDU technology.

9.2 UNIVERSITY NETWORK OF EXCELLENCE IN NUCLEAR EDUCATION

9.2.1 Background

Early in 2001, the Training Support and Services Division of OPG canvassed nuclear industry stakeholders and interested universities to participate in a new initiative. The creation of UNENE was proposed, in order to [2] “foster collaborative research and education among a consortium of universities in partnership with a sponsoring consortium of users of nuclear technology and employers of engineers and scientists possessing such expertise”. The key objectives were to:

- create and sustain nuclear research by establishing new research professorships in a group of selected universities;

- foster an active partnership among nuclear power utilities, research and regulatory agencies, and other stakeholders for synergistic support in R&D of nuclear technology;

- establish a sustainable supply of qualified nuclear engineers and scientists to meet the current and future needs of the Canadian nuclear industry;

- create a respected body of nuclear experts to provide independent assessments and advice to the public and the CNSC on nuclear energy issues.

The initial group of selected universities was in Ontario. Each would have a UNENE-sponsored Industrial Research Chair (IRC), under the auspices of the Natural Sciences and Engineering Research Council of Canada (NSERC), in a particular area of specialization. For example, OPG had already sponsored a Chair in nuclear materials research at Queen’s, and this at the time was in the final stages of negotiation with NSERC. In addition to the Ontario institutions, École Polytechnique and the University of New Brunswick with established nuclear programs were seen as making valuable contributions to UNENE.

The potential industrial sponsors were the nuclear utilities—OPG and Bruce Power in the first instance—along with COG, the CNSC and AECL. Matching funds for research would be sought from government-granting agencies such as NSERC and the Canadian Foundation for Innovation. Nuclear training would be delivered as a Diploma or further degree, specifically an M.Eng. in Nuclear Engineering. This was envisaged as an intensive course offering, with instructors from the existing pool of experts in participating institutions contributing topics in their particular areas of specialization.

After discussion and consideration of legal advice, the stakeholder representatives who constituted the provisional board decided that UNENE should become incorporated with letters patent from Industry Canada. The leading university in the initiative was McMaster, and the Provisional Secretary and Treasurer from there would continue to coordinate the activities through the incorporation process.

9.2.2 Current State of Affairs

UNENE is now a registered Corporation with its head office in Hamilton, Ontario. The incorporation documents are modelled on those of COG and are similar to the agreement documents of the federal Networks of Centres of Excellence.

The voting members of UNENE are AECL, Bruce Power, McMaster University, OPG, Queen's University, University of Ontario Institute of Technology, University of Toronto, University of Waterloo and University of Western Ontario. The non-voting members are COG, University of New Brunswick and École Polytechnique. The CNSC is contributing funds and is associated with the Board, the Directors of which are drawn from the UNENE members. In addition, the members all have representatives who serve on the Educational Advisory Committee and the Research Advisory Committee.

The budget for the first year of operating (2002-2003) was originally estimated to be close to $2M, with OPG contributing the major industrial share, Bruce Power and AECL equally contributing the next largest, then COG and, finally, the CNSC with the lowest industrial share. The only university contribution came from the funds associated with the established IRC at Queen's.

9.2.3 UNENE Educational Advisory Committee

The Educational Advisory Committee intends to have the first M.Eng. program ready to be offered early in 2003. It is a non-research degree and its structure is based on that of the Advanced Design and Manufacturing Institute (ADMI) in Ontario, which is a joint venture among the universities McMaster, Toronto, Waterloo and Western. Thus, UNENE coordinates the suite of graduate level courses offered by the participating universities. A student taking the courses for a degree will enrol at a UNENE university—the "home" university—and will be subject to the same regulations for admission as other graduate students. Most of the enrolling students are expected to be industry employees who enrol part-time for the M.Eng. to upgrade their knowledge and skills and improve their opportunities for professional development and career enhancement. Some will be industry employees who wish to take only one or two courses for credit. Another category of student will be those enrolled full-time who hold industry scholarships and are expected to join the sponsoring company after graduation. There is the possibility also that students already enrolled in graduate programs at UNENE universities will be able to take individual courses.

Courses will be delivered at a central institution—which need not be a UNENE member; a conference centre with appropriate facilities may be more convenient during universities' busy term time, for example. An instructor from a "delivering institution" will present course material over two one-week periods separated by one week or so. Each week of study will comprise the weekend and two weekdays, thereby splitting the commitment for part-time students between the employer and the employee. The intensive nature of this delivery arrangement entails a departure from the normal lecture mode. A typical three-credit-hour lecture course, for example, which would constitute about 36 hours of classroom time over a university term, must be broken up with demonstrations, practical classes, etc., to make it palatable to both student and instructor in the UNENE format.

In order to graduate, a student must complete at least ten courses. The normal time for this will be about 2½ years, and a minimum of two courses will be required in any year. The courses to be prepared deal with technical subjects like reactor physics, nuclear materials, reactor chemistry and corrosion, thermalhydraulics, etc., along with business-related subjects. Commitments for preparing most of them have already been obtained, and instructors will be from industry as well as universities.

Fees will be paid on a per-course basis. The intention is that, as in the ADMI model, 50% of a student's registration fee for a course will go to the delivering institution, 20% to the registering university and the remaining 30% to the UNENE office. Instructors will receive a stipend.

9.2.4 UNENE Research Advisory Committee

The Research Advisory Committee is seen as a vehicle for maintaining contact between the industry members of UNENE—the sponsors—and the researchers in the UNENE universities—in particular, the chairholders. It will also select students to receive UNENE scholarships to pursue research M.Sc. or Ph.D. degrees under the normal university programs. Advertising for the Chair positions at the Ontario member universities (other than Queen's, which is already established) has begun and appointments are expected to be made soon.

Panel Finding 1

The Panel is greatly encouraged by the progress made in establishing UNENE in such a short time. It recognises the potential that the initiative holds for bringing stability to the human resources in the nuclear industry in general and AECL in particular, and for developing research expertise complementary to AECL's. Continued sponsorship of UNENE, membership of the Board, and participation in the advisory committees will be important for AECL.

9.2.5 COG Networks of Centres of Excellence

Coincidentally with the UNENE initiative, COG is instituting Networks of Centres of Excellence (NCE) in its technical program areas. This implementation of one aspect of the COG strategic plan addresses several issues of human resources in the industry—maintaining a registry of resources and facilities available to the industry, comparing existing expertise with industry needs, considering CNSC concerns about capability maintenance, and coordinating R&D programs within specific technical areas.

The intention is to broaden the base of experts in the COG Technical Committees. In particular, the largely untapped sources of nuclear expertise in the universities would be made available through the memberships of Research Chairs, for example, while technical experts would be seconded to Technical Committees as required.

The COG Fuel Channel program has the fewest participants at the Technical Committee and Working Group levels and has only two dozen or so people doing the research; its needs have been addressed first by consultants [3]. Implementation of the findings and the inauguration of the NCE were expected for 2002. With slightly more participants at the Technical Committee and Working Group levels but fewer people doing the research, the Health Safety and Environment program and its needs have been addressed next. A consultant will prepare a report and this should be followed by implementation of the NCE late in 2003. In view of the proposed reorganization of AECL's programs in radiobiology, as discussed in Chapter 7, the Panel will follow with interest the progress towards establishing this NCE in Health, Safety and the Environment. Similar exercises for the remaining two COG programs—Chemistry, Materials and Components along with Safety and Licensing—are expected to lead to implementation in 2004.

Panel Finding 2

The COG initiative is laudable in that improved communications among experts along with integration and coordination of related research programs must help the industry. The visualised NCEs complement UNENE and to some extent have similar goals. In many program areas the same people will be involved in both UNENE and the corresponding NCE—as with the UNENE Chair in Fuel Channel Materials, for example. Intellectual property rights will create issues at the COG Technical Committee level.

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2. M. Mathur, Address to Engineering Faculty; University of New Brunswick, OPG Training and Support Division, June 2001

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Excellence"; COG 02-900, June 2002

APPENDIX A: TERMS OF REFERENCE OF THE RESEARCH AND DEVELOPMENT ADVISORY PANEL TO THE BOARD OF DIRECTORS OF ATOMIC ENERGY OF CANADA LIMITED

1. Mandate

The Research and Development Advisory Panel ("the Panel") shall advise the Board of Directors ("the Board") of Atomic Energy of Canada Limited ("AECL"), through the Science and Technology Committee ("the Committee") of the Board with respect to the strategic needs, alliances, and direction of the R&D activities of AECL, in particular those areas supporting the Nuclear Platform. The Panel shall provide advice to the Committee as to whether these programs have the appropriate quality, scope, composition, and balance between short- and long-term activities, to sustain AECL's nuclear program, nationally and internationally.

AECL shall nominate a Vice-president and technical secretary to support Panel activities.

2. Duties/Responsibilities

To fulfil its Mandate, the Panel shall undertake the following duties and specific responsibilities, as prescribed by the Committee:

2.1 The Panel shall meet not less frequently than three times during each AECL fiscal year, working to a budget administered by the nominated Vice-president. As a first priority, the Panel shall provide to the Committee and the Board a Report of its key findings and recommendations that need to be considered in AECL's next planning cycle. The Panel shall supplement this Summary with a more detailed public Report for consideration by AECL's management.

2.2 The Panel shall meet with AECL staff in developing its Report.

2.3 Panel representatives shall participate, by invitation, in meetings of the Committee, and provide advice and confidential reports, as appropriate. The Committee, however, reserves the right to sit in camera.

2.4 The Panel shall meet periodically with representatives of Canadian utilities to discuss their needs and requirements so as to reflect these in the Panel's advice to the Board.

2.5 In examining and advising on existing and proposed national and international scientific collaboration, the Panel shall also evaluate AECL's current and potential relationships with Canadian universities, and other post-secondary educational institutions, and organizations in the public and private sector conducting Canadian nuclear-related research.

2.6 Members of the Panel may, after consultation with the Committee, appear before properly constituted boards, commissions or committees of the federal or provincial governments, and prepare reports and recommendations on public policy issues, with respect to matters relevant to its Mandate or as prescribed by the Committee.

2.7 The Panel shall have responsibility for the annual W.B. Lewis Lecture, including, but not limited to, speaker selection, organization and publicity, to be performed within the Panel budget.

2.8 The Panel will discuss strategic needs, alliances, R&D, and other activities, plans, and strategies of AECL that are considered confidential and proprietary information of AECL. ("Confidential Information"). AECL shall remain the exclusive owner of the Confidential Information disclosed to the individual Panel members, who shall protect the disclosed Confidential Information by using their best efforts to prevent the unauthorized dissemination or publication of the Confidential Information. Each Panel member agrees to notify AECL immediately upon becoming aware of any unauthorized disclosure of the Confidential Information. No Panel member shall disclose the Confidential Information to any third party, or use or exploit such Confidential Information for any purpose without the express, written permission of AECL.

3. Timetable

The Panel shall plan its deliverables to the Committee and Board according to the following timetable:

- March: Plan of upcoming year's activities presented for Committee review.
- November: Draft of summary/annual Report presented to Committee. Timed for consideration in AECL's planning cycle.
- December: Management comments delivered for Panel consideration
- January: Presentations of final summary/annual report to Committee and Board, for Board approval.
- May: Annual Report(s) translated, printed and distributed

Revised 2002 July 22

APPENDIX B: PANEL MEMBERSHIP

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APPENDIX C: PANEL PUBLICATIONS AND SUBMISSIONS

REPORTS

- Report of the AECL Research & Development Advisory Panel for 2001
- Report of the AECL Research & Development Advisory Panel for 2000
- Report of the AECL Research & Development Advisory Panel for 1999
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- Report of the AECL Research & Development Advisory Panel for 1997
- Report of the AECL Research & Development Advisory Panel for 1996
- Report of the AECL Research & Development Advisory Panel for 1995
- Report of the AECL Research & Development Advisory Panel for 1994
- Report of the AECL Research & Development Advisory Panel for 1993
- Report of the AECL Research & Development Advisory Panel for 1992

SUBMISSIONS/PAPERS

- *Vision 2020 and Beyond: The Need for Nuclear Research and Development in Canada in the 21st Century*, Revised 2002 December
- *Special Report on Radiobiology Research at AECL*, 2002 August 1
- Response by the R&D Advisory Panel to the Government's Discussion Paper on Canada's Contribution to Addressing Climate Change, June 20, 2002
- Appendix to AECL's NG CANDU Business Case, *The Next-Generation CANDU® Reactor (NG CANDU) and its Research and Development Requirements*, submitted to Government, October 22, 2001
- Presentation to the Canadian Nuclear Safety Commission Public Hearing on the Environmental Assessment of Pickering Nuclear Generating Station-A Return to Service, *The Environmental Imperative for the Return to Service of the Pickering-A Nuclear Generating Station*, December 14, 2000
- A report for senior levels of government, *Vision 2020 and Beyond—The Need for Nuclear Research and Development in the 21st Century*, September 1999

- Submission prepared at the request of Natural Resources Canada, *A Rationale for Canadian Expenditure on Nuclear Research and Development in the 21st Century*, May 14, 1999

- Presentation to Natural Resources Canada on Consultation on Options for Federal Oversight of Nuclear Fuel Waste Management and Disposal, February 17, 1999

- *The Importance of the Canadian Neutron Facility to the Support and Future Development of CANDU Reactors*, November 1998

- Submission to the Parliamentary Sub-Committee on Natural Resources on Bill to Review Nuclear Safety Act, October 1996

- Submission to the Environmental Review Panel for the Nuclear Fuel Waste Disposal Concept, August 1995

- Submission to the Science and Technology Review, Secretariat of Industry Canada, September 1994

APPENDIX D: FREQUENTLY USED ABBREVIATIONS/ACRONYMS

Abbreviation/Acronym	Definition
ACR	Advanced CANDU Reactor
AECL	Atomic Energy of Canada Limited
ALARA	As Low As Reasonably Achievable
BWR	Boiling Water Reactor
CANDU X	Advanced CANDU Reactor Concept
CANDU®	CANadian Deuterium Uranium Reactor
CANFLEX®	CANDU Flexible Fueling
CANFLEX-SEU	CANFLEX with Slightly-Enriched Uranium Fuel
CATHENA	Canadian Algorithm for Thermalhydraulic Network Analysis
CCGT	Combined-Cycle Gas Turbine
CNSC	Canadian Nuclear Safety Commission (formerly Atomic Energy Control Board (AECB))
COG	CANDU Owners Group
CRL	Chalk River Laboratories
CVR	Coolant Void Reactivity
DONJON	Reactor Physics Code
DRAGON	Reactor Physics Code
DUPIC	Dual Use of PWR Fuel in CANDU
FAC	Flow Accelerated Corrosion
GHG	Greenhouse Gases
IAEA	International Atomic Energy Agency
IPCC	Intergovernmental Panel on Climate Change

Abbreviation/Acronym	Definition
KAERI	Korean Atomic Energy Research Institute
LLOCA	Large Loss of Coolant Accident
MPa	Megapascal
MOX	Mixed Oxide Fuel
NG CANDU	Next Generation CANDU
NGS	Nuclear Generating Station
NRC	Nuclear Regulatory Commission (U.S.)
NRU	National Research Universal Reactor
PWR	Pressurized Water Reactor
R&D	Research & Development
RFSP	Reactor Physics Code
SCW	Supercritical Water
SEU	Slightly Enriched Uranium
UNENE	Universities Network of Excellence in Nuclear Engineering
WL	Whiteshell Laboratories
ZED-2	Zero Energy Deuterium (lattice-testing reactor)
WIMS	Reactor Physics Code

APPENDIX E: PANEL ACTIVITIES

Meeting #41, March 21-22, Sheridan Park, Mississauga	
Presentation	**Name of Presenter**
R&D Staffing Update	P. Quinn
Technical Aspects of Plant Security	B. Perrin
Update from the Chief Scientist	R. Duffey
Universities' Network of Excellence in Nuclear Engineering (UNENE) Initiative	D. Lister
R&D Safety Testing Facilities	B. Kupferschmidt
Decommissioning & Waste Management	C.J. Allan
NG CANDU	S. Yu, D. Wren
Nuclear Security	B. Shalaby

Meeting #42, May 29-31, Chalk River Laboratories	
Presentation	**Name of Presenter**
AECL's Radiation Biology	B. Kupferschmidt/T. Walker
Anaerobic Chamber and Fracture Device plus the Scanning Auger Microscope (SAM)	B. Hocking/F. Szostak
X-ray photoelectron spectroscope (XPS)	B. Hocking
Computational Reactor Physics Aspects of ACR (NG-CANDU)	D. Rozon
AECL's Kyoto Strategy (Introduction and Climate Change Modelling with Magicc Scengen	A. Miller, T. Poehnell
CANDU-X	H. Khartabil
Feedback from Royal Society Research and Security Conference	R. Armstrong
Regulatory Implications of Previously Unsuspected Low Dose Radiation Effects	R. Mitchel
ZED-2 experiments in support of ACR (NG CANDU)	R. Jones

Meeting #43, September 25-27, Waterloo	
Presentation	**Name of Presenter**
Waste Management	Professor J. Sykes, University of Waterloo
Visit to Bruce Power	D. Harrington; K. Talbot, R. Mohindra, R. Chun, R. Liddle, Bruce Power

Meeting #44, December 5-7, Sheridan Park	
Presentation	**Name of Presenter**
AECL Quality Issues	A. Aly
ACR Licensing Process	V. Snell
Feeder Cracking	C. Stuart, M. Wright
AECL Media Relations and Public Communications	M. Kealey
Update from Chief Scientist	R. Duffey

R&D Advisory Panel Subcommittee and Other Meetings		
Date	**Participants**	**Topic**
July 11	T. Rogers, J. Jennekens and CNSC	Security
July 24	T. Rogers, D. Burns, T. Gendron	Feeder Thinning and Cracking
July 24	T. Rogers, D. Burns, P. Davies	Pressure Tubes for the ACR
August 19	R. Duffey, D. Lister, A.I. Miller	Methane, Hydrogen Process
August 22	R. Armstrong, D. Burns, D. Lister, T. Rogers, D.F. Torgerson	Canadian Neutron Facility
August 22	R. Armstrong, D. Burns, D. Lister, T. Rogers, J.M. Hopwood	ACR R&D Update
August 23	R. Armstrong, D. Burns, D. Lister, T. Rogers, M. Puls	ACR Pressure Tube Rupture and Leak Detection
August 23	R. Armstrong, D. Burns, D. Lister, T. Rogers, E. Nadeau	Probabilistic Approach to Fuel Channels
August 23	R. Armstrong, D. Burns, D. Lister, T. Rogers, R. Sauve	Computational Mechanics of Reactor Systems including Fuel Channels
August 23	R. Armstrong, D. Burns, D. Lister, T. Rogers, S. Sharma	Feeder Stress Analysis

R&D Advisory Panel Subcommittee and Other Meetings		
Date	**Participants**	**Topic**
August 27	J. Jennekens, D. Lister, T. Rogers	Subcommittee meeting
August 27	T. Rogers, D. Lister, J. Jennekens, C.J. Allan	AECL's strategy on waste management and disposal, and waste disposal R&D
August 27	T. Rogers, D. Lister, J. Jennekens, B. Perrin, J.P. Letourneau	Physical Security Update
August 27	T. Rogers, D. Lister, J. Jennekens, A.J. White	Introduction to Safety Facilities
October 23	J.F. Colvin, NEI	W.B. Lewis Lecture "Nuclear Energy - Fulfilling the Promise"
October 24	T. Rogers, D. Lister, J. Jennekens, R. Armstrong, D. Burns,	Vision 2020, ACR Reactor Physics Codes, Position Paper on Nuclear Platform
December 18	T. Rogers, D. Rozon, D. Burns, P. Boczar, P. Chan, H. Chow	ACR Reactor Physics
December 18	T. Rogers, D. Rozon, D. Burns, R. Armstrong, R. Duffey	Government Funding of Nuclear Research in USA and Elsewhere