CANADIAN NUCLEAR SOCIETY

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DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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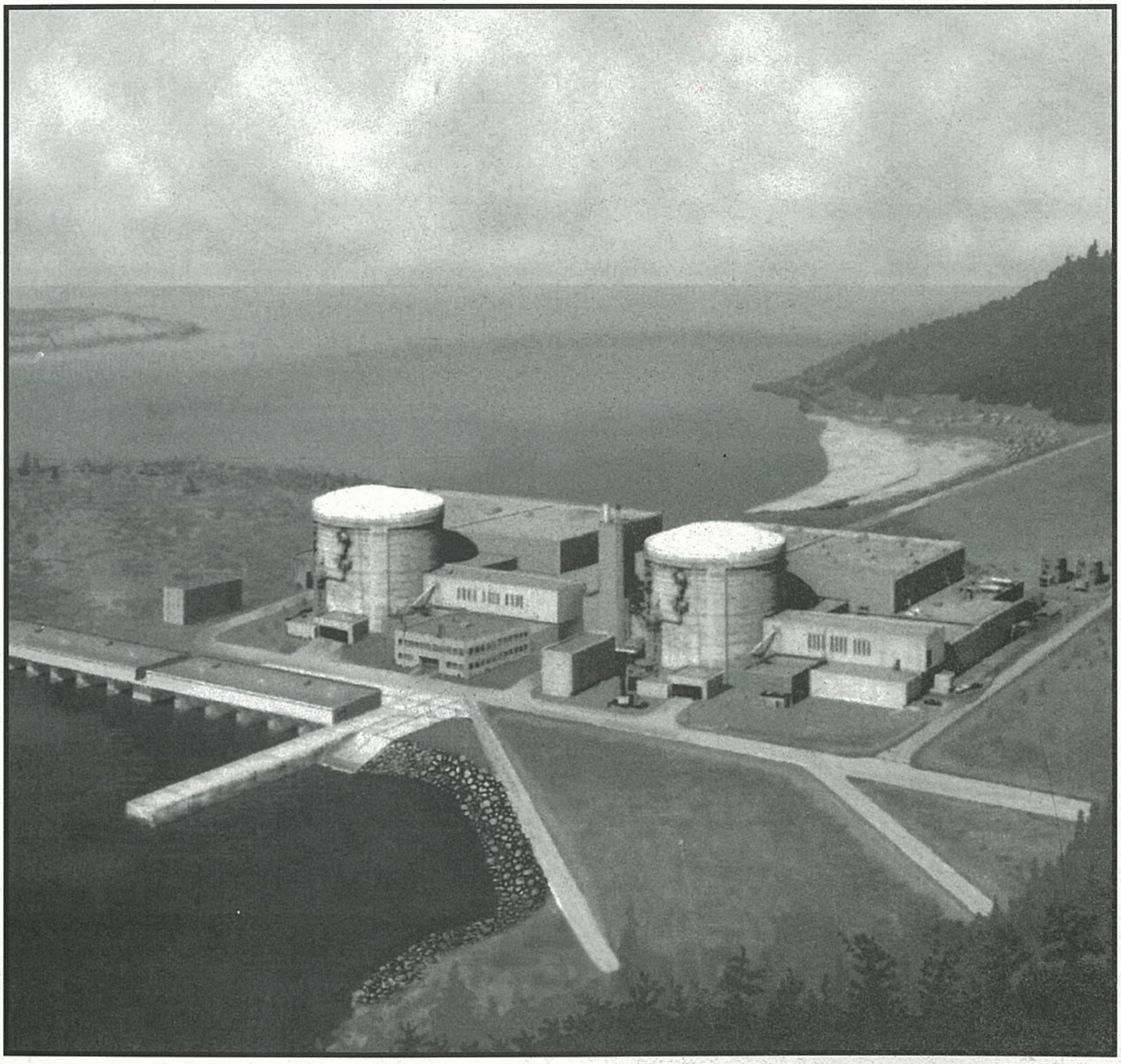

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Cover Illustration

The illustration on the cover is an artist's rendition of the Qinshan III site in China with two CANDU 6 units.

(Photo courtesy of AECL)

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La SNC procure aux Canadiens intéressés à l'énergie nucléaire un forum où ilf peuvent participer à des discussions de nature technique. Pour tous renseignements concerant les inscriptions, veuillez bein entrer en contact avec le bureau de la SNC, les membres du Counseil ou les responsables locaux. La cotisation annuelle est de 60.00$, 35.00$ pour les retaités, et 20.00$ pour les étudiants.

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EDITORIAL

ACTIVE BUT NOT POPULAR

The past few months have been very active ones for the Canadian nuclear community (as reflected in the reports and articles in this issue of the *CNS Bulletin*).

The 5th International Conference on Simulation Methods in Nuclear Engineering was held successfully in Montreal in early September, despite labour problems at the venue hotel. The marvellous International Conference on Deep Geological Disposal of Radioactive Waste drew 300 delegates from 19 countries to Winnipeg later that month for a gathering that was widely acclaimed. Also in September, representatives of the Canadian Nuclear society prepared a brief and appeared before the parliamentary committee reviewing Bill C-23, the proposed nev Nuclear Safety and Control Act.

In October, a significant Canadian delegation attended the 10th Pacific Basin Nuclear Conference in Japan to continue to tell that part of the world the Canadian nuclear story (and to remind delegates that the 11th PBNC meeting would be held in Canada, at Banff, in May 1998). In November, CNS representatives presented a further brief to the Environmental Assessment Review Panel studying the deep geologic disposal concept. Finally, near the end of November the CNS ran a CANDU Reactor Safety Course that drew more than 90 participants.

However, the most notable event occurred abroad - the signing, in late November, of the contract to supply two CANDU units to China. Sadly, that event, which should have drawn praise and applause was, instead, criticized from some quarters - by anti-nuclear groups as expected but also in the columns of a supposedly business-oriented national paper.

The misperceptions and deliberate misinterpretations of things nuclear by various sectors of the public seems to continue and even proliferate. Reference continues to be made to the "tens of thousands" killed by the Chernobyl accident despite extensive international studies and analyses showing otherwise. Waste disposal continues to be described as an unsolved (and. to some, an unsolvable) problem even though conferences, such as that in Winnipeg, give evidence of sound technical solutions.

It would appear that most of the "baby boomers" will never embrace things nuclear. Let us accept that and make efforts to reach the young generation, through talks at schools, support of science fairs, more Deep River Academies, and other means. (How about a WEB interactive nuclear "game" ?) If given the facts the generation that is still young will recognize that nuclear science and technology is truly beneficial.

IN THIS ISSUE

This issue of the CNS Bulletin begins in a somewhat unusual way with what is essentially a news item - the signing of the contract to construct two CANDU units in China. To accompany that, and to provide some background to that important event, we have an article on the **Chinese Nuclear Program** drawn from a talk given by **Dr. Li Yuhan** of the China National Nuclear Corporation at the 10th Pacific Basin Nuclear Conference.

Then follows reports and papers from two successful conferences this fall. First there is a report on the **International Conference on Deep Geological Disposal of Radioactive Waste** held in Winnipeg in September, and two Canadian papers from that conference - one by **Bob Morrison et al** on the **Policy Framework for Radioactive Waste Disposal,** and the other by **Colin Allan and Keith Nuttall** on the **Canadian Program for Geological Disposal of Nuclear Fuel Waste.**

The other meeting report is on the **5th International Conference on Simulation Methods in Nuclear Engineering,** which is accompanied by selected **Abstracts** of some of the deeply technical papers presented at that conference.

Next is a review of one of the key technologies that has been developed to keep CANDU plants operating, in the paper **Five Years of SLAR Implementation in the CANDU Community** by **John Gierlach.**

As further background to the report in the last issue of the CNS Bulletin on the MAPLE reactors to be built by Nordion International at the Chalk River Laboratories for isotope production, there is an excellent review by **Bob Lidstone et al** on **The Development of MAPLE Technology.**

Then, for a change of pace, there is an intriguing essay by **Keith Weaver** (of crossword puzzle fame) on **Problems and Solutions.** (We would be interested in your comments about the desirability of "non-technical" articles such as this.)

There is a section on "General News", including, sadly, several **Obituaries** of notable colleagues no longer with us.

And, of course, there is the section on **CNS News** with brief reports of some of the many activities of your Society.

Finally, we note some recent **books** of possible interest, provide the usual up-dated **calendar** and the inimitable **Darker Side** on the back page.

We hope that you enjoy this issue and that you will greet the coming year with optimism.

Your comments and your suggestions for papers or articles are always welcome.

DEADLINE

The deadline for the next issue, which will be published about the end of February, will be **February 3, 1997**

China CANDU Deal Signed

On November 26 Reid Morden, president of Atomic Energy of Canada Limited and Jiang Xinxiong, president of the China National Nuclear Corporation, signed a contract of sale for two CANDU 6 units to be built in Qinshan about 125 kilometres south of Shanghai. Both Prime Minister Jean Chrétien and China's Premier Li Peng were present for the ceremony. The intense negotiations leading up to the contract began with a country to country Memorandum of Understanding signed in October 1995 during the visit of Premier Li to Canada.

The total value of the two unit station is about $4 billion with the Canadian scope amounting to about $1.5 billion. This has been financed through the Export Development Corporation (EDC) with an interest rate set at the 7.49 %, the consensus rate of the Organization of Economic Cooperation and Development. China has an excellent record of repayment of its Canadian loans for export sales. In addition AECL has entered into a heavy water lease agreement which will bring about $450 million over 15 years. No financing is involved.

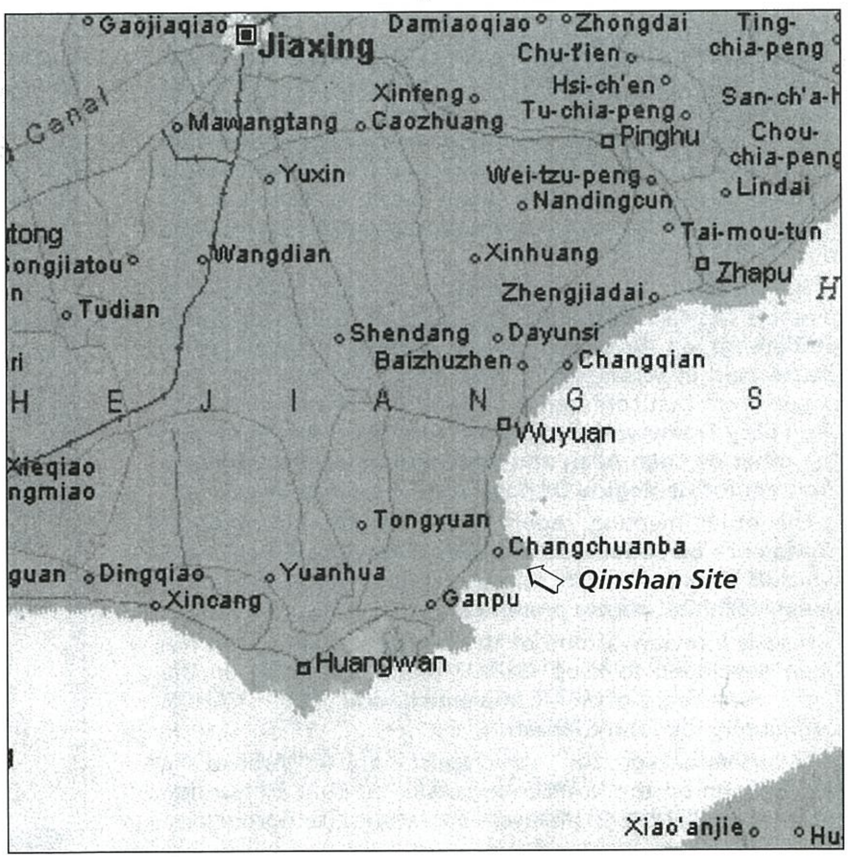
AECL's partners include Bechtel of USA and Hitachi of Japan who will be responsible for the balance of plant and turbine generator respectively. Canatom will be involved in the design. Among the major components to be supplied from Canada are the calandrias and some of the steam generators which will be designed by Babcock and Wilcox Canada.

The Qinshan III site for the two CANDUs can accommodate two further CANDU 6 units. One 300 MW Chinese designed plant has been built nearby (Qinshan I) and two 600 MW PWRs, also basically Chinese, are under construction (Qinshan II).

The CANDU plants for China will be essentially the same as Wolsong 3 and 4, with some changes to match the site and a limited number of improvements. Some of the site related factors are the need to design for typhoons of up to 400 km/hr, 33 degree cooling water (sea water), and a design earthquake of 0.15 g. The information display (which will be in Chinese) will be improved, a steel lining will be installed in the spent fuel bay and the plant is to be designed for a 40 year life. A 72 month schedule is planned for the project with 54 months for actual construction. Subject to government approval construction is expected to begin early in 1997.

For background on China's nuclear program see the paper elsewhere in this issue by Dr. Li Yuhan, vice-president of the China National Nuclear Corporation.

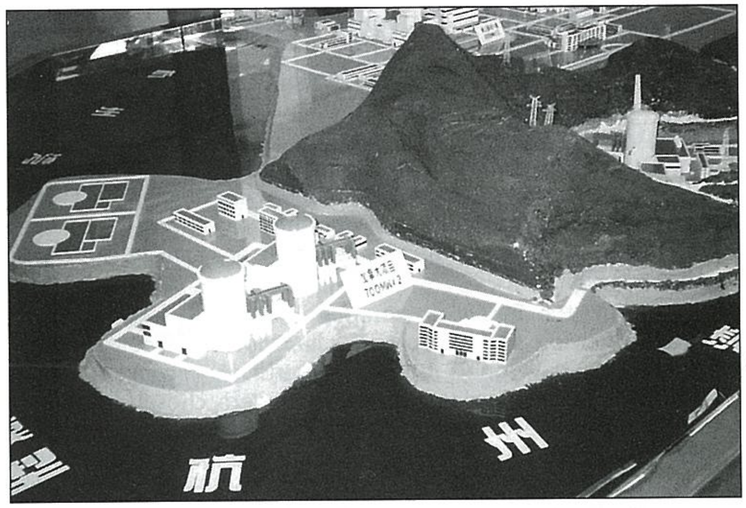
View of the Qinshan III site.



China's Future Power Demand

The Role of Nuclear Energy

Ed. Note: *In the context of AECL's Qinshan project readers of the CNS Bulletin may be interested in the overview of China's nuclear power program given at the 10th Pacific Basin Nuclear Conference in Japan, October 1, 1996.*



Photograph of model of Qinshan area in China. Qinshan III site with two CANDU units is in the foreground. At the back right and centre are sites Qinshan I and II with one 300 MW and two 600 MW units respectively.

1. Electric Power Demand and Energy Resource Structure

The past several 5-year plans have seen rapid progress in China's electric power industry. By the end of 1995, the mainland of China, the national installed capacity reached 210GW, with the annual generated electricity of 990,000GWH. Both figures rank fourth place in the world. But the level of 0.165KW per capita is only one third of the world average and failed to meet the demands of national economic development and improvements in living standards.

Towards the end of the current (Ninth) 5-Year Plan, i.e. by the year of 2000, the installed capacity is expected to reach 290GW, with the annual generated electricity up to 1,400,000GWH. By 2010, the installed capacity is expected to reach 590GW, with the generated electricity of 2,750,000GWH; by 2020, 800GW and 3,500,000GWH respectively, according to the experts' estimation. The installed capacity per capita is planned to reach 0.5kw by 2020, which is roughly the current international average. These figures show China's substantial demand for electric power.

However, in terms of the national geography, economically-developed regions are short of energy resource. 80% of the coal is concentrated in the northwest and 70% of the hydro resource is located in the southwest, whereas, the heavy populated and economically developed areas are in the east and southeastern coastal regions.

2. Nuclear Power

Chinese government has long attached importance to the development of electric power industry. ***The Outline for the PRC Ninth Five-year Plan for National Economic and Social Development and Long-term Goal for the Year of 2010*** stipulates the principle of adapting to regional characteristics, combining hydropower and fossil fuel power, developing nuclear power to certain extent. Based on the national energy resource characteristics, China's electric power industry focuses on coal-fueled power supply, with vigorous development of hydro power. However, the national coal production and hydro resource capacity lag in meeting the power demand. Experts estimate the gap to be 20GW by year 2010.

The economically developed east coastal areas are affected by the serious power supply and demand conflict, which caused the transport of coal from west to east and north to south. Besides the impact on the environment, the long distance transportation of coal to the coastal region takes 48% of the railway transportation capacity and 25% of the motorway transportation capacity. The good safety record and economics of the Qinshan and Daya Bay nuclear power plants in the coastal region prove nuclear power to be the ideal option to supplement coal fueled power and hydraulic power. Vigorous optimization of energy supply structure and promotion of nuclear power development will ease the transportation stress and reduce air pollution by controlling the discharge of CO_2.

3. The Ninth 5-Year Nuclear Power Plan

The development of nuclear power is seen as a necessity. During the ninth 5-year plan period, four

by Dr. Li Yulun
Vice President, China National Nuclear Corporation

NPPs, consisting of eight units, of installed capacity of 6620 MW will be constructed. Qinshan II NPP with 2x600 MW PWR units is being constructed on the principle of "self-reliance as the dominant factor combined with international cooperation". June, 1996 saw the pour of the first concrete for unit 1, which is to enter into grid in the year 2002. Lingao nuclear power project is 2x900 MW PWR units. The main equipment is supplied from abroad on the contracts signed. The first concrete pour is scheduled for May next year and the first unit is to enter into grid in year 2003.

It is planned to construct two 720MW (pressurized heavy water reactor) units for Qinshan III project. At present, the final contract negotiations are under way. Two 1000MW PWR units are under discussion with the foreign suppliers. All the above-said nuclear power units are to be put into operation early next century. By then, the total installed nuclear capacity will reach 8860MW.

To fill up the 20GW power pupply gap by year 2010, the option of developing nuclear power in the economically-developed region is extensively recognized. Some new nuclear power sites were chosen and the preliminary feasibility studies were reviewed. Sites including Haiyang of Shandong, Lianyungang of Jiangsu, Sanmen of Zhejiang, Hui'an of Fujian, Yangijang of Guangdong and Pengze of Jiangxi have the total planned capacity of 24GW to 28GW. The installed capacity of the first projects, if completed by the year of 2010, will be 12GW. By that time, the nuclear power installed capacity will reach 20.86GW, accounting for 3.5% of the total national installed capacity of electric power.

The nuclear power installed capacity is planned to be 40-50 GW by the year of 2020, accounting for approximately 6% of the total installed capacity.

4. The Characteristics of Nuclear Power Development in China

In mainland of China nuclear power plant construction started late but is developing steadily. Even the disastrous accident in Chernobyl did not deter China's determination to develop nuclear power. The technically proven PWR has been adopted as the main stream reactor type and embodies the basic technology route for the development of nuclear power in China.

Qinshan Phase I Project, which was completed and put into operation in the early 90's, is a self-designed and self-built PWR. Daya Bay NPP, with 2 units, was an imported PWR type. Both reflect the characteristics of NPP construction in China in the starting stage, i.e. the combination of self-reliant design and construction with the introduction of foreign technology and equipment.

The start of the construction of Qinshan Phase II in June, this year, indicates that the NPPs with self-reliant design and construction meet the international practice of engineering technology. As a developing country, the difficulty in developing nuclear power in China lies in the lack of technology reserve and construction finance. Sometimes the financing factor works as a decisive one. It is this factor that underlies another characteristic for the current development of nuclear power in China, i.e. the diversity of financing determines the diversity of nuclear power technology. Case in point is the PHWR imported from Canada and the PWR type from Russia.

We think this phenomenon is only temporary as a result of the insufficient funding to satisfy the demand of construction of nuclear power plants. In the long run, over-diversification of technologies is not favorable technically, nor economically. We believe that, with the strengthening finance and maturing market economy, this temporary phenomenon will be surely changed. Following the current trend of the international nuclear power program, Chinese nuclear power sector is facing the important task deciding its future technology policy.

Since the starting point of the development of nuclear power, China has adhered to the principle of "safety first and quality first" and laid emphasis on the pomotion of economic benefits. The good operation record and the results from the close observation of their effect on the surrounding environment of the three units in operation show that the safety of nuclear power plants can be guaranteed and the economic benefit is sound.

Since the development of nuclear power in China started late, the nuclear power plants to be constructed in the Ninth Five-Year Plan period adopted the current generation of reactors and will be operated for a life-time by next century. At this time, western countries are planning to construct a new generation of NPP for the next century. This forces us to face the crossroads of the technology regeneration as soon as China steps into the development stage of nuclear power. Under this circumstance, it is the task for Chinese nuclear power professionals to offer technology that is more safe, reliable and economically beneficial.

5. The Basic Principles for the Large-Scale Development of Nuclear Power

In the Outline of the Ninth Five-Year Plan and Long-Term Goal for the Year 2010 for National Economic and Social Development, the policy has been decided for the peaceful use of nuclear energy – **"vigorously promoting the peaceful uses of nuclear technology with the emphasis on the development of nuclear power and the corresponding construction of the system of nuclear fuel cycle"**. In addition, the public acceptance environment in China is good. All these conditions serve as good foundation for the development of nuclear power in China.

However, several basic conditions are to be met for the development of nuclear power.

1. **Economical competitiveness**
   The development of China's national economy is currently undergoing the shift from planned economy to market economy. The development of nuclear power will certainly be involved in the intense competition in the energy market. Only when the specific investment and nuclear power generation cost provide profit to the investors and can be affordable to the untilties, can nuclear power be accepted. Therefore, the economical competitiveness of nuclear power is the key factor for its development.

2. **Parallel Development of Nuclear Fuel Cycle System**
   Since the nuclear fuel for nuclear power will be mainly provided by domestic suppliers, the system for nuclear fuel cycle should be correspondingly developed to ensure the stable supply of nuclear fuel in the long run.

3. **Self-reliant design and equipment localization**
   Self-reliant design and equipment localization is the way we must follow in order to bring down the specific investment. However, if the necessary investment on building up the foundation of the equipment localization were to born by utilities, the nuclear power price would be unacceptable by utilities. A reasonable solution is needed for the localization cost. The related aspects of localization, such as standardization and reactor type selection must be addressed with definite principle.

4. **China's URD**
   The task on top of the agenda of nuclear power development in China is to join the efforts of state administrative agencies, energy circle and utilities and work out our own URD. It will set out the requirements for the safety, economicalness, protection and investment, as well as the basic requirement for the design, construction, operation and maintenance of NPPs. Thus, definite rules and requirements are set forth for next generation nuclear power development. In a way, this is a kind of "captial construction" for nuclear power development, I think.

6. China's Vigorous Follow-up on Fusion Energy Utilization

At present, research on nuclear fusion has been conducted as energy project for development. It is generally regarded that fusion energy will finally solve the world energy problem. Magnetic controlled fusion of tritium and deuterium is a promising large-scale power supply for industries. The great accomplishment in 1990s shows that nuclear fusion research has shifted from scientific basic research to engineering technical feasibility study. It is less than 50 years that great success has been made since the concept of TOKAMAK device came into being. It is estimated that within 50-60 years, commercial fusion reactor will exist in the world.

As we step into the 21st century, we can foresee this prospect in the middle of the new century. The world nuclear professional circle should give consideration to the long-term nuclear energy development strategy and modify the current fission power development program accordingly.

As a developing country with limited funding, China started its research on magnetic controlled nuclear fusion in 1958. Up till now, more than ten small-scale and medium-scale research facilities have been set up. Recently, the international advanced experimental outcome for similar devices was achieved on China's HL-1M (TOKAMAK device), which encourages us to keep up-dated of international fusion research trends. The HL-2A (TOKAMAK device) is planned. We expect to raise the research level on it and make our contribution to nuclear fusion development and utilization.

Summary

1. Nuclear power enjoys a sound basis in the mainland of China and is expected to undergo a greater development in the next century.
2. Facing a period of regeneration, nuclear power development stands at a cross road of choice, with two essential factors -technological decision as basis and financing capability as the key.
3. The final solution to the environment protection and energy resource demand lies in the utilization of nuclear fusion.

CNA Awards

The Canadian Nuclear Association is seeking nominations for its 1997 awards:

W.B. Lewis Medal

awarded for outstanding scientific or technical achievements in the Canadian nuclear industry.

Ian McRae Award

awarded for outstanding, lifetime, contribution other than scientific to the Canadian nuclear industry.

Outstanding Achievement Award(s)

awarded for significant technical or non-technical achievement in, or contribution to, the Canadian nuclear industry.

For more information contact Colin Hunt at the CNA offices in Toronto;
Tel: 416-977-6152 ext. 24; Fax: 416-979-8356;
e-mail: huntc@cna.ca

Deep Geological Disposal Conference

Close to 300 experts from 19 countries converged on Winnipeg, September 16 to 19 for an International Conference on the Deep Geological Disposal of Radioactive Waste. Almost two thirds of the delegates were from outside Canada, making it a truly international event.

The stated objective of the conference was to provide a global focus on current research and implementation strategies for the deep geological disposal concept, and to exchange ideas and contribute to a shared body of knowledge on the subject.

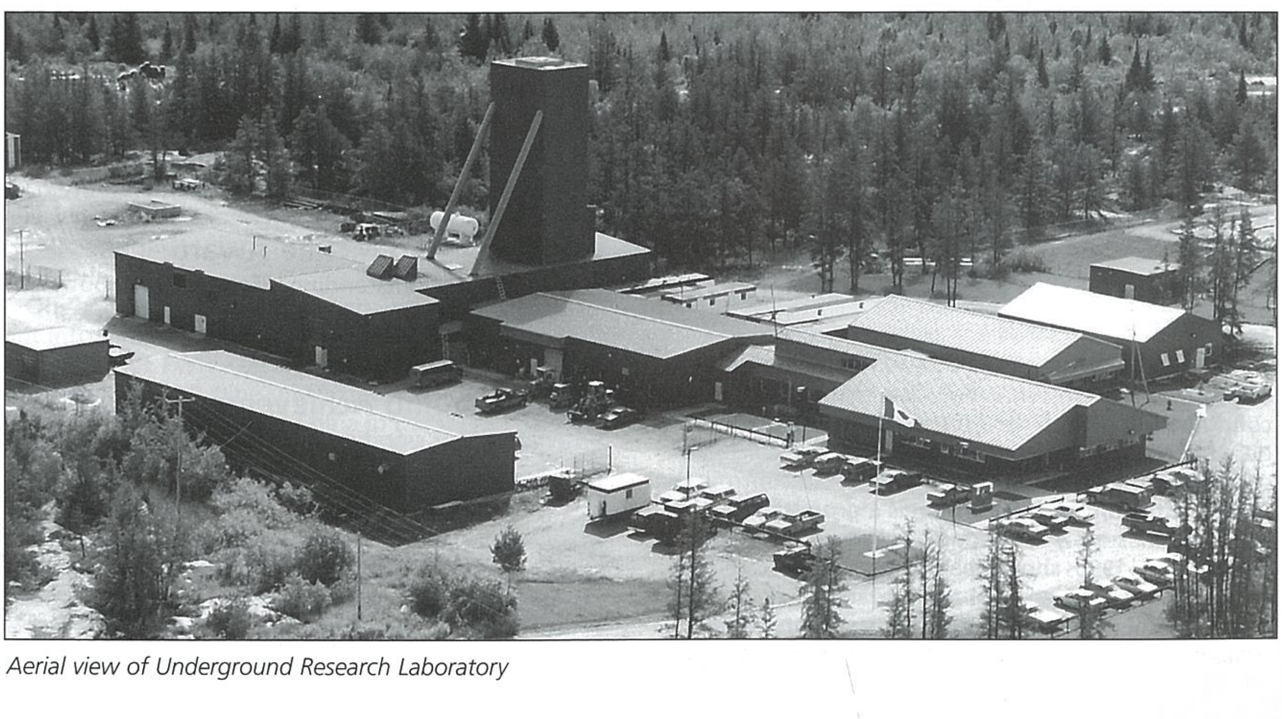
"Deep geological disposal" refers to disposal methods that physically separate the emplaced waste from the surface environment by a zone of undisturbed rock or sediment. There is a broad international consensus that deep geological disposal is the preferred method of waste management for long-lived radioactive waste. In 1995 the Nuclear Energy Agency (NEA) of the Organization of Economic Cooperation and Development (OECD) adopted a "collective opinion" on the Environmental and Ethical Basis of Geological Disposal which concluded that geological disposal was justified both environmentally and ethically.

The conference program included over 90 presented papers with an additional 32 displayed in a poster session (which was cleverly combined with a reception to ensure good attendance). The papers dealt with the full range of issues associated with deep geological disposal, from government policy to details of proposed container designs.

Three other smaller meetings were organized to take advantage of the gathering of world experts - a one-day workshop on Excavation Disturbed Zone (mining with minimal impact) presented by the conference organizers; a meeting of an IAEA expert group on safeguards related to underground disposal (SAGOR); and a one-day Symposium on Low Level Waste arranged by COG (CANDU Owners Group).

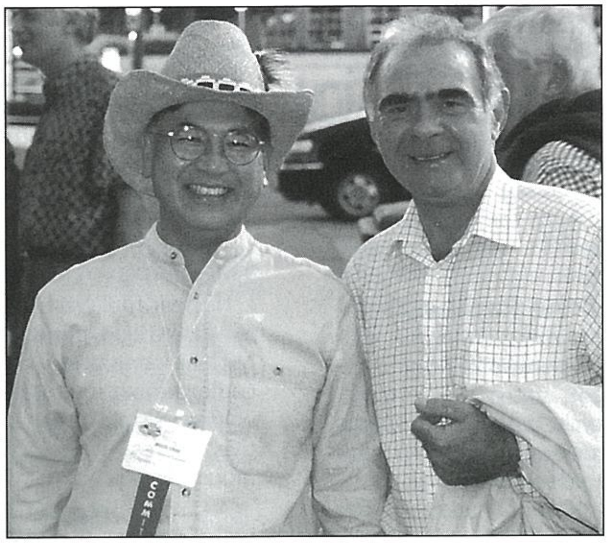
As well as the technical papers there were two sessions and a "round table" on "Social Issues and Public Consultation". Although most of the papers on this topic were from Canada a number of foreign delegates participated actively in the "round table" discussion, clearly indicating that the problem of public understanding and acceptance is universal. Unfortunately, no easy answers emerged for this difficult aspect.

The first morning and the second afternoon saw two parts of a plenary session on **International Trends in Geological Disposal** with speakers from nine countries presenting overviews of their programs for managing high level radioactive waste. The balance of the conference ran as three parallel sessions (plus the



Aerial view of Underground Research Laboratory poster session).

Dr. Bob Morrison, of Natural Resources Canada, led off the conference with a review of the background and development of the "policy framework" for radioactive waste in Canada that was announced earlier this year. (His paper is reprinted elsewhere in this issue of the *CNS Bulletin.*) **Dr. George Dials,** of the US Department of Energy provided a encouraging report on the progress at the Waste Isolation Pilot Plant (WIPP) at Carlsbad, New Mexico for the disposal of transuranic radioactive waste from the US defence program. This plant is expected to begin operation in 1998 whereas the project for civilian waste at Yucca Mountain is still mired in political arguments. Positive progress was also reported from France, the Czech Republic and Sweden.



Mitch Ohta, conference chair, and Keith Nuttall, technical program chair pose in their casual attire at the beginning of the "Rails and Trails" social evening at the International Conference on Deep Geological Disposal of Radioactive Waste in Winnipeg, September 1996.

A paper that drew considerable interest described the new company formed by the two utilities in Finland which is proceeding to implement a plan for the geological disposal of spent fuel.

A "round table" discussion session on "Social Issues in Siting" drew about 40 participants. It was moderated by Dave Hardy, who had also presented a paper earlier on lessons learned from Canadian siting exercises. There was little consensus on how to deal with the problem of gaining public acceptance except that it is necessary to keep options open and to be prepared to take a long time to communicate with and listen to the communities involved.

About 70 of the foreign delegates took advantage of a tour of AECL's Underground Research Laboratory (URL) and Whiteshell Laboratories on the Friday after the conference. URL is an excavation over 400 metres deep in a pluton of the Canadian Shield about 15 kilometres from the Whiteshell Laboratories. As well as perfecting special mining techniques to minimize damage to the rock URL is being used for extensive experiments related to rock mechanics, hydrology, thermal conductivity and other properties of interest. Work on barriers and containers as well as fundamental studies are carried on at the Whiteshell Laboratories.

The lunches and "break" refreshments were excellent as was the reception held in the area of the poster session, guaranteeing a good audience. Nevertheless, the social highlight was a "Rails and Trails" evening. That involved a ride in double decker buses out to an old station where delegates boarded a turn of the century train for a journey out into the Manitoba countryside for a dinner and country entertainment at a ranch outside the city. Included was a mock holdup during which conference chairman was "arrested" and later held in a "jail" at the ranch.

The very well organized conference was planned and implemented by a team from URL and WL under the chairmanship of Mitch Ohta, director of URL. It was sponsored by the Canadian Nuclear Society with the cosponsorship and cooperation of a number of other societies and international organizations. Some delegates commented that the conference reflected the Canadian program as being well-organized, of high quality, with attention to detail and involving international collaboration.

As well as the paper by Morrsion et al, noted above, this issue of the CNS Bulletin also contains a reprint of the paper by Colin Allan and Keith Nuttall on the Canadian program.

Delegates to the International Conference on Deep Geological Disposal of Radioactive Waste in Winnipeg, September 1996, wait to board the restored turn-of-the-century train during the "Rails and Trails" social evening.

Policy Framework for Radioactive Waste Disposal in Canada[1]

R.W. Morrison, P.A. Brown and G.A. Underdown[2]

Introduction – Scope of the Radioactive Waste Issue

Canada has a nuclear fuel cycle based on a unique reactor system, the CANDU, developed by Atomic Energy Canada Limited (AECL), which uses natural uranium in a once-through fuel cycle. Canada's nuclear power programme is sixth in the world in terms of electricity generated.

Radioactive wastes are a byproduct of the peaceful uses of nuclear energy, from mining and milling uranium ore through to fabricating uranium fuel and generating electricity. The wastes also result from producing and using radioisotopes in research, industry and medicine, and are produced in many regions of Canada. The wastes are categorized as nuclear fuel waste, low-level radioactive waste, and uranium mine and mill tailings.

At present most Canadian radioactive waste is stored safely in a manner that meets the licensing requirement of the federal regulator, the Atomic Energy Control Board (AECB) . However, there are pressures to move from storage to disposal. A number of environmental assessments are either under way or have made recommendations to the federal government to move towards a permanent solution for these wastes. Canada must now translate its technical knowledge into implementation of long-term, cost-effective solutions for its radioactive waste. The costs of disposal are high and are estimated to be in the order of $12 to $15 billion over the next 70 to 100 years. While there are many stakeholders involved in the disposal question, for economic and other considerations, it is important that a coordinated plan for disposal evolve rather than have each owner/producer develop their own solution in isolation.

Bob Morrison

Nuclear fuel waste is the spent fuel that results from generating electricity from Canadian nuclear reactors. There are 22 such nuclear reactors in Canada, operated by three utilities: Ontario Hydro, Hydro-Québec and New Brunswick Power. With 20 reactors in Ontario, Ontario Hydro is the largest producer and owner of nuclear fuel waste in Canada, and as a result, has a significant interest in disposal. In addition, small amounts of other fuel waste result from reactors used for research (including prototypes) and for the production of radioisotopes for research, medical and other industrial applications.

Nuclear fuel waste is safely stored, awaiting disposal, in water-filled pools or dry concrete canisters at the nuclear generating stations. The nuclear fuel waste could remain in storage for several decades. Its total volume is small when compared with all other radioactive wastes, and with hazardous wastes from other industries.

A disposal concept for Canada's nuclear fuel waste has been studied extensively under the Canadian Nuclear Fuel Waste Management Program, a Canada-Ontario R&D program initiated in 1978. The concept is based on a geologic repository in crystalline rock, and is generic rather than site specific. It is based on burial of the nuclear fuel waste, at depths of 500 to 1000 metres, in plutonic rock of the Canadian Shield, using a multi-barrier approach with a series of engineered and natural barriers. These include the fuel bundle waste form, container, buffer and backfill, and the host rock. As part of this program, a conceptual design of a disposal facility for used nuclear fuel and a methodology to model the post-closure, or operational, phase of such a facility has been developed.

In 1981, through the Canada-Ontario Joint Statement, the two governments announced that no disposal sites would be selected until after the concept had been accepted as safe. The deep geological disposal concept developed by Atomic Energy of Canada Limited (AECL), in collaboration with Ontario Hydro, is now undergoing a public Panel review to determine if it is safe and acceptable. In September 1994, AECL submitted the Environmental Impact Statement (EIS) on the disposal concept to the Panel. The EIS provides information requested by the Panel and presents AECL's case for the acceptability of the concept.

The Canadian Environmental Assessment Agency (CEAA) panel review, conducted under the federal *Environmental Assessment and Review Guidelines Order,* is to determine if the concept is a safe and acceptable disposal method for nuclear fuel waste. The Panel will prepare a report with recommendations on disposing of the nuclear fuel waste, to be presented to governments in 1997. It will help governments reach decisions on the acceptability of the disposal concept and on the next steps of the implementation of disposal. The federal government

[1] Paper given at the International Conference on Deep Geological Disposal of Radioactive Waste, September 1996.

[2] Natural Resources Canada.

has been the major investor in the nuclear fuel waste disposal concept and would want to see the concept implemented, if found safe and acceptable by the Panel and by governments. The 1981 Canada-Ontario Joint Statement noted that, since no disposal sites would be selected until after the concept is accepted, there was no need to identify a proponent for implementation. Once a decision has been made to implement the disposal concept, a proponent would have to be selected, a siting process agreed to and suitable disposal sites identified.

AECL has developed key skills and expertise required for implementation, for example, in site characterization and performance assessment. It would be beneficial to make effective use of these and other skills and expertise in implementing the disposal concept.

Low-level radioactive waste is all other waste, including intermediate-level and decommissioning waste, from the application of nuclear energy. The waste is generally classified as either historic waste or ongoing waste. Historic low-level radioactive waste is waste for which the producer or owner no longer exists, or cannot be made to pay for disposal. This waste generally consists of contaminated soils. Ongoing waste is non-fuel waste currently being produced from Canada's nuclear reactors, nuclear fuel processing and fabrication facilities, and from medical, research and industrial uses of radioisotopes. Decommissioning waste results when nuclear facilities are dismantled at the end of their operational life.

In the next few years, the federal government will make critical decisions on siting and disposing of the historic waste in Canada. The Siting Task Force on Low-Level Radioactive Waste Management reported to the federal Minister of Natural Resources in November 1995 that it had successfully identified a volunteer community willing to host a facility for the disposal of historic low level radioactive waste now located in the Ontario communities of Clarington, Port Hope, Hope Township, and Scarborough. The report followed a referendum in the Town of Deep River in which 72.4 percent of the voters supported an offer to host the low level radioactive waste in exchange for a compensation package and community input into the construction and operation of the facility. The federal government has until December 31, 1996, to accept the municipality's offer, and must now turn the Community Agreement-in-Principle into a legal contract. Meanwhile, in Surrey, British Columbia, another Task Force has also reported to the Minister on progress in finding a disposal site for a smaller quantity of historic waste in that Province.

One or more disposal facilities may be required for low-level radioactive waste arising from ongoing operational activities, and major waste producers are working toward solutions. Ontario Hydro has outlined options either to develop an independent Ontario Hydro facility, which could be collocated with the nuclear fuel waste disposal facility, or to work in cooperation with other waste producers to develop a multi-user disposal facility. AECL has developed a below-ground concrete vault known as IRUS (Intrusion-Resistant Underground Structure) for relatively short-lived waste. The Low-Level Radioactive Waste Management Office (LLRWMO) is the agent of the federal government to resolve historic waste problems and to establish, as required, a user-pay service for disposing of ongoing low-level radioactive waste. It has examined the requirements of licensed producers of small volumes of radioactive waste and determined that, based on volumes and the economies of scale involved, there is a need for a national user-pay disposal facility.

Major waste producers have ongoing R& D programs to support their own low-level radioactive waste disposal requirements. Research programs are carried out under the CANDU Owners Group (COG). Canadian utilities and AECL are partners in this effort. Work is planned for developing procedures to characterize the many types of low-level radioactive waste to ensure conformance to disposal requirements.

To dispose of ongoing low-level radioactive waste, the producers and owners need to identify suitable sites, design the disposal facility in accordance with site requirements, and submit their disposal plans for all required approvals before building and operating the disposal facility. The nature of any implementing agencies, and the role of the producers and owners as proponents, must be addressed within the context of the policy framework.

Uranium mine and mill tailings are a specific type of low-level radioactive waste generated during the mining and milling of uranium ore for the production of uranium concentrate used to produce the fuel for both domestic and foreign nuclear reactors for generating electricity. These wastes are generally held in containment areas close to the mine sites. Because of their large volumes, the tailings are usually decommissioned where they are deposited, typically in tailings ponds. As with other wastes, the producer or owner is responsible for decommissioning activities, which usually require CEAA public reviews.

For the first time in Canada, a CEAA Panel carried out a public review of the decommissioning plans for the uranium tailings management areas located in the Elliot Lake region of Northern Ontario. The public hearings began in late 1995, ended in January 1996, and the Panel submitted its report in June 1996. The decommissioning plans presented by the mining companies were approved by the Panel, with minor modifications. Assuming government accepts the panel's recommendations, and the AECB gives its approval to implement the plans, the companies can proceed to complete decommissioning activities.

In a few cases in Canada, in the past, producers have abandoned uranium tailings sites and governments are now considering bringing these sites up to today's environmental standards. Discussions are under way between the federal government and the provinces to reach an agreement on their respective responsibilities. A milestone was reached in January 1996 when the government of Canada entered into an agreement with Ontario on cost sharing of decommissioning activities, in the case of abondoned uranium mine tailings. In 1995, the AECB passed regulations which required that uranium mine companies provide financial assurances for these decommisioning activities at the beginning of mining operations.

Federal Government Responsibilities

Canada is a federation of ten Provinces and two territories. The Federal Government has legislative authority over the development and control of nuclear energy through the *Constitution Act, 1867,* and the *1946 Atomic Energy Control Act.* It regulates nuclear energy through the Atomic Energy Control Board (AECB), which has a mission to ensure that the use of nuclear energy does not pose undue risk to health, safety, security and the environment. Its licensing system is the main mechanism for delivering this objective. Regarding the disposal of radioactive wastes, the federal government has the following responsibilities:

Ensure that a comprehensive and integrated disposal policy framework is established in Canada.

A comprehensive and integrated disposal policy framework should incorporate institutional, financial and legal frameworks that will facilitate the efficient and effective disposal of all radioactive wastes in Canada. Establishing such an overall framework involves clearly understanding the roles and responsibilities of the major stakeholders and putting in place the institutions and funding arrangements to determine who does what and who pays within the legal context.

Maintain an independent nuclear regulatory body, which has the mandate to ensure that the disposal of radioactive wastes does not pose any undue risks to workers or members of the public;

This is accomplished under the existing Atomic Energy Control Act. The Act is in the process of being updated and Bill C-23, the proposed Nuclear Safety and Control Act, is presently before the House of Commons.

Ensure that waste producers will have sufficient funds in place for disposal of their wastes;

Canada's approach to waste management and disposal follows the "Polluter Pays" principle, meaning that the producers and owners of waste should pay for disposal. Although mechanisms currently exist under AECB legislation for ensuring that the owners provide financial assurances for some wastes, these need to be expanded to include all wastes. The federal government will develop a range of acceptable mechanisms which could be considered, including a trust fund, an environmental fund managed in a manner similar to pension funds, or monies recorded in the financial statements of current waste producers and owners.

Ensure that research and development capabilities are available to support the development of disposal technologies and facilities;

A national radioactive waste management program needs an infrastructure that incorporates the R&D capabilities to develop appropriate disposal technologies and facilities. In the past, the federal government has initiated and funded the development of technologies for various radioactive wastes. The largest and most comprehensive program, started in 1978, was the Canadian Nuclear Fuel Waste Management Program. This Canada-Ontario R&D program resulted in the development of the deep geological disposal concept for nuclear fuel waste. Started as a federally funded program, it is now funded solely by the major nuclear fuel waste producer, Ontario Hydro.

For low-level radioactive waste, the federal government, through AECL, funded the development of the IRUS disposal facility for relatively short-lived waste. The federal government has also sponsored programs for disposing of uranium tailings, most notably, the National Uranium Tailings Program, a program to develop appropriate models, measurement methods and disposal technologies. Most recently, the federal government, together with the provinces and mining companies, sponsored studies under the federal Mine Environment Neutral Drainage (MEND) program, which focuses on controlling acid generation from sulphide-bearing tailings, including uranium tailings.

In the future, with the growing application of the "Polluter Pays" principle, it is anticipated that waste producers and owners will increasingly support R&D activities.

Carry out disposal activities for historic radioactive wastes that are a federal responsibility;

The federal government is responsible for safely disposing of some historic radioactive wastes. The LLRW-MO is the agent of the government with a mandate to clean up sites contaminated with historic low-level radioactive waste. The federal government has set up task forces, notably in Ontario and British Columbia, to find suitable disposal sites for some historic waste through voluntary and consultative processes with concerned communities.

The federal government also owns historic wastes, through AECL, and through the responsibility that the government has taken on for some historic uranium tailings and historic low-level radioactive waste. There is a need to reach an agreement with the provincial governments on appropriately dividing responsibilities for such tailings. A Memorandum of Agreement between the federal government and the province of Ontario outlines the respective roles and responsibilities of the two governments and provides for overall equal sharing of decommissioning and perpetual care costs of abandoned Ontario uranium mine sites.

Ensure that public environmental review processes are in place and that the results from the public consultations are factored into the establishment of disposal facilities;

The new Canadian Environmental Assessment Act fulfills this requirement through a formal public review process carried out by an independent Panel. Such reviews are required for new nuclear initiatives such as proposals for disposing of radioactive wastes. The process incorporates broad public consultation and participation through public hearings. The Panel's recommendations, following from the public review process, are made public and submitted to ministers for decisions.

Ensure that Canada contributes to the international radioactive waste management efforts;

Canada is seen as a leader in developing both the technology and the public consultation processes for radioactive waste management, and can contribute to the development of internationally recognized standards and practices. Canada actively participates in and benefits from international initiatives related to the safe management of radioactive wastes, and keeps abreast of relevant international developments.

Development of a Policy Framework for the Disposal of Radioactive Waste in Canada

Canada has many kinds of radioactive wastes that are produced by several producers and owners involved in many nuclear activities in different regions of the country. Plans and schedules for disposal activities may vary for the different waste types and need to be flexible enough to address emerging waste priorities and regional variations. Each province may have a different approach to regulation or environmental assessment. For instance, Saskatchewan will be focused on uranium mine wastes. Québec and New Brunswick will be concerned about the waste from their single CANDU reactors, while Ontario will need to address the full spectrum of radioactive wastes.

Because of the diversity of ownership and location of radioactive wastes in Canada, the policy framework needs to ensure that all radioactive wastes have a producer or an owner to fulfill waste management responsibilities. These responsibilities would include managing the wastes in storage and preparing for disposal by developing plans, identifying disposal sites, acting as the proponent, submitting to public environmental reviews, making licence applications, obtaining necessary approvals and operating the disposal facility. Arrangements must also be in place to facilitate the transfer of responsibilities from one organization to another, where this is required, such as from a producer organization to an implementing agency.

Selecting sites for radioactive waste disposal facilities would generally be carried out in keeping with the principles of safety and environmental protection, voluntary participation, shared decision making, openness and fairness.

At any one time, there is likely to be a need for only a few radioactive waste disposal facilities. The exception, of course, is uranium tailings where the number is dictated by the number of uranium mines operating or undergoing decommissioning. For nuclear fuel waste, it is unlikely that more than one disposal facility will be required at any time in Canada. For low-level radioactive waste, very few sites are expected to be in operation, and each will most likely be dedicated to a particular waste type. For example, short-lived waste could go into an intrusion resistant underground structure (IRUS) type facility, utility-generated wastes could be disposed of at a disposal facility with utility-specific requirements, while the large volumes of historic low-level radioactive waste would need to be accommodated in another type of facility. Integration of these facilities at one site would provide for a comprehensive, cost-effective, approach to disposal.

Each waste disposal facility could have several customers from different regions of Canada. It is important that these customers have access to the facilities as needed, at a cost that encourages them to dispose of their waste. For nuclear fuel waste, the producers, mainly the nuclear utilities, will pay for disposal. The federal government is also an owner of fuel waste through AECL. A variety of options could be envisaged for organizing and financing nuclear fuel waste disposal.

For ongoing low-level radioactive waste, some larger producers might want to manage their own waste through to disposal. They might make their facility available to other smaller producers or owners, by incorporating them into the management and financial structure of the operation, or by charging an appropriate disposal fee. Some smaller producers may wish to organize separate facilities specific to their own needs. In each case the producers would pay for disposal. The number and location of facilities would depend on several factors, including safety and cost-effectiveness. A trade-off for low-level radioactive wastes is the cost and risk of transporting them, balanced against the economies of scale of larger, centralized facilities.

As long as producers were properly organized and funded to achieve federal objectives for disposal, the federal government would likely not need to be part of a producer's organization. However, the producers might ask for federal government support in developing a national facility, or in ensuring access and fair pricing for all producers. The LLRWMO could establish a national user-pay facility, if one is required.

For historic low-level radioactive waste resulting from nuclear activities, the federal government has accepted ownership and responsibility for their disposal. In some cases, provinces have agreed to accept responsibility for, or assist with, interim storage. The LLRWMO has been the federal agent for cleaning up and storing such waste. Now that the Siting task Force in Ontario has identified a community willing to host a disposal facility for these wastes, the federal government will have to identify an agent, similar to the LLRWMO, to implement the disposal of historic low-level radioactive waste for which it is responsible. The agent would work closely with the relevant province and with the communities involved.

Uranium tailings are likely to be managed in situ at mine sites and the producer would take on responsibility for decommissioning in compliance with AECB licence conditions. There would appear to be little need, in most cases, for broader organizations to carry out this function.

For historic uranium tailings, it is also likely that they would be managed in situ. The federal government needs to reach an agreement with the provincial governments on appropriately dividing responsibilities for such tailings. A Memorandom of Agreement between the federal government and the province of Ontario outlines the respective roles and responsibilities of the two governments and provides for overall equal sharing of decommissioning and perpetual care costs of abandoned Ontario uranium mine sites.

Elements of a Comprehensive Radioactive Waste Policy Framework

The elements of a comprehensive radioactive waste policy framework consist of a set of principles governing the institutional and financial arrangements for disposal of radioactive waste by waste producers and owners, which are acceptable to the federal government. The principles will guide the implementation of radioactive waste disposal in Canada, in a safe, comprehensive, cost-effective, and integrated manner.

It is the federal policy role to determine the broad range of financial and institutional arrangements, for disposal of all wastes, which are acceptable to the federal government. The regulatory role is to enforce regulatory requirements for safe disposal and to ensure financial guarantees are in place within the broad range of arrangements acceptable to the federal government to carry out disposal and to meet these requirements.

The principles address the main institutional and financial issues. They stress that the federal government should ensure that the disposal of radioactive wastes takes place in a safe, comprehensive, integrated manner. They identify the roles and responsibilities of the federal government and the waste producers and owners. They reinforce the importance, to the federal government, of putting in place a financial framework with the mechanisms to ensure that the funds are available to pay for the disposal of radioactive wastes, when disposal needs to take place. They also indicate specific directions and rule out others. The policy framework puts the onus on the owners of the wastes. It allows variations in approach for the different waste types. It limits government operational management to situations where it is the owner of the waste.

Principle #1: The federal government will ensure that radioactive waste disposal is carried out in a safe, environmentally sound, comprehensive, cost-effective, and integrated manner.

This addresses the fundamental jurisdictional responsibility of the federal government. The federal government needs to bring stakeholders together to ensure that radioactive waste disposal takes place and that it takes place in a safe, environmentally sound, comprehensive, cost-effective, and integrated manner.

Principle #2: The federal government has the responsibility to develop policy, to regulate, and to oversee producers and owners to ensure they comply with legal requirements, and meet their funding and operational responsibilities in accordance with approved waste disposal plans.

The policy role for the management and disposal of radioactive wastes lies with the federal government consistent with its responsibility for promoting the orderly development of nuclear energy in Canada. This would entail the development, and ongoing review, of the institutional and financial arrangements that are put in place to confirm that they meet the intent of the principles of the policy framework in an equitable and efficient manner.

The federal regulatory and oversight role is needed to ensure that radioactive waste disposal takes place in a safe, sustainable, equitable, and efficient manner. This will require that waste producers and owners: develop waste disposal plans; submit their plans to the federal regulator for assessment and approval according to health, safety, and environmental criteria; submit their plans to the federal government for assessment and approval according to equity and efficiency criteria; fully fund waste disposal plans; submit evidence of financial security for waste disposal in accordance with these plans; allow that inspections and audits be carried out to confirm that waste disposal plans are being implemented and funding is being allocated.

Principle #3: The waste producers and owners are responsible, in accordance with the principle of "polluter pays", for the funding, organization, management and operation of disposal and other facilities required for their wastes, recognizing that arrangements may be different for nuclear fuel waste, low-level radioactive waste and uranium mine and mill tailings.

Waste producers and owners need to meet the requirements of federal regulation and oversight for planning, funding and implementing waste disposal in a safe, comprehensive and integrated manner. Institutional and financial arrangements may be different for nuclear fuel waste, low-level radioactive waste and uranium mine and mill tailings. Clearly, specific arrangements, organizations and financing for each waste type will be defined through negotiations with relevant stakeholders.

Implications

The Policy Framework sets the stage for Canada to translate its technical knowledge into implementation of long-term, cost-effective solutions for its radioactive wastes, while ensuring that funding arrangements are in place to meet the financial requirements of future solutions. The federal government recognises its important role in making the transition to long-term solutions for used fuel, low-level radioactive wastes, and uranium mine and mill tailings. In addition to providing policy direction, Natural Resources Canada will work towards establishing an agreement among the major stakeholders on their respective roles and responsibilities and the approaches and plans for implementing solutions.

With regard to used fuel disposal, the Policy Framework provides a clear indication to the CEAA Panel presently conducting the public review of the concept of disposal of used nuclear fuel, that the government is committed to addressing this issue. The Policy Framework does not prejudge the recommendations of the Panel, to be submitted to governments in 1997. Rather, it emphasises the importance that the federal government places in the Panels views, and that it is putting in place mechanisms to implement their recommendations, should the Panel find that the central concept is viable and recommends proceeding to the siting phase. The federal government is looking forward to those recommendations and, with the Radioactive Waste Policy Framework in place, is signalling its clear intent to respond to them.

With regard to low level radioactive waste, the July 4, 1996, announcement by the federal government to determine if a disposal facility for historic low-level radioactive wastes could be sited at Deep River, Ontario, is in keeping with the principles of the Policy Framework. This responds to the recommendations of the independent Siting Task Force on low level radioactive waste management in Ontario. The next step is to finalise an agreement between the federal government and the Town of Deep River on the conditions under which the Town will accept the wastes. This agreement needs to be in place prior to December 31, 1996. Once the agreement is in place, work can begin on the assessment work necessary to determine if a licensable facility can be constructed at the Deep River site. It is expected that this will take about 4 years to complete. The wastes, which are presently located in the communities of Clarington, Port Hope, Hope Township, and Scarborough in Southern Ontario will not be moved until such time as a facility has been constructed for their disposal.

Work will also begin in order to determine if co-disposal of other low level radioactive wastes could take place at Deep River. In particular, other low level waste producers such as Ontario Hydro, Cameco, and AECL, may wish to utilise the disposal facility, provided one is constructed. These producers would require to enter into an agreement with the town to determine the conditions under which the town will accept the wastes. In addition, there are existing wastes from early R&D activities at the Deep River site which could be disposed of in a cost-effective manner in such a facility.

For uranium mine and mill tailings the mining companies are clearly responsible for decommissioning. The role of governments in the long term care and maintenance needs to be determined. At present, the Uranium and Thorium Mining regulations require that the mining companies provide for the decommissioning of the mine site and the mine and mill tailings. Consultations will be initiated to determine the range of financial mechanisms acceptable to the federal government to ensure that these responsibilities are fully met.

Conclusion

The Policy Framework is an important milestone towards the goal of ensuring a safe, comprehensive, environmentally sound, integrated, and cost-effective approach to the disposal of radioactive wastes in Canada. It lays the ground rules and defines the role of government and waste producers. With the Policy Framework in place, the context is set for further development of the financial and institutional structures that will govern waste disposal.

The role of the federal government is to develop policy, to regulate, and to ensure that waste owners and producers comply with legal requirements and meet their funding and operational responsibilities in accordance with approved waste disposal plans. The waste producers and owners are responsible, in accordance with the principle of "polluter pays" for the funding, organisation, management and operation of disposal and other facilities required for their wastes. Arrangements may be different for nuclear fuel waste, low-level radioactive waste, and uranium mine and mill tailings.

Nuclear fuel waste is presently stored safely at the reactor sites. Provided the CEAA Panel finds the disposal concept to be safe and acceptable the Policy Framework provides for an organisation to be put in place to carry out the next steps and for funds to be available when required for disposal. For low-level radioactive waste, both historic and ongoing, the federal government has already taken a leadership role on this issue in announcing its intention to evaluate the suitability of a low-level radioactive waste disposal facility in Deep River, Ontario. For uranium mine and mill tailings the mining companies are responsible for both the decommissioning activities and the funding of those activities.

The Policy Framework emphasises the Government of Canada's commitment to the principles of sustainable development. Nuclear energy is an environmentally sound energy option that does not contribute to climate change. Clearly assigning the roles and responsibilities, and taking action to dispose of radioactive wastes from the entire nuclear fuel cycle, is an environmentally responsible initiative that will ensure that the costs related to nuclear activities are not simply passed from one generation to the next. Resolution of radioactive waste disposal issues will increase the attractiveness of nuclear energy and improve its contribution to Canada's efforts to achieve an energy supply that is based on the principle of sustainable development.

The Canadian Program for Geological Disposal of Nuclear Waste[1]

Colin Allan and Keith Nuttall[2]

Introduction

Canada's strategy for the management of its nuclear fuel waste is to provide interim storage of its used fuel, either in water pools, or in dry storage systems. These storage systems meet the fundamental objectives of protecting worker safety, public health and the environment, but they represent an interim solution requiring on-going institutional control. Thus in parallel we are developing the technology for the eventual disposal of nuclear fuel waste – either direct disposal of used fuel or the disposal of the high-level waste that would result if Canada should decide at some future date to reprocess its fuel – to provide a system that is passively safe, i.e., one that does not depend on institutional control for safety.

Following 18 years of development, the Canadian program has now reached a major milestone. The program is at the end of disposal concept and technology development and is now undergoing a comprehensive environmental review. This paper will review:

- the history of the Canadian program;
- the disposal concept and the associated technologies;
- the program achievements and the lessons learned; and
- the status of the environmental review.

In this way we plan to show that real and significant progress has been made in understanding the issues and requirements, and in demonstrating the safety and viability of geological disposal, and that there is a basis for confidence in moving forward.

Background and Program History

The Canadian Nuclear Fuel Waste Management Program was launched in 1978 as a joint initiative by the governments of Canada and Ontario following the recommendations of a study of options completed in 1977 [1]. As a result of public concerns over experimental drilling early in the program, a decision was made to separate technology development and demonstration from site selection [2]. Thus, selection of a nuclear fuel waste disposal site would not proceed until the technology had first been developed and reviewed. So, a generic rather than a site-specific concept has been developed. The review of the concept is currently underway. It began formally in 1988 and is expected to be completed in 1997.

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As part of the generic development, much of the technology and many of the activities that would be used in characterizing a site and designing and licensing a disposal facility have been developed and tested, including the siting, characterization, construction and operation of the Underground Research Laboratory (URL) with over 2 km of drifts and shafts. The URL has enabled large-scale in situ tests and demonstrations of excavation methodology, engineering activities, and selected elements of vault design, to be carried out. The program has also included:

- the design and testing of engineered systems and components;
- development and demonstration of methods for monitoring, characterizing and modelling the geosphere and the biosphere; and
- conceptual engineering studies of disposal systems that integrate the information from field and engineering studies. These studies have provided the basis for assessing feasibility, cost, and safety, and have been used as part of developing and demonstrating methodologies for performing pre- and postclosure environmental and safety assessments.

Public consultation and public opinion research and international collaboration have also been important components of the program.

Participants in the program have included AECL, the lead agency for research on disposal; Ontario Hydro, which has advanced the technologies for storage and transportation as well as contributing financially and technically to the R&D on disposal; Natural Resources Canada (NRCan); Environment Canada; scientists at Canadian universities; and consultants in the private sector. As well, advice and oversight have been provided by an independent Technical Advisory Committee. Members of this committee are nominated by Canada's learned societies.

[1] paper given at the International Conference on Deep Geological Disposal of Radioactive Waste.

[2] AECL, Whiteshell Laboratories

The Disposal Concept

The concept is based on disposal in plutonic rock of the Canadian Shield which extends over a large part of Canada [3, 4]. In common with other national programs, a series of engineered and natural barriers will isolate the nuclear fuel waste from the biosphere. The main elements of the concept include:

- a waste form that will resist dissolution and leaching; long-lasting containers in which the waste would be sealed, and which are designed to have a minimum lifetime of 500 years, although much longer lifetimes are possible;
- emplacing these containers in a vault excavated (nominally) 500-1000 m deep in plutonic rock of the Canadian Shield;
- separating the containers from the surrounding rock with clay-based buffer materials and using seals and backfill materials to close the various openings, tunnels, shafts and boreholes to ensure that water movement and the transport of contaminants is by the slow process of diffusion;
- and the rock mass and hydrogeological setting in which the disposal vault is located.

There is an international consensus that deep geological disposal can effectively achieve the goal of safely managing nuclear fuel waste in the long term [5, 6].

During the past 17 years, AECL has carried out detailed studies on this multiple-barrier system. The choice of materials and designs for the engineered barriers will be made taking into account the characteristics of the site being studied so that engineered barriers will be in harmony with the environmental characteristics of the site (e.g., the geochemistry and geomechanics) and the processes acting in this environment (e.g., corrosion, sorption, diffusion, advection). In this way the site environment will contribute to the longevity and effectiveness of the barriers. Such a disposal system is intended to be a permanent method of management. There would be no intention to retrieve the waste or rehandle it in the future, although retrieval would be possible. Choices could include, for example,

- the form of the waste – used-fuel bundles or solidified reprocessing waste;
- the disposal container material – titanium alloy, copper, or other durable material;
- the container design – internal particulate support or a rigid support structure;
- the composition of materials used for the buffer, backfill and seals;
- the excavation method – blasting or boring;
- the depth, geometry, and the number of levels of the vault;
- the size and shape of the excavated openings; and
- the location of the waste containers – within disposal rooms or in boreholes in the floor of the rooms.

A systems approach has been adopted for design and performance assessment. We have sought to develop a thorough scientific understanding of the performance of the different components of the system and how these components interact and influence one another, so that the overall system can be designed to provide a high degree of protection. One of the objectives during concept development has been to retain flexibility so as to be able to adapt the detailed design to the characteristics of a site, recognizing that the choice of sites is likely to be more influenced by issues of social acceptability than by technical considerations.

Achievements and Lessons Learned

Now that AECL has submitted its Environmental Impact Statement [3, 4] and the review of the program is well under way, it is timely to reflect on the achievements of the program, and the lessons learned, as well as to look forward.

Our research and development programs have provided us, we believe, with a soundly-based and scientifically defensible understanding of how the engineered barriers will perform under the conditions expected in the Canadian Shield [7, 8]. For container materials, for example, the original target was to achieve a minimum container lifetime of 500 years and early work established that this goal could be achieved with a thin-walled titanium container. Subsequent studies on the corrosion of titanium alloys and copper indicated that, for the expected groundwater chemistry, a thin-walled titanium alloy container can be designed to have a corrosion lifetime in excess of tens of thousands of years, and a 25 mm thick copper container can potentially provide containment in excess of 106 years [9, 10]. Such advances in understanding and in our ability to defend, scientifically, this understanding can have a profound impact on the approach taken to facility design and implementation, and on decision-making.

Studies of natural analogues have been an important component of our research [11]. For example, the Cigar Lake uranium deposit in northern Saskatchewan has been studied since 1984 [12, 13]. The uranium ore in the deposit has essentially the same composition as used fuel. It was formed some 1.3 billion years ago and has been in contact with groundwater since its disposition. Yet the uranium has remained stable under the reducing conditions prevailing in the deposit. Similar conditions are expected to occur in a disposal vault.

The program has provided us with an understanding of the processes governing groundwater flow on the Canadian Shield and the technology for site characterization [14]. To illustrate this understanding, AECL has developed and calibrated a large-scale groundwater flow model of the Whiteshell Research Area in southeastern Manitoba [15-18]. The model covers an area of about 500 km2 of the granitic Lac du Bonnet Batholith and adjacent gneissic terrain, and encompasses the site of the URL and AECL's Whiteshell Laboratories. Regional studies were initiated in 1980 and have included the frilling, logging, testing and long-term monitoring of fifteen deep (up to 12 m) boreholes at six detailed study areas distributed throughout the large regional area. The program has also provided the technology to characterize the geology, hydrogeology and geochemistry on a given site for use in performance assessment studies. This capability has been demonstrated in the development of the URL.

The URL, located near AECL's Whiteshell Laboratories in southeastern Manitoba, was constructed specifically to perform large-scale, in situ experiments in plutonic rock of the type expected to be suitable for disposal. It was the first such test facility in the world to be built below the water table in previously undisturbed rock. The work at the URL, and in an extensive network of boreholes surrounding it, has assisted in developing methods for characterizing the geology of actual disposal sites. Results from the surface characterization and construction phases of the URL were incorporated into the geosphere model that was used to illustrate the disposal concept in the EIS. The changes to pre-existing conditions in the rock and in the groundwater during excavation and operation of the URL continue to be monitored, and these date have been used to test and to calibrate hydrological and geological models.

The URL has a vertical access shaft that extends to a depth of 445 metres below the surface. Horizontal passageways and rooms for experiments have been constructed at depths of 240 and 420 metres. Major experiments in the URL recently completed or now in progress include [19, 20]:

1) The Buffer/Container Experiment, a full-scale simulation of borehole emplacement of a heated waste container,
2) The Mine-by Experiment, a study of the material properties and response to excavation of an intact volume of highly stressed rock,
3) The Quarried Block Radionuclide Migration Experiment, which is designed to study the transport of radionuclides in natural fractures in quarried blocks of granite under in situ groundwater conditions,
4) The Excavation Stability Study, a study of the effect of tunnel shape and direction on the stability of excavated openings in highly stressed rock,
5) The Tunnel Sealing Experiment, designed to investigate the construbability and performance of prototype concrete bulkheads and highly compacted bentonite bulkheads, and to test grouting methods and materials, and
6) Ongoing investigations of solute transport by groundwater in previously characterized zones of highly and moderately fractured rock.

One of the most notable achievements of the program has been the development of a probalistic risk assessment methodology as incorporated in the Systems Variability Analysis Code, SYVAC, for use in evaluating system performance far into the future. Two case studies have been performed on hypothetical disposal systems with characteristics based on information developed in the research program [3, 21-23]. The case studies demonstrate how postclosure assessment could be done during concept implementation. They have also produced quantitative estimates of effects for comparison with criteria, guidelines, and standards for protection of human health and the natural environment. The characteristics of the disposal vault designs have been based on conceptual engineering design studies [24, 25]. One of the conceptual engineering designs was also used for a preclosure assessment case study [26].

It is worthwhile reviewing some of the lessons learned in the development and execution of the program. One of the most important lessons is the need for and the key role of integration. The technology for geological disposal is multidisciplinary and requires expertise in a wide range of geosciences, including: structural geology, hydrogeology, geochemistry and geophysics, rock mechanics, and geotechnical engineering; in material sciences, including: expertise in corrosion sciences, metallurgy, clay and cement-based sealing materials; in the environmental sciences, including: expertise in hydrology, soil sciences, biology, atmospheric processes, radiation biology; and in performance assessment and modelling. Integrating the knowledge derived from development work in these various disciplines into practical and self-consistent designs and models of the overall system and the various sub-systems is a major challenge, one which we believe has been successfully met in the Canadian program.

We have achieved this in part by having members of the team work in close proximity to one another in multidisciplinary project teams. In this way each member of the team has an appreciation of the use to which his research is to be put and the team in general, and in particular, those with responsibility for repository design, for system modelling and for performance assessment have an understanding of the limitations of the current scientific understanding, of research results and of experimental data bases. Continuity of experience and maintenance of the knowledge base have been critical to our success.

Another lesson relates to the importance of, but also, at times, the difficulty of communicating. Communication is obviously a key requirement for effect integration, but it is equally important in building public and stakeholder understanding and confidence. There seems to be no simple formula to ensure effective communication. Rather, messages must be communicated frequently, and information must be prepared in a variety of formats around specific themes to meet the needs of those seeking the information. In the final analysis there is no substitute for face-to-face dialogue. Natural analogues appear to have a unique role in understanding and communicating the long-term performance of disposal system components and indeed the performance of the system as a whole. In addition, our experience clearly demonstrates that visits by the public to major experimental facilities such as the URL to see what a deep disposal facility might look like, to see the engineered technologies being tested and demonstrated, and to discuss these with scientists and engineers working in the program, is of immeasurable value in communicating the elements of the concept and building confidence.

Finally, the importance of international co-operation should be recognized. Such co-operation adds to the knowledge base from which all national programs draw, it contributes to the development of consensus views on such issues as ethics [6] and long-term performance assessment [5], it contributes to peer review, formal peer reviews, and perhaps more important, peer review that is inherent in collaborative programs, and it contributes to confidence building which is, in the end, fundamental to proceeding.

The Review Process

It was recognized early in the evolution of the Canadian program that the waste disposal concept needed to be both technically sound and socially acceptable. From our early efforts at public involvement we recognized that it was unlikely that public support could be obtained unless the fundamental concerns of the public were addressed. The general public, potential host communities and political leaders are important constituencies that contribute to decision-making about waste management. Therefore, identifying and understanding the issues of concern to the public have been important considerations throughout the development of the Canadian disposal concept.

As indicated above, it was decided early in the Canadian program that site-specific work would not begin until the concept and the technology for disposal had been reviewed. This review is currently underway. A formal mechanism for public involvement in the early phases of project definition is defined in Canadian environmental assessment and review legislation. This process is being used for the public review of the disposal concept. Social and ethical issues are an important element in the review.

The overall objective of the environmental assessment legislation is to ensure that environmental questions receive the same consideration as technical, economic or political considerations and that environmental issues are incorporated into projects at the planning stage, before irrevocable decisions are made. The legislation also allows those potentially affected by a project to have a say in the decision-making.

The federal Department of Energy, Mines and Resources (EMR, now Natural Resources Canada, NRCan) referred the concept for review under the Environmental Assessment and Review Process (EARP) in 1988. As the "Proponent" for this review, AECL was required to prepare an Environmental Impact Statement (EIS) describing the concept, which it submitted to the Panel in October 1994 [3, 4]. The Environmental Assessment Panel responsible for carrying out the review is an independent group appointed by the government to represent a range of Canadian viewpoints and interests. The Panel has appointed a Scientific Review Group (SRG) composed of scientists from a variety of relevant disciplines, to assist it in assessing the technical validity and acceptability of the disposal concept. The Canadian Environmental Assessment Agency (CEAA), provides administrative support.

The Panel has the responsibility to review AECL's concept, along with a broad range of nuclear fuel waste management issues. These include the criteria for determining safety and acceptability; the approaches used, and proposed, to manage nuclear fuel waste both in Canada and other countries; the potential social, economic, and environmental effects of waste disposal; and the potential impact of recycling and other processes on waste volume.

All federal departments with a relevant interest in the concept are expected to participate in the review process. These include the Atomic Energy Control Board (AECB, Canada's nuclear regulator), Natural Resources Canada, Environment Canada, Health Canada, and Transport Canada.

When the EARP review is concluded, the Panel will make recommendations as to the acceptability of the concept and the course of future action regarding nuclear fuel waste disposal. Government decisions will then follow.

In the spring of 1990, a series of "Open Houses" were held to inform interested parties, not directly connected with the nuclear industry or with the scientific review process, about how they could take part in the review. "Scoping Hearings" took place in the autumn of 1990 to identify issues of concern, and to assist the Panel in setting guidelines for the EIS. One hundred and thirty participants made presentations, including government departments, scientific and business organizations, special interest groups, and private individuals. Among the major issues raised were arguments for and against storage as compared with disposal, the adequacy of the regulatory criteria, and monitoring the performance of the disposal vault. In June 1991, the Panel used draft EIS guidelines for comment. Over thirty different groups and individuals submitted comments. The Panel issued its final EIS guidelines to AECL in March, 1992 [27].

After the submission of AECL of its EIS and a set of nine supporting Primary Reference Documents to the Panel in October 1994, a nine-month period of review followed for the public, government agencies and technical specialists to evaluate, and provide comments to the Panel on, the completeness of the EIS measured against the Panel's Terms of Reference

*The 65 written submissions by review participants on the completeness of AECL's environmental impact statement, the transcripts of scoping meetings and public hearings sessions, and other participant written submissions to the Environmental Assessment Panel are available from the Panel Secretariat, Nuclear Fuel Waste Management and Disposal Concept Review, Canadian Environmental Assessment Agency, 200 Sacré-Coeur Blvd., Hull, Quebec K9A 0H3.

and the Guidelines for the preparation of the EIS. This review period ended on 1995 August 8. Comments were received from some sixty-five groups or individuals*. After reviewing the participants' and AECL's documentation, the Panel announced its intention to proceed with public hearings and issued further details of the approach and schedule. It also asked AECL to provide additional information on issues related to long-term safety which AECL submitted to the Panel in 1996 May [28]. The public hearings are divided into three phases [29, 30]:

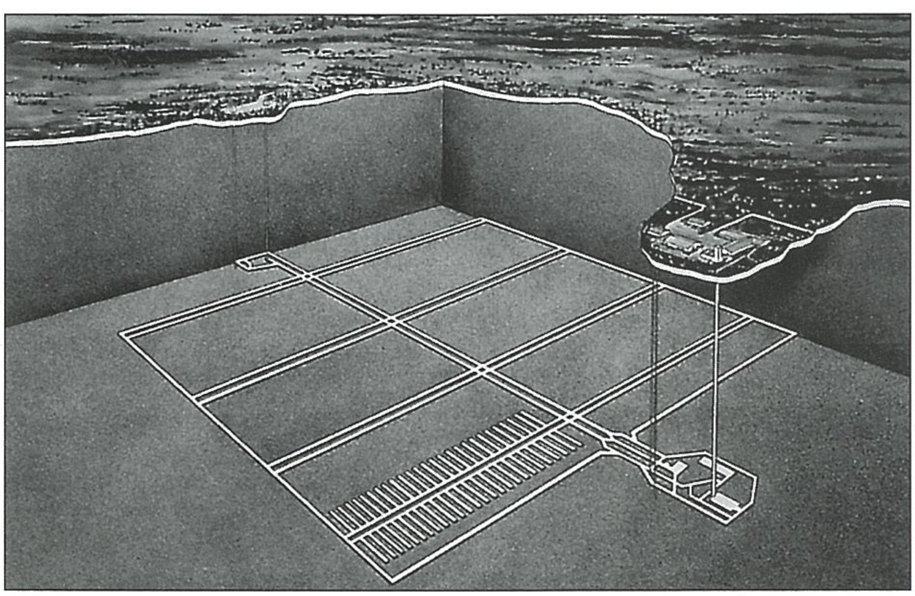
1. Phase I was designed to assist the Panel in addressing issues in the Panel's terms of reference which go beyond the generic concept for deep geologic disposal including: the criteria by which safety and acceptability of a concept for long-term management and disposal should be evaluated; the degree to which this generation should relieve future generations of the burden of caring for the waste; social, economic and environmental implications of a possible nuclear fuel waste management facility; the general criteria for site selection and a future site selection process; and the potential costs and benefits to potential host communities. This phase occurred in 1996 March and April in Toronto and other communities in Ontario.
2. Phase II is focussed specifically on scientific and technical issues related to the long-term safety of AECL's generic concept for deep geologic disposal of nuclear fuel waste. This phase began in 1996 June and will be completed in 1996 November.
3. Phase III will be held over six weeks during the period 1997 January to March in a number of communities in the five provinces previously visited by the Panel during the scoping phase of this review. This phase will involve presentations on the following: recommendations to assist governments in reaching decisions on the acceptability of the disposal concept; steps to be taken to ensure safe long-term management of nuclear fuel waste; criteria by which the safety and acceptability of a concept for long-term waste management and disposal should be evaluated; social, economic and environmental implications of a possible nuclear fuel waste management facility, including the impact of transportation of nuclear fuel waste; general criteria for site selection and on a future site selection process; and the costs and benefits to potential host communities.

When the review is concluded, the Panel will make recommendations on whether AECL's concept is safe and acceptable, or should be modified, and on the future steps to be taken in Canada for the management of nuclear fuel waste.

The Future

The future of the Canadian program will depend on the recommendations of the Panel that is reviewing the EIS and the disposal concept and on future decisions of governments. As discussed elsewhere in these Proceedings, the Minister of Natural Resources Canada has recently announced a policy framework for radioactive waste management in Canada [31]. The framework states:

- The federal government will ensure that radioactive waste disposal is carried out in a safe, environmentally sound, comprehensive, cost-effective and integrated manner.
- The federal government has the responsibility to develop policy, to regulate, and to oversee producers and owners to ensure that they comply with legal requirements and meet their funding and operational responsibilities in accordance with approved waste disposal plans.
- The waste producers and owners are responsible, in accordance with the principle of "polluters pays", for the funding, organization, management and operation of disposal and other facilities required for their wastes. This recognizes that arrangements may be different for nuclear fuel



An artist's view of a future deep geological disposal vault.

waste, low-level radioactive waste and uranium mine and mill tailings.

The staff of the AECB, in their comments on the EIS, state that they "have adopted the view that disposal should proceed as soon as adequate protection of health and the environment can be assured" [32].

AECL, in its EIS [3, 4], recommends that "Canada progress towards disposal of its nuclear fuel waste by undertaking the first stage of concept implementation – siting."

Ontario Hydro, in a submission to the Panel during the phase I hearings [33], indicated that it intends to take a lead role in implementing used fuel disposal, either jointly with the other waste owners, or as the implementing organization.

Thus, the groundwork has been well prepared, so that if the Panel recommends proceeding toward implementation of geological disposal, and if governments accept such a recommendation, Canada will be well positioned to begin the siting process. Any forward moving program will have the benefit of the R&D that has been carried out to date and of the results of the environmental review now underway, a review that involves a thorough and extensive evaluation of the technical, social and ethical issues, all of which are fundamental to building confidence in geological disposal as the appropriate strategy for the long-term management of Canada's nuclear fuel waste.

Acknowledgements

The authors would like to acknowledge, with appreciation, the sustained and dedicated efforts of the many organizations and individuals who have contributed to the Canadian Nuclear Fuel Waste Management Program over the past two decades. Funding for the Program has been provided by AECL and Ontario Hydro.

References

The original paper had 33 references. If desired, please contact the authors.

FIRST CALL FOR PAPERS
4th INTERNATIONAL CONFERENCE ON CANDU MAINTENANCE

Toronto, Ontario
16 – 18 November 1997

In response to the very successful conference in 1995 the sponsors, the Nuclear Operations Division of the Canadian Nuclear Society, have decided to increase the frequency of the CANDU Maintenance Conferences from every three to every two years.
Both technical and human performance issues will be addressed, with emphasis on acutal experience, especially in:

- current and emerging maintenance technologies and tooling
- today's maintenance needs and tomorrow's solutions
- strategies to improve maintenance
- managing maintenance and maintenance integration.

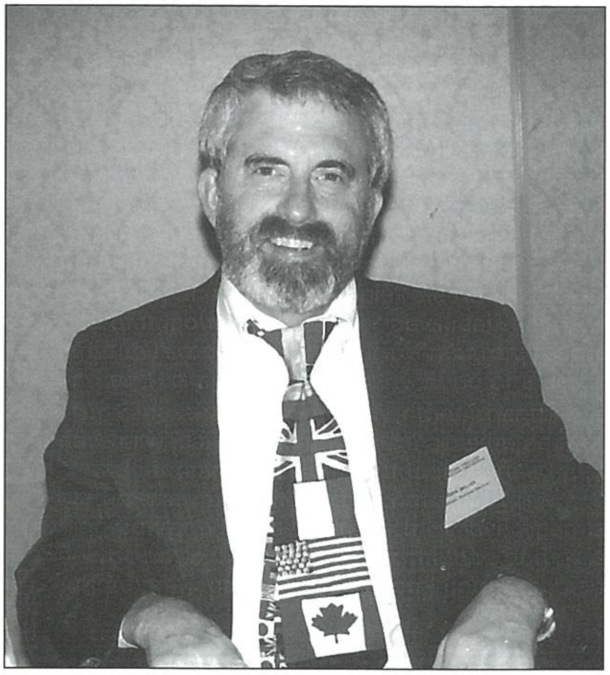
A detailed "Call for Papers" has been mailed with this issue of the CNS Bulletin.

For more information call

Martin Reid	905-839-1151 ext. 3645	Tim Andreeff	416-592-7676
Karel Mika	519-361-3278	Dominic Iafrate	905-697-7496

Simulation Conference

Report on the 5th International Conference on Simulation Methods in Nuclear Engineering



Dr. Don Miller, president of the American Nuclear Society and guest speaker at the 5th International Conference on Simulation Methods in Nuclear Engineering displays his "international" tie.

Over 100 analysts convened in Montreal for three days in early September to share their experiences and insights at the 5th International Conference on Simulation Methods in Nuclear Engineering.

Over the course of the conference 61 papers were presented, in a plenary session the first morning and 10 parallel sessions over the remaining two and a half days. There were six topical groupings; thermalhydraulics had three sessions, reactor physics and safety analyses two sessions each, and plant control, code validation and fuel / fuel channels each had one session.

The plenary session touched on all of the topical areas, with the following papers:

Dynamic Benchmarking of Simulation Codes
by R. E. Henry and Chan Y. Paik

Recent Trends in Methodologies for CANDU Finite Core Analysis at AECL
by B. Rouben

Models for Fluid/Structure Interaction in a Nuclear Reactor During an Earthquake
by G. Rousseau

Coupling of Subroutine Version of ELOCA Code for High Temperature Fuel Behaviour to CATHENA System Thermalhydraulics Code
by L. N. Carlucci, J. R. Gaul, V. I. Arimescu, D. J. Richards

Overview of TUF Code for CANDU Reactors
by W. S. Liu, R. K. Leung, J. C. Luxat

Uncertainty Analysis for Simulation Code Validation
by H. E. Sills, D. Evens, J. Pascoe

John Saroudis of AECL Montreal and **Raymond Leung** of Ontario Hydro were the conference co-chairmen. **Hong Huynh,** of Hydro Quebec (and current president of the *Canadian Nuclear Society*) was a very active "adviser". As a testament to the organization , a labour dispute at the hotel hardly upset the running of the conference.

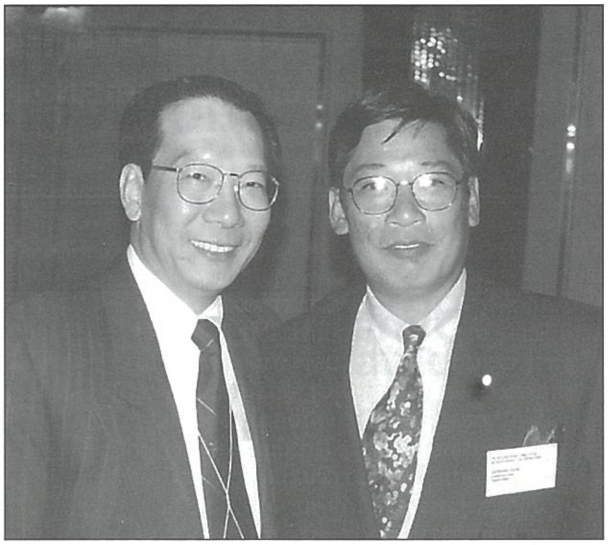
Dr. Don Miller, chair of nuclear engineering at Ohio State University and current president of the American Nuclear Society, was the guest speaker at the conference banquet on the first evening. He began with a review of some of the topics currently being addressed by the USNRC's Advisory Committee on Reactor Safeguards on which he is a member before turning to a Vision of the Next 50 Years of Nuclear Science and Technology, the title of his talk.

Among the concerns of the ACRS is the issue of digital instrumentation and control. Miller commented that perhaps some day the USA might catch up to Canada in this area.Another topic being pursued by the ACRS is what the USNRC calls "risk informed performance regulation" where the objective is to reduce deterministic requirements and move to a risk basis for operations planning and procedures. This needs an up-to-date PRA.

Looking at the future he referred to the booklet, *A Vision for the Second Fifty Years of Nuclear Energy* produced by the International Nuclear Societies Council (of which the CNS is a member). With the USA situation obviously in mind, he spoke of nuclear technology evolving from a political issue to a people and humanitarian issue and noted the many beneficial aspects such as; an economical source of energy with minimal environmental impact; medical diagnostics and therapy using nuclear techniques; and food irradiation. He called on all involved in nuclear science and technology to strive to see that this vision becomes a reality.

The conference was jointly sponsored by the Canadian Nuclear society and the American Nuclear Society.

To give readers of the *CNS Bulletin* some flavour of the papers given at this specialized conference some abstracts selected from each of the topical areas are printed below. Copies of the full proceedings (in two volumes) are available from the CNS office in Toronto. (Contact Sylvie Caron at 416-977-7620 ext. 18; FAX 416-979-8356; e-mail: carons@cna.ca.



Conference "advisor" Hong Huynh and co-chairman Raymond Leung confer during the 5th International Conference on Simulation Methods in Nuclear Engineering in Montreal, September 1996.

Selected Abstracts from Simulation Conference

Dynamic Benchmarking of Simulation Codes

Robert E. Henry, Chan Y. Paik, George M. Hauser
Fauske & Associates, Inc.
Burr Ridge, Illinois

Abstract

Computer simulation of nuclear power plant response can be a full-scope control room simulator, an engineering simulator to represent the general behavior of the plant under normal and abnormal conditions, or the modeling of the plant response to conditions that would eventually lead to core damage. In any of these, the underlying foundation for their use in analyzing situations, training of vendor/utility personnel, etc. is how well they represent what has been known from industrial experience, large integral experiments and separate effects tests. Typically, simulation codes are benchmarked with some of these; the level of agreement necessary being dependent upon the ultimate use of the simulation tool. However, these analytical models are computer codes, and as a result, the capabilities are continually enhanced, errors are corrected, new situations are imposed on the code that are outside of the original design basis, etc. Consequently, there is a continual need to assure that the benchmarks with important transients are preserved as the computer code evolves. Retention of this benchmarking capability is essential to develop trust in the computer code.

Given the evolving world of computer codes, how is this retention of benchmarking capabilities accomplished? For the MAAP4 codes this capability is accomplished through a "dynamic benchmarking" feature embedded in the source code. In particular, a set of dynamic benchmarks are included in the source code and these are exercised every time the archive codes are upgraded and distributed to the MAAP users. Three different types of dynamic benchmarks are used:

- plant transients,
- large integral experiments, and
- separate effects tests.

Each of these is performed in a different manner. The first is accomplished by developing a parameter file for the plant modeled and an input deck to describe the sequence; i.e. the entire MAAP4 code is exercised. The pertinent plant data is included in the source code and the computer output includes a plot of the MAAP calculation and the plant data.

For the large integral experiments, a major part, but not all of the MAAP code is needed. These use an experiment specific benchmark routine that includes all of the information and boundary conditions for performing the calculation, as well as the information of which parts of MAAP are unnecessary and can be "bypassed".

Lastly, the separate effects tests only require a few MAAP routines. These are exercised through their own specific benchmark routine that includes the experiment specific information and boundary conditions. This benchmark routine calls the appropriate MAAP routines from the source code, performs the calculations, including integration where necessary and provide the comparison between the MAAP calculation and the experimental observations.

Simulation of RD-14M Single-Phase Pump Rundown Tests Using the TUF Pump Model

P.T. Wan, J. Pasco, J. Anderson, C. Raczynski and R. Leung
Ontario Hydro

Abstract

This paper reports on recent progress in the simulation of RD-14M single-phase pump rundown tests using the TUF pump model. TUF is an advanced two-fluid system-thermalhydraulic computer code used in the safety and operational analysis of Ontario Hydro's nuclear reactors. RD-14M is an experimental facility possessing many of the physical and geometrical characteristics of a CANDU reactor heat transport system.

In this paper, a recent series of RD-14M pump rundown experiments is described. The model used in TUF for simulating the steady and transient behaviour of the primary pumps is also presented. The pump model in TUF requires the user to input constitutive relationships in the form of constants for the homologous head and torque curves as well as a number of constants (e.g., moment of inertia, the coefficient of static friction, and the coefficient of dynamic friction) that are required for modelling the pump transient behaviour. using the same methodology as that for characterizing the primary heat transport pumps in Darlington reactors, the constants required for modelling the RD-14M pumps were determined based on experimental data from three RD-14M rundown test (C9511, C9514 and C9519). The resulting TUF model of an RD-14M pump was then used to simulate a fourth independent RD-14M pump rundown test (C9513). Reasonable agreement was obtained between the computed results and experimental data.

An Investigations of the Local Non Uniformities in the Ignalina RBMK-1500 Reactor Core Characteristics

B.R. Sehgal, A.A. Balygin[1]
Royal Institute of Technology (KTH)
Stockholm, Sweden

Introduction

The Ignalina nuclear power plant (INPP), in Lithuania, consist of two of the highest power (1500 MW3 each) RBMK reactors. Essentially, these reactors employ, the same core configuration as the 1000 MWe RBMK plants, but have higher volumetric and linear power densities. After the Chernobyl accident, modifications were introduced, in the RBMK core configurations, to substantially reduce the large positive void coefficient, innerent in these cores. The major modifications were a) a much faster shut-down system b) the introduction of the additional absorbers in the core and c) an increase of U^{235} fuel enrichment from 2.0w% to 2.4w%. The latter modifications, responsible for the reduction of the positive void coefficient, also lead to greater heterogeneity in the core, and perhaps, to larger local variations in the core characteristics. In this study, one of our objectives is to understand the spatial characteristics of the core, e.g., the radial and axial variations of power, of reactivity coefficients, of control rod worths, etc. Another objective is to assess the change in core characteristics due to the progressive loading of the Erbium-poisoned 2.4w% U^{235} enriched fuel in the Ignalina core. It should be mentioned that the 2.4w% fuel was not introduced in the ignalina core earlier in order not to decrease the thermal margin. The calculations are performed with the STEPAN code.

[1] On loan from the Division of Channel Reactor Russian Research Center, Kurchatov Institute, Kurchatov Square, Moscow, Russia.

Gentilly-2 Overpower Transient Initiated by a Loss of Electrical Power

A. Baudouin, C.H. Nguyen and G. Hotte
Hydro-Québec
G.D. Harvel, M. Shad and M. Soulard
AECL CANDU

Introduction

On September 14, 1995, a power excursion occurred at the Gentilly-2 CANDU-6 power station as a result of a loss of electrical power to key system pumps. The station was operating normally at full power when the event occurred. It was initiated by the inadvertent slow transfer of class IV electrical loads from the main service transformer to the standby transformer, causing a simultaneous trip of the four main heat transport pumps and the liquid zone control system pumps. The station was automatically shut down within two seconds by Shutdown System No. 1 (SDS1). SDS2 and the regulating system stepback also tripped. In these first two seconds, 26 of the 58 SDS1 and SDS2 incore flux detectors reached their overpower trip (ROPT) setpoints, and the SDS1 out-of-core ion chambers registered a high rate of power increase reaching 10%/s.

This paper describes the information available about the power transient from plant station logs, and the analyses that have been carried out to verify if the observed plant behaviour is consistent with current analysis models and plant representations.

Conclusions

The power excursion which occurred at G2 in September of 1995 was unexpected because past events of the same type had not resulted in any significant power transient. This was however the only situation where all four PHT pumps tripped simultaneously at full power, in combination with the coincident loss of liquid zone system pumps. In addition, safety analyses had used simplified, although conservative, models and core representations to assess shutdown systems effectiveness. These did not model in great detail nor take credit for the neutronic behaviour during a loss of class IV power event which can sometimes lead to an early reactor trip and improved trip effectiveness.

The simplifying assumptions which are thought to have contributed most to the lower predicted power increase are:

a) proper accounting for the detailed neutron flux distribution and fuel burnups in the reactivity calculation of the point kinetics model, and
b) the absence of adequate representation of boiling in subchannels when the cross-sectional average conditions are subcooled.

The various sensitivity analyses quantify the relative importance of the phenomena at play, and show that the power increase observed at G2 does not invalidate current uncertainty allowances used for reactivity coefficients in POWDERPUFS-V. They highlight the difficulties in modelling the very detailed transient void distributions which are believed to be major contributors to the overpower transient, and highlight in particular the difficulties in representing transient void distributions in this operating range at full power, slightly above the onset of boiling.

Pre- And Post-Test Cathena Simulations For RD-14M Critical Break Experiments

E.J.M. Yetman and T.V. Sanderson
AECL Whiteshell

Abstract

Historically, peak fuel element simulator (FES) sheath temperatures in RD-14M Loss-of-Coolant Accident (LOCA) experiments have not exceeded 550°C. However, in licensing analysis scenarios, peak sheath temperatures during the early blowdown phase of a LOCA have been predicted to reach or exceed 1000°C. Experimental data at these conditions can aid in the validation of codes used for licensing analysis purposes.

A series of critical break LOCA experiments was performed in RD-14M to provide experimental FES sheath temperatures up to 1000°C. This paper summarizes the CATHENA simulations used to help design the test series. Post test simulations of selected tests are also discussed.

For this test series, RD-14M was modified to use a single channel per pass; all other channels were isolated at the headers. No emergency core cooling was used. Experiments were conducted either with the power supplies ramped to decay levels 2 s after initiating the break or with the power supplies left at initial conditions until the test was terminated by a process protection trip. The FES trip temperature was increased to 1000°C for the final test.

A CATHENA scoping analysis predicted an inlet header break between 15 mm and 20 mm at a loop flow of 3.7 L/s would produce a critical break with this geometry. Experimental results confirmed these predictions. For experiments conducted with an 18 mm inlet header break with no power ramp down, a peak sheath temperature of 968°C was reached. CATHENA accurately predicted the flow split point in the channel. The code overestimated the top, centre FES temperature by 141°C. This is considered to be a conservative estimation of the peak sheath temperatures.

Simulation of Relief Valve Dynamic Behaviour

K.F. Hau, N. Lee, and A. Usmani
AECL CANDU

Abstract

Three heavy water spill incidents occurred at Wolsong-1, Pickering-A, and Bruce-A power plants in late 1994 and early 1995. In all incidents, the heavy water spills were caused by opening of the degasser/bleed condenser relief valves (RV). Detailed assessments of these incidents were carried out by the owners of the operating plants and by AECL. One of the key lessons learned from this assessments is that stable operation of the RVs is required to prevent damage to valve internals and associated piping resulting from waterhammer/dynamic loads due to the RV chatter.

The RV chatter phenomenon depends strongly on the performance characteristics of the valve, the associated piping configuration, and the operating conditions. To help understand and explain the chatter phenomenon, and to assist the evaluation of the dynamic behaviour of the existing or new RV installations, two RV models were developed and incorporated into the existing waterhammer computer code, PTRAN. This paper describes the basic principle of the models and presents the simulation results in comparison with the test data.

First Experimental Results of the Thermal Behaviour of AECL's CANSTOR Spent Fuel Dry Storage Module

R. Moffett
AECL, Montréal

Abstract

This paper presents the first experimental results of the thermal behavior of AECL'S CANSTOR spent fuel dry storage module. The CANSTOR module is an air-cooled concrete vault about 22 m long, 8 m wide and

7 m high. It can store 12000 CANDU spent fuel bundles inside 200 baskets which are stacked into two rows of 10 storage cylinders. The first module was built on the site of Hydro-Québec's Gentilly-2 station during the summer of 1995.

Dissipation of the residual heat generated by the spent fuel is a major factor in spent fuel dry storage design and one of the key elements for its licensing. The fuel temperature must be kept below 160°C to avoid oxidation. Experiments on a mock-up and calculations showed that the air cooling circuit provides at least 15°C margin for the fuel with 6-year cooled fuel subject to the ambient design temperature of 40°C. Nevertheless, the Atomic Energy Control Board of Canada (AECB) requested Hydro-Quebec to monitor the temperatures and limit the age of the fuel to more than 8-year cooled. During the construction, fourteen temperature sensors were installed to measure the temperature of the air, concrete and top of storage cylinders. A computer based data acquisition system has been used to collect the data, starting before the first fuel was loaded.

The first loading campaign occurred during the fall of 1995, mainly during the months of October and November. The module was half filled with 6000 bundles that had been cooled in the spent fuel bay for more than 8 years, in accordance with the AECB license. No loading was done during the 1995-1996 winter. This provided a few months of data with quasi-constant power dissipation. This paper presents this data and compares it with the calculations used in support of the licensing submission. It is shown that fuel cooled less than 8-years could be loaded into the CANSTOR module.

CNA / CNS WINTER SEMINAR

Ottawa, Ontario
10 - 11 February 1997

The annual Winter Seminar hosted by the Canadian Nuclear Association and the Canadian Nuclear Society will be held, again in Ottawa, on the evening of February 10 and All day February 11.

This meeting has traditionally provided a concise overview of the Canadian nuclear program and offered a chance to meet with politicians and senior government officials.

For information contact:

Sylvie Caron or Colin Hunt at the CNA / CNS office in Toronto
Tel. 416-977-6152 (Sylvie ext 18; Colin ext 24)
FAX - 416-979-8356

18TH ANNUAL CONFERENCE CANADIAN NUCLEAR SOCIETY

Toronto, Ontario
8 - 11 June 1997

The 18th Annual conference of the Canadian Nuclear society will be held in parallel with the 37th Annual conference of the Canadian Nuclear Association.

Papers are invited on technical developments in all subjects relating to applications of nuclear technology.

Summaries of between 750 and 1200 words (with tables and figures counted as 150 words each) must be post-marked no later than **15 January 1997.**

They should be sent to either:

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Five Years of SLAR Implementation in the CANDU Community

John M. Gierlach, P.Eng., Ontario Hydro

Abstract

Ontario Hydro Nuclear (OHN) has provided leadership in SLAR related services to their customers in the CANDU community for their SLARette, SLAR and MiniSLAR campaigns over the past five years. These customers included Bruce (units 1, 2, 3, and 4), Point Lepreau, and Gentilly nuclear stations. The services included:

- *Development of SLARette, SLAR, and MiniSLAR components and systems;*
- *Technical support for SLARette campaigns; and*
- *Operation of the SLAR and MiniSLAR systems.*

OHN SLAR staff visited over 1,000 fuel channels in this five year period and observed that:

- *Over 75 percent of the fuel channels with 'fat' fuel channel spacers[1] required repositioning to achieve station target life even though over 85 percent of the spacers were found at design locations;*
- *Ninety percent of the fuel channels with 'thin' fuel channel spacers[2] required repositioning to achieve station target life as fewer than 45 percent of the spacers were found at design locations; and*
- *SLAR processing times increased as the fuel channels aged.*

Following a continuous improvement philosophy, SLAR staff implemented various system and process improvements in this five year period. The improvements resulted in critical path outage time savings and cost savings. The improvements, many of which were jointly funded, allowed OHN to achieve and sustain excellence in the operation and maintenance of SLAR.

1.0 FIVE YEARS OF SLAR IMPLEMENTATION

Spacer Location and Repositioning (SLAR) is a maintenance activity developed for the rehabilitation of CANDU reactor fuel channels, and has the capability of locating and repositioning fuel channel spacers ('spacers') in in-service reactors.[3] The system used consists of a Delivery System and an Inspection System[4].

The SLAR system was originally developed as a COG project managed by Ontario Hydro, jointly funded by Ontario Hydro, Atomic Energy of Canada Limited (AECL), Hydro Quebec, and New Brunswick Power. The Ontario Hydro group responsible for SLAR ('SLAR staff') currently resides in the Fuel Channel Inspection and Maintenance Department of the Nuclear Technology Services Division of OHN.

1.1 IMPLEMENTATION ACCOMPLISHMENTS

SLAR staff have provided implementation support to their customers for their SLAR and SLARette campaigns over the past five years utilizing over 100 person years of qualified SLAR experience. SLAR staff have:

- Successfully processed over 1,000 fuel channels;
- Performed over 1,300,000 millimeters of spacer movement; and
- Operated over 10,000 hours on reactor without damaging a fuel channel.

1.2 SLARETTE SERVICES

Prior to 1990, the SLAR proof of principle was performed using a 'dry' SLARette system, at Pickering unit 4. The system consisted of the SLAR Inspection System coupled with a modified CIGARette drive mechanism. SLAR staff commissioned and operated the SLAR Inspection System. The successful proof of principle was followed by the 'dry' SLARette of 6 fuel channels in Bruce unit 2 in 1990. SLAR staff commissioned and operated the SLAR Inspection System for this campaign. The problems associated with feeder freezing during these campaigns resulted in the design of the current 'wet' SLARette system.

Subsequent to 1990, SLAR staff provided SLARette technical support to New Brunswick Power, Hydro Quebec, and AECL. Support was provided during the Point Lepreau SLARette outages in 1991, 1992, and 1993 and during the Gentilly unit 2 SLARette outage in 1995. SLAR staff were present at site and provided operating expertise for the Inspection System. SLAR staff also provided enhanced locate expertise to AECL after their Embalse SLARette outage in 1993.

1.3 SLAR SERVICES FOR THE GENTILLY AND POINT LEPREAU NUCLEAR STATIONS

In the fall of 1991, the first SLAR implementation was performed at Gentilly unit 2. SLAR staff were assigned to Gentilly and commissioned and operated the SLAR Inspection System. The reactor was at approximately 56,000 EFPH. Out of 77 fuel channels visited, 36 were repositioned successfully to a target of 190,000 EFPH. The inability to reposition 41 fuel channels was due to the design limitations of the Mark II SLAR Tool.

In 1995, SLAR implementation was performed at Point Lepreau for 372 out of 380 fuel channels. SLAR staff were assigned to Point Lepreau and commissioned and operated the SLAR Inspection System with New Brunswick Power staff. New Brunswick Power staff were trained by SLAR staff prior to the campaign. The reactor was at approximately 101,000 EFPH. Out of 372 fuel channels visited, 371 were repositioned successfully to a target of 246,000 EFPH.

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The Mark III SLAR Tool was unable to reposition the spacers in the one remaining channel successfully. Average cycle time was about 6 hours per channel.

1.4 SLAR AND MINISLAR SERVICES FOR THE BRUCE NUCLEAR STATION

In 1993, 1994, and 1995, SLAR implementation was performed at Bruce unit 3 and Bruce unit 4. SLAR staff commissioned and operated the SLAR Inspection System. Bruce unit 3 was visited in 1994. The reactor was at approximately 106,000 EFPH. Out of 232 fuel channels visited, 231 were repositioned successfully to a target of 239,000 EFPH. Average cycle time was about 8 hours per channel. Bruce unit 4 was visited in 1993 and 1995. The reactor was at approximately 93,000 EFPH and 99,000 EFPH respectively. Out of a total of 207 fuel channels visited, 199 were repositioned successfully to targets exceeding 194,000 EFPH. Average cycle time was about 15 hours per channel.

In the fall of 1995, the first MiniSLAR implementation was performed at Bruce unit 1. SLAR staff commissioned and operated the SLAR Inspection System. The reactor was at approximately 107,000 EFPH. Out of 109 fuel channels visited, 72 were repositioned successfully to a target of 156,000 EFPH. Sixteen channels were repositioned successfully to targets exceeding 136,000 EFPH. Average cycle time was about 8 hours per channel.

2.0 INITIAL FUEL CHANNEL CONDITIONS ENCOUNTERED

SLAR was performed on over 1,000 fuel channels in a five year time period. The data recorded for these channels provides a meaningful database for analysis.

2.1 'FAT' FUEL CHANNEL SPACER REACTORS

SLAR was performed on two reactors with 'fat' fuel channel spacers, Bruce unit 1 and Bruce unit 3.

One hundred and nine fuel channels, with 2 spacers per channel, in Bruce unit 1 were visited in 1995. Eighty-seven percent of Bruce unit 1 spacers were found close[5] to design locations (figure 1). Regardless of this fact, all fuel channels required repositioning to achieve unit target life.

Two hundred and thirty-two fuel channels, with 4 spacers per channel, in Bruce unit 3 were visited in 1994. Ninety percent of spacers were found close to design locations (figure 2). Sixty-two percent of the fuel channels required repositioning to achieve unit target life.

2.2 'THIN' FUEL CHANNEL SPACER REACTORS

SLAR was performed on three reactors with 'thin' fuel channel spacers, Bruce unit 4, Gentilly unit 2, and Point Lepreau. Each reactor had 4 spacers per channel.

Seventy-seven fuel channels in Gentilly unit 2 were visited in 1991. Two hundred and seventeen fuel channels in Bruce unit 4 were visited in 1993 and in 1995. Three hundred and seventy-two fuel channels in Point Lepreau were visited in 1995. When 'as found' spacer locations are tabulated for these reactors, only 44 percent of the spacers were found close to design locations (figure 3). Ninety percent of the fuel channels required repositioning to achieve unit target life.

3.0 FUEL CHANNEL CONDITIONS ENCOUNTERED DURING REVISITS

SLAR was performed on three 'thin' fuel channel

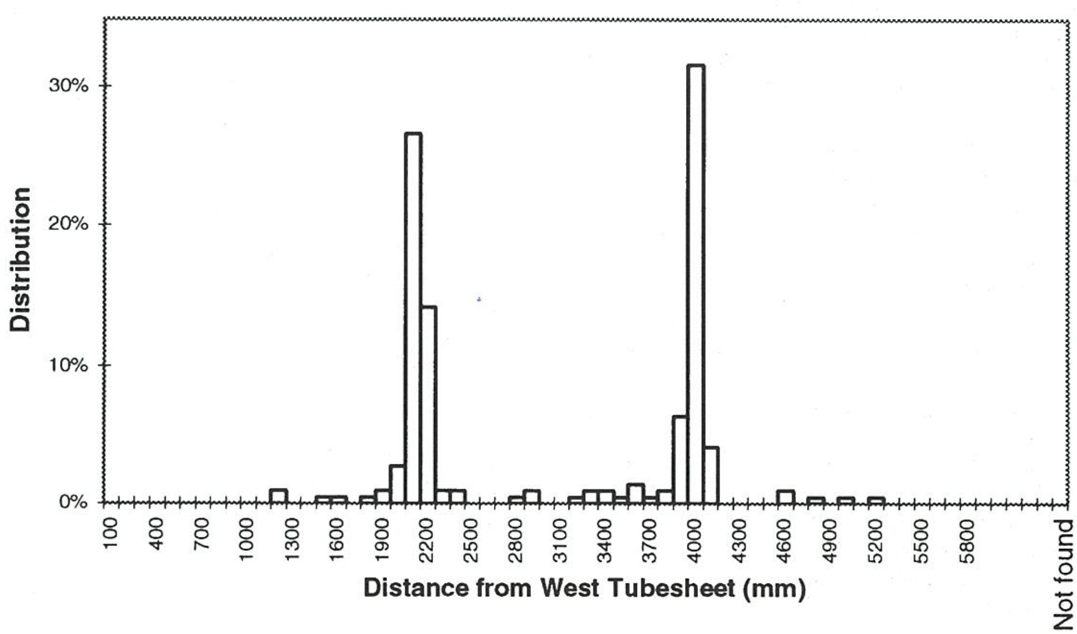

Figure 1: Bruce unit 1 'as found' fuel channel spacer locations. Note the concentration of fuel channel spacers found around design locations.

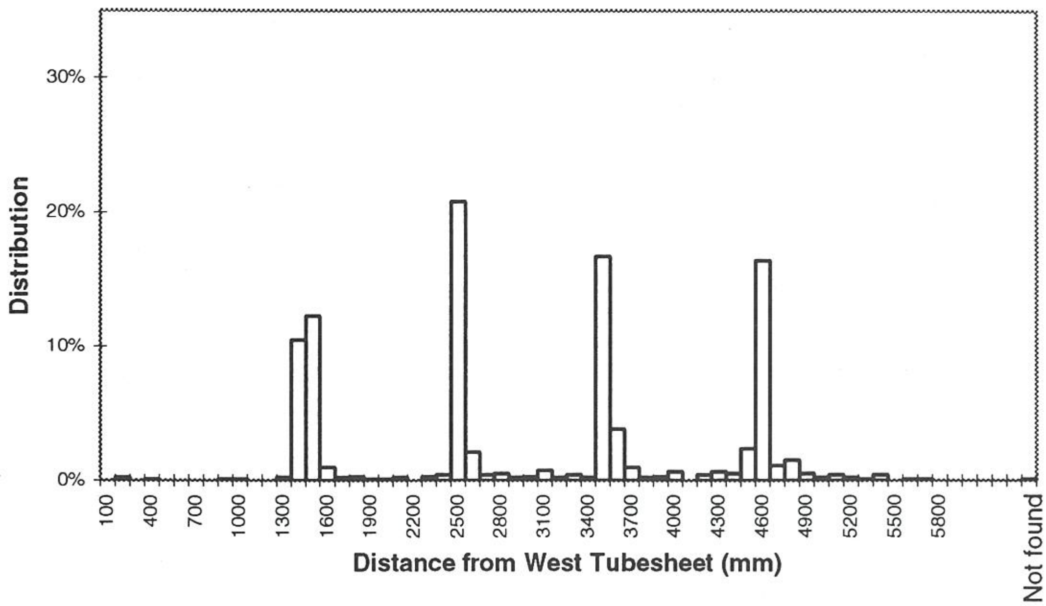

Figure 2: Bruce unit 3 'as found' fuel channel spacer locations. Note the concentration of fuel channel spacers found around design locations.

spacer reactors, Bruce unit 4, Gentilly unit 2, and Point Lepreau, at various stages of their lives. Observations were made by the operating crews that suggest an ongoing trend: as EFPH increases, SLAR processing time increases.

3.1 INCREASE IN PROCESSING TIMES RESULTING FROM A DECREASE IN MOVEMENT

The measure 'millimeters of movement for each LIM fire' (*mm/LIM fire*) is used to gauge the trend in spacer movement. This measure (*mm/LIM fire*) is used because it is independent of other parameters; it is dependent only upon the fuel channel. An increase in SLAR processing time corresponds to a decrease in *mm/LIM fire.*

The measure mm/LIM fire was tabulated for campaigns at 'thin' fuel channel spacer reactors. The frequency of fuel channels with spacer movement of less than 10 *mm/LIM fire* went from none for a reactor at 80,000 EFPH up to 29 percent for a reactor at 101,000 EFPH. In addition, the frequency of channels with greater than 100 *mm/LIM* fire went from 34 percent for a reactor at 80,000 EFPH down to 10 percent for a reactor with 101,000 EFPH (figure 4). As EFPH increases, a reduction in movement per LIM fire is evident. This results in an increase in SLAR processing time.

3.2 INCREASE IN PROCESSING TIMES RESULTING FROM AN INCREASE IN EDDY CURRENT 'NOISE'

Eddy current non-destructive examination techniques are the primary method used to determine the location of fuel channels spacers by the SLAR system. Fuel channel revisits allow eddy current signal changes to be observed over the life of the fuel channel.

An eddy current 'noise' signal that masks the eddy current signal produced by a spacer is produced when the fuel channel ages. Additional spacer detection techniques were thus used to deal with the eddy current 'noise' signals. These techniques were used during two phases of the SLAR process, resulting in an increase in SLAR processing time. As EFPH increases, eddy current 'noise' signals will increase. This results in an increase in SLAR processing time.

4.0 SLAR CONTINUOUS IMPROVEMENT

OHN uses a continuous improvement philosophy, the Business Improvement Process (BIP), to ensure customer satisfaction. BIP allows OHN to achieve and sustain excellence in the operation and maintenance of SLAR through the involvement, commitment and contribution of SLAR staff. Various improvements have been initiated over the past five years using this philosophy.

4.1 SYSTEM DEFICIENCIES AND PROCEDURES

It is inevitable that on the job learning will be encountered in a system as complex as SLAR. SLAR Deficiency Reports (SDR) and a change control system were implemented by SLAR staff to initiate, track, and implement corrections and improvements to the SLAR system such as hardware and software maintenance and upgrades.

SLAR staff have identified 317 SDR initiatives to date that have been implemented on SLAR systems at Bruce, Point Lepreau, and Gentilly nuclear stations. Examples include:

- Upgrades to application software to improve operations and reduce critical path outage time;
- Improvements to the LIM cabinet protection and control circuitry to prevent pressure tube damage;

and

- Reduction of LIM duty cycle to save over a minute of critical path outage time for each LIM fire.

In addition, SDR initiatives have reduced SLAR downtime during implementation from five percent in 1993 to less than one percent in 1995.

Procedure sets have been written by SLAR staff to cover commissioning, operation, and maintenance of the SLAR system. These have been reviewed after each SLAR outage and improved as required. The procedure set currently consists of a total of 57 procedures covering every facet of commissioning, operation, and maintenance of the SLAR system. SLAR procedure sets have been sold to Hydro Quebec and have been licensed to New Brunswick Power.

The benefits of procedures are incalculable, as seen during the LIM failure at Bruce unit 1 in 1995. Proper procedures coupled with LIM cabinet SDR initiatives were the primary factor in preventing damage to the pressure tube.

4.2 MARK III SLAR TOOL AND MULTIFREQUENCY GAP

During the 1991 SLAR at Gentilly unit 2, it was discovered that the Mark II SLAR Tool was unable to move fuel channel spacers as expected. Immediately after the outage, SLAR staff coordinated the effort to design and develop the Mark III SLAR Tool. Instead of using jacks to lift the pressure tube to obtain pressure tube to calandria tube gap, the new tool would physically bend the pressure tube to obtain pressure tube to calandria tube gap. The Ontario Hydro design was built and tested at the AECL Sheridan Park Laboratory. The project was jointly funded by Ontario Hydro, AECL, Hydro Quebec, and New Brunswick Power.

As a result of the Mark III SLAR Tool construction, it was discovered that the existing SLAR Gap Measurement Sub-System was not able to provide meaningful measurements of pressure tube to calandria tube gap. When this was discovered, Ontario Hydro developed the Multifrequency Gap System. The Multifrequency Gap System uses 3 frequency eddy current instrumentation to measure gap as opposed to the original 2 frequency eddy current instrumentation developed for SLAR. Initial work was jointly funded by Ontario Hydro, AECL, Hydro Quebec, and New Brunswick Power.

Recent modifications to the system were jointly funded by Ontario Hydro, Hydro Quebec, and New Brunswick Power. These modifications increased the robustness of the system and improved measurements of pressure tube to calandria tube gap. The Multifrequency Gap System can be used with SLARette, SLAR, or MiniSLAR systems. The system was used during the 1993 campaign at Bruce unit 4, the 1994 campaign at Bruce unit 3, and the 1995 campaigns at Bruce unit 4, Point Lepreau and Bruce unit 1.

4.3 ENHANCED LOCATE AND SLARON

During the 1991 SLARette at Point Lepreau, it was discovered that spacers were difficult to locate in fuel channels with 'E series' pressure tubes. Immediately after the outage, SLAR staff began the search for a solution to this problem and developed enhanced locate software. Initial work was jointly funded by Ontario Hydro, AECL, Hydro Quebec, and New Brunswick Power. Enhanced locate software is now used exclusively when eddy current 'noise' in encountered in a fuel channel.

To improve operator analysis of fuel channel spacer locations, a new version of the enhanced locate software was developed by SLAR staff in 1994. This new version of enhanced locate software automated

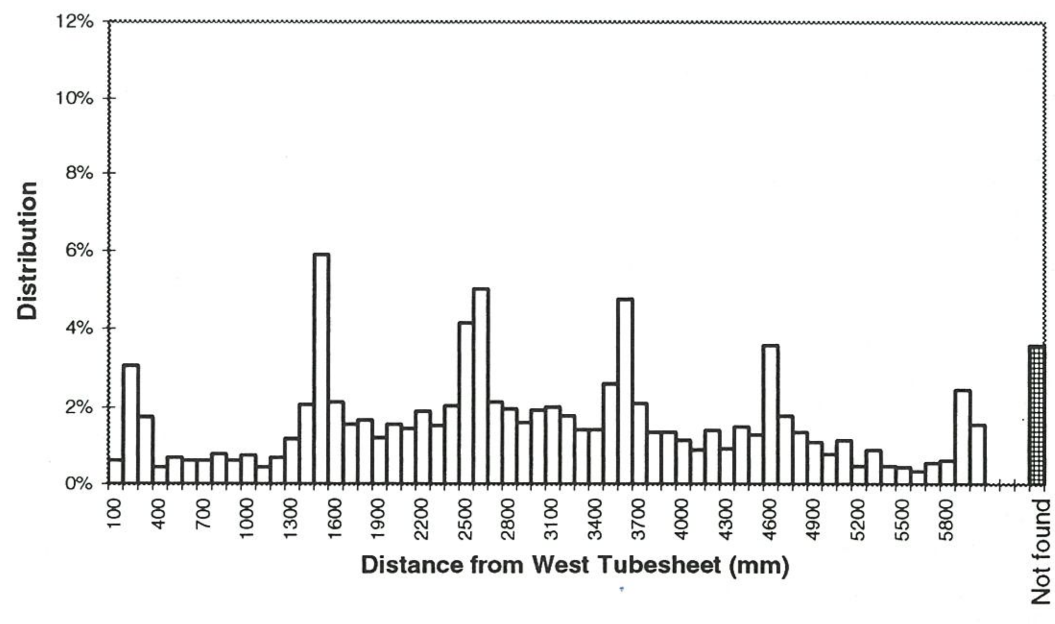

Figure 3: Combined 'as found' fuel channel spacer locations for 'thin' spacer reactors. Note the number of spacers found in the end bell regions and between design locations.

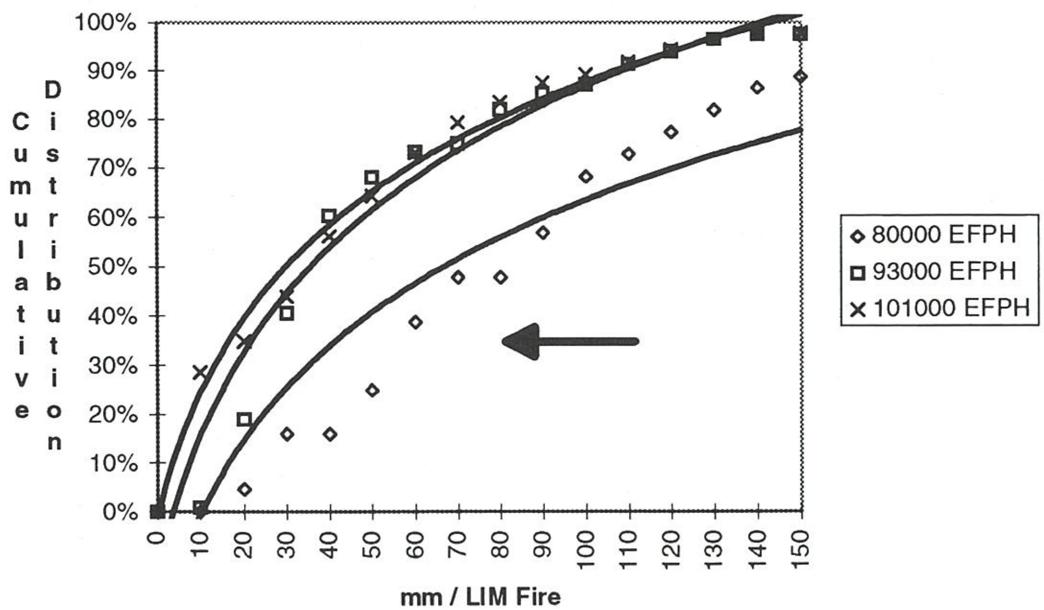

Figure 4: Reduction in movement per LIM fire as a result of reactor aging. Note that a decrease in movement corresponds to an increase in processing time.

many of the features of the earlier software. The software is now able to immediately recognize fuel channel spacers and results in a saving of at least one minute of critical path outage time per inspection scan. These modifications were jointly funded by Ontario Hydro, Hydro Quebec, and New Brunswick Power and can be used with SLARette, SLAR, or MiniSLAR systems. It was used during the 1995 campaigns at Bruce unit 4, Gentilly unit 2, Point Lepreau and Bruce unit 1.

SLARON is an interactive computer program that is used to determine the optimal positioning of fuel channel spacers. As a result of the observations made by SLAR staff during operations on reactors, it was determined that critical path outage time could be saved. This was done by transferring the SLARON software from a Personal Computer (PC) to a UNIX workstation. SLAR staff coordinated this effort which reduced SLARON execution time from minutes to seconds of critical path outage time. These modifications were jointly funded by Ontario Hydro, Hydro Quebec, and New Brunswick Power and can be used with SLARette, SLAR, or MiniSLAR systems. UNIX based SLARON was used during the 1994 campaign at Bruce unit 3 and the 1995 campaigns at Bruce unit 4, Gentilly unit 2, Point Lepreau and Bruce unit 1.

4.4 SLAR INSPECTION TRAILER AND MINISLAR

The SLAR Inspection Trailer is a mobile trailer that contains the SLAR Inspection System. A need was identified to SLAR Bruce unit 1 and Bruce unit 4 in a limited period of time in 1995. It was determined that critical path outage time could be saved by permanently installing the Inspection System in a mobile trailer and by simply plugging the trailer into the appropriate unit requiring SLAR. SLAR staff coordinated this effort that decreased the installation and removal of the Inspection System from weeks to days. The SLAR Inspection Trailer was used during the 1995 Bruce unit 1 MiniSLAR campaign.

The need to SLAR Bruce unit 1 also resulted in the development of the MiniSLAR delivery system. The existing Bruce Delivery Machine was unable to reach Bruce unit 1. SLARette could not readily handle Bruce fuel channels. A joint team consisting of Bruce staff and SLAR staff was formed to address these problems. The result was a delivery mechanism in a small mobile package that could deliver a Mark III SLAR Tool through the complete fuel channel without compromising tool life. The MiniSLAR delivery mechanism was used during the 1995 Bruce unit 1 MiniSLAR campaign.

4.5 MINISLAR SCADA AND FATIGUE MONITORING COMPUTER

The MiniSLAR system as originally envisioned would have operated similarly to a SLARette system, where one operator would operate the Inspection System, and another operator would operate the Delivery Mechanism. It was decided by SLAR staff to implement a Supervisory Control and Data Acquisition (SCADA) system that would allow a single operator to control the Inspection System and the Delivery Mechanism. SCADA allowed the automation of many of the SLAR functions, and introduced safety interlocks which included restrictions on LIM energization and tool pressurization. The MiniSLAR SCADA system was used during 1995 Bruce unit 1 MiniSLAR campaign and can be used with SLARette, SLAR or MiniSLAR systems.

The ability to SLAR Bruce unit 1 was restricted by a limit placed upon the number of SLAR Tool pressurizations allowed per channel. To ensure pressure tube integrity, the need to monitor both the number of, and magnitude of, SLAR Tool pressurizations at a particular location in the pressure tube was identified. It was decided by SLAR staff to implement a Fatigue Monitoring Computer. This PC based computer would monitor the location and magnitude of each SLAR Tool pressurization. The Fatigue Monitoring Computer was used during 1995 Bruce unit 1 MiniSLAR campaign and can be used with SLARette, SLAR or MiniSLAR systems.

4.6 FUTURE IMPROVEMENTS

SLAR staff are continually striving to reduce the critical path outage time and to reduce the costs associated with SLAR. To this end, future initiatives are being undertaken in the areas of the Inspection System and the SLAR Tool.

The SLAR Inspection System currently consists of a combination of eddy current and ultrasonic instruments coupled with a combination of PDP11 and PC computers. A full inspection system consists of three eddy current instruments, four ultrasonic instruments, nine computers, and sundry electronics. The aging of these components coupled with a drive to reduce critical path outage time has resulted in the investigation of alternative architectures for the Inspection System. The goal is to reduce maintenance costs associated with outdated equipment, as well as to reduce critical path outage time by combining and integrating existing components. It is envisioned that an improved system will be available in 1997 for use with SLARette, SLAR or MiniSLAR systems.

Currently the Mark III SLAR Tool is built as a disposable tool. SLAR staff are evaluating the benefits of making the SLAR Tool modular. The goal is to reduce costs associated with purchasing SLAR Tools, as well as to reduce critical path outage time associated with SLAR Tool changes. A modular SLAR Tool would allow tool components to be re-used, thus achieving an overall cost saving. With a modular tool, it would be possible to quickly change tool components during an outage, as opposed to replacing the complete tool, thus reducing critical path outage time. SLAR staff are also investigating the modification of SLAR Tool eddy current probes to improve pressure tube to calandria tube gap measurement and the modification of SLAR Tool ultrasonic blister probes. It is envisioned that a new SLAR Tool will be available in 1997 for use with SLARette, SLAR or MiniSLAR systems.

5.0 CONCLUSIONS

SLAR staff visited over 1,000 fuel channels in the period 1990 to 1995:

- Over 75 percent of the fuel channels with 'fat' fuel channel spacers required repositioning to achieve station target life even though over 85 percent of the spacers were found at design locations; and
- Ninety percent of the fuel channels with 'thin' fuel channel spacers required repositioning to achieve station target life as fewer than 45 percent of the spacers were found at design locations.

An increase in SLAR processing time was also experienced during revisits as a result of:

- A decrease in movement per LIM fire; and
- An increase in eddy current 'noise' signals.

Following a continuous improvement philosophy, SLAR staff implemented various system and process improvements in this five year period. These improvements included:

- The SLAR Change Control System;
- SLAR Procedures;
- The Mark III SLAR Tool;
- The Multifrequency Gap System;
- The Enhanced Locate System;
- The UNIX SLARON System;
- The SLAR Inspection Trailer;
- The MiniSLAR Delivery mechanism;
- The MiniSLAR SCADA system; and
- The Fatigue Monitoring Computer.

SLAR staff are currently evaluating the following system improvements for use in 1997:

- A new Inspection System; and
- A modular SLAR Tool.

ACKNOWLEDGMENTS

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FURTHER INFORMATION

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1 'Fat' fuel channel spacers have a helical coil diameter of 6.8 mm.
2 'Thin' fuel channel spacers have a helical coil diameter of 5.5 mm.
3 SLARette and miniSLAR are equivalent to SLAR in this respect.
4 For the purposes of this paper, the Inspection System is defined as eddy current and ultrasonic instrumentation, the inspection computers, the LIM Cabinet, the D2O Cart, and the SLAR Tool.
5 Defined as within +/- 200 millimeters.

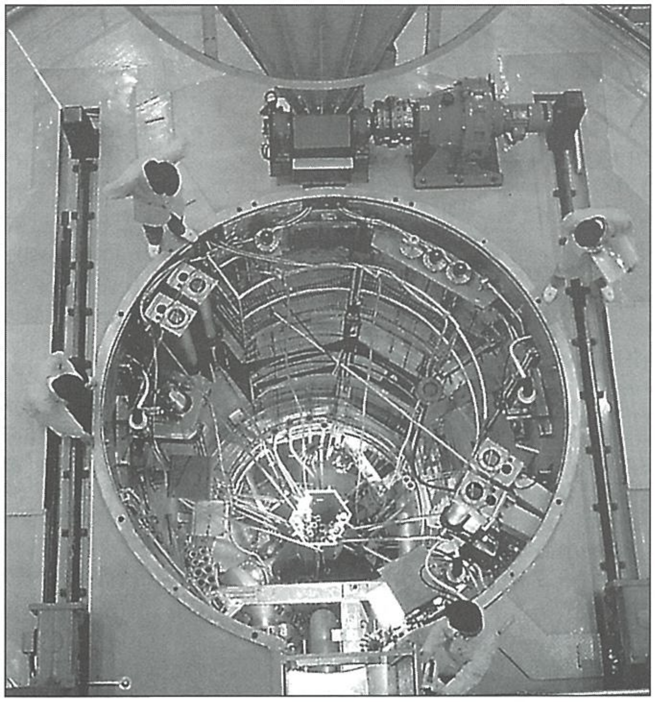
The Development of Maple Technology

For Materials Testing, Isotope Production, and Neutron-Beam Applications

R.F. Lidstone,[1], G.E. Gillespie,[1], and A.G. Lee[1]
W.E. Bishop[2]

ABSTRACT

AECL continues to develop MAPLE technology to meet Canadian and international requirements for high-performance research reactors. The initial focus was on a 10-MW_t Canadian facility for radioisotope production, the HANARO multipurpose-reactor project, and an associated R&D program. Recently, AECL began to define the concept for a new Canadian Irradiation Research Facility (IRF) which will support the continued evolution of CANDU® (CANadian Deuterium Uranium) technology and generate neutrons for basic and applied materials science. AECL is also developing a standardized MAPLE research-centre design with integrated neutron-application facilities; various reactor-core options have been optimized for different combinations of utilization: a 19-site core for neutron-beam applications and ancillary isotope production, a 31-site core for multipurpose materials testing and neutron-beam applications, and twin 18-site cores for high-flux neutron-beam applications.



A top-down view of the core of Korea's HANARO research reactor which incorporates MAPLE technology.

I. INTRODUCTION

Research reactors have contributed substantially to the development of nuclear power. The first research reactors were built mainly to investigate the characteristics of fission chain-reacting assemblies. The resultant hands-on experience was applied to constructing the first generation of high-power (>10 MW_t) research reactors, many of which played a key role in testing materials and components for power reactors. Then, as national infrastructures became established, countries that developed their own power-reactor systems began to design and build the first power-demonstration reactors and commercial nuclear-electric stations. Subsequently, many other countries built research reactors based on proven concepts and acquired power reactors plus associated technology from the original developers. All countries that have established the nuclear power option to date have relied on the previous experience of building and operating research reactors[1].

Although the quest for nuclear power provided the main stimulus for building reactors of all types, the availability of relatively intense neutron fluxes in research reactors prompted investigation of the interactions between neutrons and matter which characterized the neutron's unique properties. Research on the scattering of neutron beams led to the harnessing of the neutron as a powerful tool to characterize the structure of matter. Also, the commercial production and distribution of radioisotopes gradually developed as the feasibility of neutron transmutation was established1.

The continued viability of research reactors will undoubtedly stem from this proven utilization. The experience of building and operating a research reactor will continue to provide important training of personnel for later application in nuclear-electric stations. The development of power-reactor technology will depend on loop and capsule irradiations in suitable research reactors. The continued expansion of nuclear medicine will rely largely on research-reactor-generated radioisotopes. New industrial applications will likely be found for materials processed or activated in research reactors. Near-term research in boron neutron capture therapy (BNCT) may pave the way for large-scale implementation of an effective new tumor treatment. Increasing recognition of the linkage between economic competitiveness and national innovative capabilities in materials technologies will spur ongoing world-class neutron-beam research and promote the development of better national and international neutron-source facilities.

Notwithstanding the utility inherent in all research reactors, national nuclear-research institutes usually prefer high-power research reactors because they generate relatively intense fast and thermal neutron fluxes (~10^{18} $n\bullet m^{-2}\bullet s^{-1}$ or more) at power outputs above 10 MWt. With few exceptions, only high-power research reactors can irradiate power-reactor fuel assemblies and other reactor components in a

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[1] AECL Whiteshell Laboratories
[2] AECL Chalk River Laboratories

radiation environment that realistically simulates current light- and heavy-water-moderated power reactors. Although more modest facilities are also useful for neutron-based research in materials science[2], the minimum requirement for a world-class national neutron source is a peak (perturbed) thermal flux of ~2 x 10^{18} $n \bullet m^{-2} \bullet s^{-1}$ at the beam-tube entrances. Likewise, for key medical and industrial radioisotopes, the viability of commercial production hinges on specific activities that demand the high thermal or epithermal neutron flux levels associated with a core of average power density greater than 100 $kW_t \bullet L^{-1}$.

Despite the building of several new research reactors and the refurbishment of various existing national facilities in the last decade, there is an ongoing need for new national facilities that meet the foregoing requirements for materials testing, radioisotope production, and neutron-beam applications. Many of the older high-power research reactors are approaching the end of their useful lifetimes and experiencing problems of technical obsolescence. Furthermore, in many countries with operable research reactors, the absence of a high-power reactor precludes realistic materials testing, limits the scope and sensitivity of neutron-beam applications, and constrains the viability of isotope production.

In Canada as in many other countries, research reactors have played a central role in the development of the national nuclear power program but there is need for the renewal of the research-reactor infrastructure. The NRX and WR-1 high-power research reactors have been permanently shut down and NRU is approaching the end of its useful lifetime. Accordingly, in response to ongoing Canadian as well as international requirements, AECL is defining the concept for a new national Irradiation Research Facility (IRF) and continuing to develop MAPLE technology.

II. MAPLE REACTOR CONCEPT

Since its inception in 1983, the MAPLE concept[2] has been developed to meet Canadian and international requirements for high-performance research reactors. MAPLE refers to a family of pool-type reactor facilities that employ a compact, LEU-(Low-Enrichment-Uranium-) fueled, H_2O-cooled core within a heavy-water vessel to furnish neutrons efficiently to various types of irradiation facilities. The MAPLE design is distinguished mainly by the unique reactor assembly, the layout of the primary cooling system, the use of a digital computer system to control all main process systems as well as the reactor itself, and two fully independent shutdown systems.

To date, the MAPLE family includes the MAPLE-1 (formerly called MAPLE-X10) facility[3], the HANARO (previously KMRR) multipurpose reactor facility[4], the IRF, and a standardized multipurpose MAPLE research centre with three different reactor variations: a medium-strength neutron source (Mk2), a materials-testing reactor (Mk3), and a high-strength neutron-source concept (Mk4). Table 1 summarizes their principal specifications.

The MAPLE reactor-assembly concept employs 19.7-wt%-enriched LEU fuel in standard assemblies of 18, 36 or 58 rods to form either a simple or a complex core (0.6 m or 0.7 m active length) within a cylindrical D_2O-filled vessel. The fuel

Table 1: Summary of Specifications for MAPLE Reactor Facilities

MAPLE Version		MAPLE-1	HANARO	IRF	MAPLE-Mk2	MAPLE-Mk3	MAPLE-Mk4
Type of Utilization		Radioisotope Production	Multipurpose Materials Tests	CANDU Materials Tests	Medium-Strength Neutron Source	Multipurpose Materials Tests	High-Strength Neutron Source
Power Output (MW_t)		10	30	40	10-14	30	~30
Core Volume (L)		53	120+	2 x 70++	63	120	2 x 70
D_2O Tank	Diameter (m)	0.8	2.0	2.0	1.6	2.0	2.0
	Height (m)	0.6	1.2	1.2	0.9	1.2	1.2
Fuel Tests	Number of Loops	–	2	3-5	–	0-2	–
In-core* or Core-edge Irradiation Sites	Number	–	3*	4*	2	2-4*	–
	Peak Thermal Flux (10^{18} $n \bullet m^{-2} \bullet s^{-1}$)	–	4.4	2	1.5-2.2	2-3	–
	Peak (>IMeV) Flux (10^{18} $n \bullet m^{-2} \bullet s^{-1}$)	–	1.7	1.5	0.5-0.6	1-5-2.0	–
Outer Core** & Reflector Irrad. Sites	Number	24	8** & 25	~10	24	24	10
	Peak Thermal Flux (10^{18} $n \bullet m^{-2} \bullet s^{-1}$)	1.6	3.1**, 2.0	~3	1.4-2.0	~3	~3
Neutron Beam Tubes	Number	0	7	10	6-8	4-8	10-12
	Peak Thermal Flux (10^{18} $n \bullet m^{-2} \bullet s^{-1}$)	–	2.7	~3	1.5-2.2	~2.5	~6

+ excluding outer-core sites and fuel-test loop

++ excluding FN sites and fuel-test loops rods use a meat of U_3Si_2 or U_3Si dispersed in aluminum which is co-extrusion clad with finned aluminum sheaths. To date burnable poisons have not been employed; however, fuel rods that incorporate either gadolinium or cadmium are now under development for the IRF. A simple core consists of a hexagonal arrangement of 18, 19, or 31 sites, most of which contain a hexagonal flow tube fueled with 36-rod driver assemblies; four to eight sites contain circular flow tubes fueled with 18-rod reactivity-control assemblies and provide surrounding water annuli into which hafnium cylinders may be inserted. With a simple core, a MAPLE reactor is H_2O-moderated and D2O-reflected. For the HANARO reactor, eight sites outside the 31-site central core accept 18-rod assemblies which creates a complex core with mixed H_2O and D_2O moderation. The IRF reactor assembly also employs mixed moderation with a split-core concept that places three horizontal CANDU-fuel-test sections between two core segments, each of which comprises an 18-site simple core plus two sites fueled with fast-neutron (FN) assemblies that contain 58 rods in two rings surrounding a central irradiation thimble.

The primary cooling system cools the core, except for any fuel-test loops, using two independent (one for MAPLE-1) circuits that draw H_2O from two nozzles in an outlet chimney that mounts on the reactor vessel. In each cooling circuit, a vertical in-line pump (or an identical standby unit) forces the water through plate-type heat exchangers and back to the inlet plenum. A fraction of the inlet coolant is discharged directly to the pool to create a flow down the chimney that confines the core flow to the lower part of the chimney. For the IRF and later designs, a venturi-type flow diode is located in each inlet pipe to limit the reverse flow through the circuit and ensure adequate core cooling flow in the unlikely event of a piping failure. For protection against potential loss of core cooling, MAPLE-1 uses an inlet-coolant accumulator tank and a check valve instead of a second independent cooling circuit with an inlet flow diode. The focus on prevention of fuel overheating during loss-of-cooling accident conditions is considered prudent because of the relatively low melting point of aluminum-based fuels compared to the zirconium-clad UO_2 of most power reactors.

The reactor control system operates four control absorbers (three for MAPLE-1) in each simple core. The hollow-cylindrical hafnium-metal control absorbers are attached to shafts that extend up through the chimney to a drive unit mounted on a support structure that is located above the pool. Computer-driven stepping motors actuate the control-absorber shafts. A Digital Control System (DCS) uses dual-redundant computer hardware to provide computerized control and monitoring for all reactor systems and experimental facilities. It has two main components, the Digital Control Computer (DCC) for control functions and data acquisition, and the Plant Display System which generates the operator displays, processes operator commands and transmits control commands to the DCC, provides alarm annunciation and acknowledgement, and controls the data logging. As well as the reactor regulation system, the DCS controls the primary cooling system, the D_2O cooling system, the secondary (process) cooling system, the pool water-make-up system and the H_2O purification system. It also provides balance-of-plant monitoring which includes surveillance of safety-systems, various electrical systems, and pool water and gate systems.

In view of the limitations of active safety systems [minimum unavailability of 0.001 acceptable to Canada's AECB (Atomic Energy Control Board)], the MAPLE concept incorporates two independent diverse shutdown systems. The first shutdown system functions by interrupting the power to the electromagnetic latches in the shaft drives of the hafnium control absorbers and enabling them to fall into the core. Except for the 31-site core, a highly diverse second shutdown system rapidly dumps the D2O from the region of the reactor vessel neighbouring the core, where it is normally held in place by helium-gas pressure. For the 31-site core, the second shutdown system inserts a second set of hafnium control absorbers that are normally hydraulically poised above the core.

The MAPLE containment concept acknowledges the difficulty of ruling out the possibility that neutrally buoyant material might cause single-channel flow blockage; moreover, reactors that support fuel development inevitably perform certain experiments that cross the threshold of fuel-element failure. Accordingly, the preliminary IRF concept (which incorporates high-power fuel-test loops) relies on a CANDU-type reinforced concrete containment building to house the reactor and its experimental equipment. For the standardized MAPLE research centre (MAPLE–Mk2, Mk3, or Mk4), a novel dual-containment approach is used to provide equivalent radiation protection of the public and on-site employees; the reactor hall (a robust reinforced-concrete structure built above the reactor pool) provides primary containment and the remainder of the reactor building acts as a secondary (vented) confinement structure. As the MAPLE-1 reactor was located within the existing infrastructure at Chalk River Laboratories (CRL), vented confinement was chosen and the reactor hall was designed as the lowest-pressure ventilation zone in the reactor building with provision for venting effluent through CRL filtration systems and then from the main site stack. The HANARO facility was also designed with vented confinement.

III. MAPLE PROJECTS AND PROGRAMS

The prototype opportunity for MAPLE technology was to build a dedicated facility (MAPLE-1) for the production of short-lived radioisotopes, such as ^{99}Mo, and transmutation-doped silicon[3]. The reactor was designed to produce a peak unperturbed thermal flux of $2x10^{18}$ $n{\bullet}m^{-2}{\bullet}s^{-1}$ in the D_2O reflector at a power density of 160 kW_t $\bullet L^{-1}$. Construction proceeded in four stages, beginning with the reactor and storage pools, reactor hall, process rooms, and building services in 1990. As of 1993 October, AECL had satisfied all of the requirements for the final stage of construction (installation of the reactor assembly and associated safety-critical systems) to the satisfaction of the staff of the AECB. However, construction was halted for nearly three years while key issues associated with the long-term production of medical radioisotopes were resolved with Nordion International Inc. and its parent, MDS Health Group Limited. The settlement concluded in 1996 July entails the completion of MAPLE-1 and construction of a duplicate back-up reactor, MAPLE-2, plus an associated isotope-processing facility for Nordion.

In support of MAPLE-1 construction and licensing, a development program was initiated to verify the performance of reactor components and characteristics unique to the MAPLE concept. To support the nuclear design, a network of externally available and in-house physics codes[5] was developed, validated, and applied to MAPLE-1 to characterize the reactivity balance, fuel management strategies, the deposition of fission energy, and the reactor's transient response to system upset[5]. Hydraulic rigs of varying size, from a one-fifth model of the reactor assembly to a full-scale rig[6] that was assembled from actual reactor components (e.g., inlet plenum, grid plate, reactivity-control devices) were built to verify the design of prototype components whose interactions could not readily be predicted. A heat-transfer data base was developed using an electrically heated single-pin experimental rig[7] and verified using a larger electrically heated facility that simulated various types of MAPLE fuel assemblies under normal and accident conditions.

Since 1986, AECL has worked with the Korea Atomic Energy Research Institute (KAERI) on the realization of the 30-MW_t HANARO multipurpose reactor facility[4]. AECL has supplied a MAPLE-type reactor assembly and associated equipment (e.g., control and shutdown systems) to meet KAERI's reactor design requirements. HANARO was designed for performing small-scale fuel and materials tests in support of both light- and heavy-water-moderated power reactors, producing radioisotopes, and facilitating basic and applied research using thermal and cold neutron beams. Following its initial criticality on 1995 February 8, commissioning tests have been performed at successively higher power levels leading to routine full-power operation.

Over the past several years, AECL has been assessing future requirements for irradiation facilities to support ongoing CANDU development and to facilitate neutron-based materials science in Canada. Three major CANDU research and development programs require irradiation facilities: fuel and fuel-cycle technology, fuel channel technology, and reactor safety research. With regard to materials science, a recent review[8] concluded that existing Canadian neutron facilities are seriously out of date and recommended that Canada make an immediate commitment to develop a fully equipped reactor-based national source for neutron beam research. The review stressed that a reactor with a full complement of instruments and a flux of 2-3 x 10^{18} $n{\bullet}m^{-2}{\bullet}s^{-1}$ would meet over 90% of Canadian needs and recommended that priority be given to the acquisition of optimized instruments rather than world leading flux levels[8].

In response to these Canadian requirements, AECL is developing the dual-purpose IRF described below. The IRF is presently at a conceptual stage whose objective is to assess and optimize reactor performance, to identify and manage the anticipated capital and operation costs, and to prepare the case for the government approvals that are prerequisite to proceeding with formal design and subsequent construction. Thus, no site-specific work has proceeded. However, the AECL Research and Development Advisory Panel has strongly recommended the IRF as the replacement for NRU.

AECL has also continued to develop the MAPLE family of multipurpose reactors to meet other anticipated Canadian and international requirements for isotope production, small-scale materials testing, and neutron-beam applications. The standardized MAPLE (Mk2, Mk3, and Mk4) research-centre concept is described and its anticipated performance is summarized in the following section.

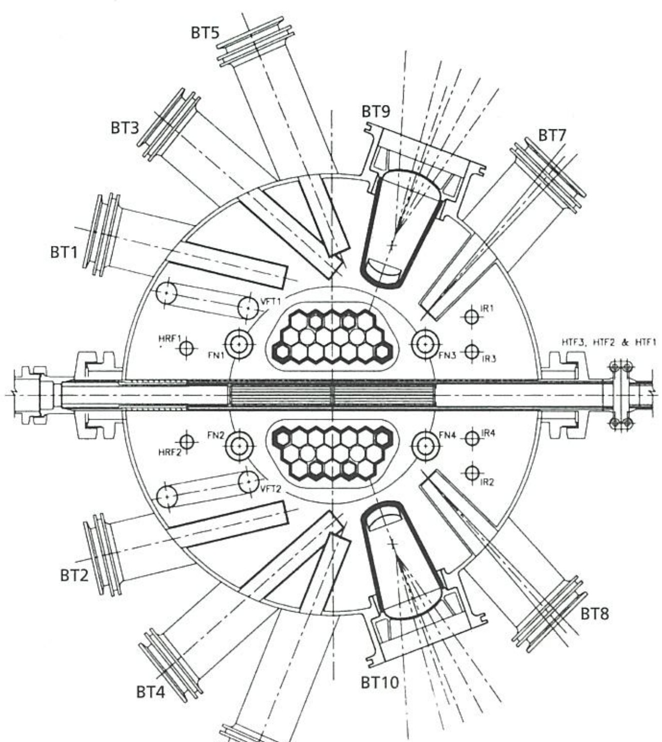


Figure 1: Plan View of IRF Reactor Vessel.

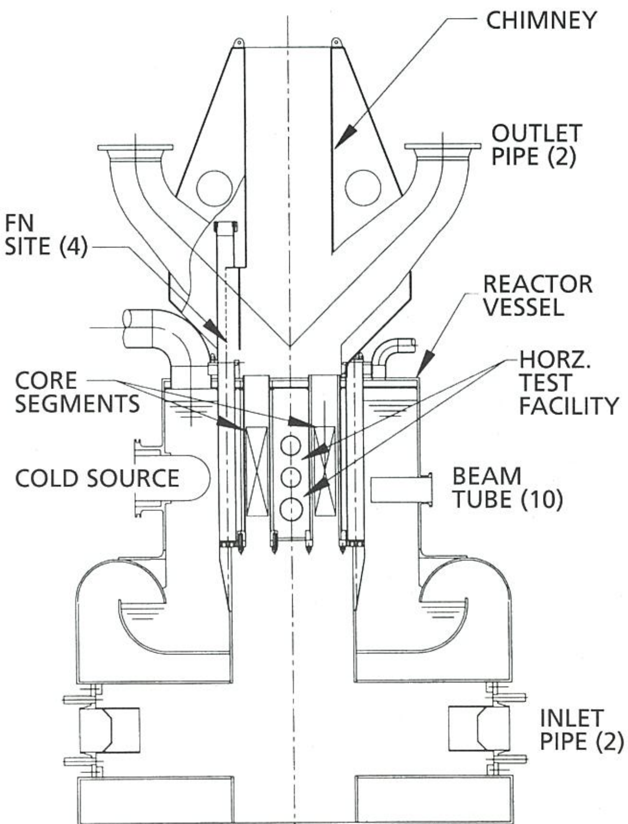


Figure 2: Vertical Section of IRF Reactor Vessel.

IV. FUTURE MAPLE FACILITIES

A. The Irradiation Research Facility

The IRF complex[9] includes the reactor building, an adjacent guide hall, and buildings for operations, administration, and utilities. The lowest reactor-building level provides access to three horizontal fuel test sections and an array of neutron instrument stations. Neutron guides extend from the outer face of the reactor pool through the building wall to an adjacent guide hall that houses additional neutron instrument stations. The operations building contains the reactor control rooms and experimental process facilities plus offices and laboratories and a hot cell for handling experimental equipment.

As shown in Figures 1 and 2, the IRF's experimental facilities include three horizontal test sections stacked vertically between the split cores described in Section II. Each test section has a guard tube that accepts a CANDU calandria tube and pressure tube and up to three fuel bundles. Provision is planned for controlling test-section power by adjusting the level of ^{10}B poison in a D_2O annulus between the guard tube and the calandria tube. The bottom horizontal test section can be configured such that the test section can be depressurized and blown down into a safety-test loop. Two vertical multi-element fuel-test facilities are provided with the fuel assembly located in the outlet leg of a U-shaped test section. Also, each 18-site core has two materials-irradiation sites where experimental rigs will provide accelerating aging conditions for zirconium-alloy specimens. The four FN-sites will accept various irradiation devices, including material-irradiation rigs, D_2O corrosion loops, and a gas corrosion loop. About ten vertical tubes will be provided in the reactor vessel for hydraulic rabbits, a pneumatic rabbit and miscellaneous other irradiations. Eight thermal-neutron beam tubes in the reactor vessel will deliver neutron beams to instrument stations in the beam hall; two of these will accommodate thermal-neutron guides that transmit neutrons to instrument stations in the guide hall. Two additional beam tubes will accommodate liquid-hydrogen cold neutron sources and a set of cold-neutron guides that deliver cold neutrons to instrument stations in the guide hall. However, as only one cold source and a single guide hall will initially be installed, the second cold-beam tube will first be used for supplying thermal neutrons.

One principal IRF requirement is to irradiate natural CANDU bundles under very uniform conditions at powers up to 1000 kW. Table 2 shows how the IRF will meet this requirement compared to NRU. To represent a CANDU-6 natural UO_2 bundle operating at 1000 kW when fresh, a 36-element 1.7%-enriched prototype bundle was irradiated vertically in NRU. In the IRF, natural UO_2 CANDU bundles may be irradiated horizontally at fully representative conditions in the centre of the IRF vessel using D_2O as the coolant.

The in-core materials-irradiation devices will provide a fast-neutron flux of over 1.3×10^{18} $n \bullet m^{-2} \bullet s^{-1}$ (i.e., 8.8 displacements annually per atom at 90% reactor availability) for a 150-mm length of zirconium-alloy specimens, and over 1.0×10^{18} $n \bullet m^{-2} s^{-1}$ (i.e., 6.7 displacements annually per atom at 90%) for a 450 mm length. As typical CANDU pressure tube material experiences one to two annual displacements per atom, the IRF will facilitate the required accelerated-aging studies. The FN sites will provide normal peak-CANDU conditions with a fast-neutron flux of 0.33×10^{18} $n \bullet m^{-2} \bullet s^{-1}$ (i.e., 2.3 displacements annually per atom at 90%) for a 440-mm specimen length

At 40 MW_t reactor power (exclusive of loops), the peak unperturbed thermal-neutron flux is $\sim 4 \times 10^{18}$ $n \bullet m^{-2} \bullet s^{-1}$ in the D_2O region outside of the split cores. Table 3 lists the calculated thermal-neutron fluxes at the beam-tube entrances for the IRF configuration shown in Figure 1.

B. MAPLE Multipurpose Research Centre

The reactor building of the standardized MAPLE multipurpose research centre is a three-story reinforced-concrete structure that contains the reactor and service pools, the reactor hall, shielded rooms for process systems, various service and workshop areas, plus a neutron-beam hall and other utilization facilities such as a BNCT room, fuel-test loop rooms, and irradiation-target handling equipment. At the operations level, the reactor hall, a six-sided 0.4-m-thick reinforced-concrete structure, accesses the reactor pool which is 5 m in diameter with a stainless-steel liner. Its depth varies according to the power and size of the reactor assembly: 11 m for the MAPLE–Mk2 reactor assembly, 13.6 m for the Mk3 assembly, and 14.8 m for the Mk4 assembly. A transfer trench connects the reactor pool to a shallower service pool outside the reactor hall. Traveling manbridges permit fuel and irradiation-rig handling using simple tools. The reactor hall is equipped with sealed hatches, personnel airlocks, and a waterlock gate to isolate the primary containment during postulated accidents. The rest of the reactor building forms a vented confinement area from which effluent may be discharged through HEPA and charcoal filters and then released from a 50-m stack.

An adjoining auxiliary building contains the reactor control room, electrical distribution rooms, rooms for common services (such as water, compressed air, uninterruptable power supplies, and diesel backup electricity), and various

Table 2: Comparison of CANDU Bundle Irradiations in IRF and NRU

	Number of Fuel Elements	Enrichment (wt% ^{235}U)	Bundle Power (kW)	Peak Outer Element Rating ($kW \bullet m^{-1}$)	Max. vs. Ave Element Rating	Axial Gradient	Max. vs. Ave Outer Element Power
CANDU	37	0.7	1000	64	1.13	1.01	~1.0
IRF	37	0.7	~1000	69	1.13	1.07	1.02
NRU*	36	1.7	1046	78	1.22	1.02	1.01

*Light-Water Content

Table 3: Unperturbed and Perturbed Thermal-Neutron Fluxes for the IRF Beam Tubes

Thermal Flux (10^{18} n•m^{-2}•s^{-1})	BT1 /2	BT3 /4	BT5 /6	BT7 /8	BT9 /10
Unperturbed	3.2	3.6	3.1	3.0	
Perturbed	2.4	2.5	1.8	1.8	
Perturbed (in cold source)					1.8

offices, workshops, laboratories, and conference rooms for operating, scientific, and support staff.

The MAPLE–Mk2 reactor assembly shown in Figure 3 uses the MAPLE-1 design modified to incorporate six or more horizontal beam tubes and an array of vertical irradiation sites. The reflector dump system actuates by selectively transferring the D_2O from within a "capped-baffle" region near the core to the external tank depicted in Figure 3. Figure 4 presents a typical horizontal layout of irradiation facilities. Three tangential beam tubes (8-mm wide x 14-mm high) are located in the thermal flux peak of the reflector tank for neutron-scattering applications, one 100-mm-diameter beam for neutron radiography is located further from the core, and one 200-mm diameter radial beam tube capable of housing a cold-neutron source and neutron guides is located just outside the dump baffle. An epithermal column (lower portion of Figure 4) may be specified to facilitate BNCT research and treatment. Vertical facilities include two hydraulic-capsule sites near the edge of the core, five high - flux isotope-production sites within the capped baffle, and twenty isotope-production sites in the outer reflector. Four flux-detector assemblies mount on the side of the D_2O vessel.

The MAPLE–Mk2 reactor fully meets international requirements for world-class neutron-beam research at a power output of 14 MW_t. This shown in Table 4 which shows the peak perturbed thermal neutron flux of ~2 x 10^{18} n•m^{-2}•s^{-1} available at tangential neutron beam tubes located ~320 mm from the core centre. The percentages shown in brackets refer to one standard deviation of statistical uncertainty in the calculations[1]. The flux quality factor quantifies the efficiency of the production of long-wavelength (>1.28 Å) neutrons, relative to the generation of short-wavelength (<0.36 Å) neutrons as the ratio of neutron flux in the sub-0.05-eV thermal group to the total epithermal-plus-fast flux. In the absence of conflicting requirements for isotope production or a BNCT facility, the number of high-flux beam tubes would be maximized and the trade-offs would be explored for increasing the flux at a large radial beam tube with a liquid-H_2 cold source while respecting the cost of a cryogenic system for removing the associated energy deposition.

At 10 MW, (which would qualify it for licensing as a research reactor in the USA, rather than a test reactor) a Mk2 reactor can facilitate wide-ranging multipurpose utilization for neutron-beam research, the production of radioisotopes, and cancer therapy. The peak perturbed thermal neutron flux is 1.6 x 10^{18} n•m^{-2}•s^{-1} which is very high for a LEU-fueled research reactor of this power level. The reactor is also capable of efficient radioisotope production as indicated by the following results which assume two days for processing and 80% extraction efficiency unless stated otherwise):

- The 7-d irradiation of 18 g MoO_3 in a hydraulic-capsule site yields 0.48 Tbq (13 Ci) of ^{99}Mo.
- The 7-d irradiation of a TeO_2 target with 45 g TeO_2 in a middle reflector site yields 0.37 Tbq (10 Ci) of ^{131}I.
- Irradiating capsules containing a total of ~60 mg ^{124}Xe for two 21-day periods yields 1 Ci (37 GBq). This scenario allows a decay period of ~28 weeks to enable the ^{126}I activity to decay to less than 0.05% of the ^{125}I activity.

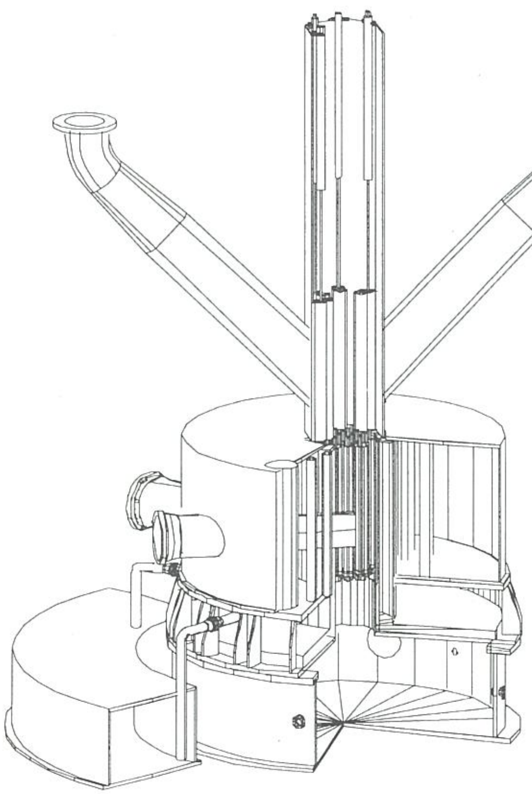


Figure 3: MAPLE–Mk2 Reactor Assembly.

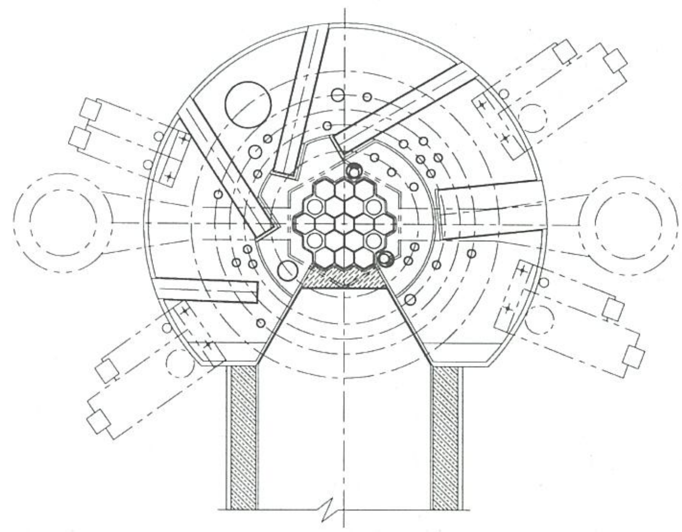


Figure 4: Horizontal MAPLE–Mk2 Layout.

Table 4: MAPLE Neutron Beam Tube Performance at 14 MW_t

Beam Type and Location*	Neutron Flux ($10^{18} n•m^{-2}•s^{-1}$)					Flux Quality Factor
	Thermal[a]	Thermal[b]	Total Thermal	Epithermal[c]	Fast[d]	
Tangential 7x14mm @ 324 mm	1.7-1.9 (1.5%)	0.45-0.49 (2.3%)	2.2-2.4 (1.7%)	0.17-0.18 (3.3%)	0.05-0.06 (6%)	8
Tangential 10-mm dia. @ 453 mm	0.40 (3.4%)	0.34 (3.6%)	0.74 (3.5%)	0.097 (7.3%)	0.005 (20%)	4
Radial 20-mm dia. @ 390 mm	0.69 (2.1%)	0.58 (2.1%)	1.3 (2.1%)	0.25 (3.2%)	0.02 (8%)	2.5

(a) <0.05 eV; (b) 0.05 eV - 0.625 eV; (c) 0.625 eV - 0.82 MeV; (d) 0.82 MeV
* Radial distance of beam-tube nose centreline from core centre.

- 37 Tbq (1.0 kCi) ^{192}Ir is produced by irradiating an assembly of four ^{192}Ir capsules containing 140 pellets (total weight 2.73 g) for 21 days in an inner reflector site.

Furthermore, a 10-MW Mk2 facility is well suited for the next stage of BNCT development. An epithermal column concept has been defined that uses a D_2O-cooled beryllium column, followed by a D_2O-cooled aluminum column, aluminum-lithium filters, and cadmium and bismuth shields. Table 5 presents its anticipated performance[1] in comparison with that of the proposed American Medical Therapy Reactor concept[10] and the measured performance of the facility at HFR-Petten[1].

The MAPLE–Mk3 variant employs a 31-site 30 MW_t core and a larger D_2O vessel than the Mk2 facility to meet materials-testing requirements that favour a high-power-density reactor with in-core irradiation space. The proposed design employs IRF fuel assemblies and reactor-control-system drives in a reactor assembly similar to that supplied for HANARO. The Mk3 reactor will provide several sites in core where the peak fast-neutron flux is ~1.7 x 10^{18} $n•m^{-2}•s^{-1}$ (i.e., 11-12 displacements annually per atom at 90% reactor availability) in zirconium specimens in IRF-type materials-irradiation rigs. Also, with peak perturbed thermal neutron fluxes of 2-2.5 x 10^{18} $n•m^{-2}•s^{-1}$ available, the Mk3 will provide neutron-beam performance that is generally similar to the IRF, HANARO, or the 14-MW_t MAPLE–Mk2 research centre.

To meet anticipated international for high-flux steady-state neutron sources, the MAPLE–Mk4 reactor employs a ~30 MW_t concept that places a region of high thermal neutron flux between two IRF-type split cores. The design concept relies on IRF fuel and other IRF reactor components with minor modifications. The reactor vessel will have two trapezoid-shaped, H_2O-cooled, IRF-type core regions with each 18-site core segment completely fueled. Horizontal penetrations are envisioned for 10-12 beam tubes, four of which (the cold-neutron beam tubes and the thermal beam tubes that feed thermal neutron guides) will access the central high-flux region where the peak unperturbed thermal neutron fluxes is about 7 x 10^{18} $n•m^{-2}•s^{-1}$. For the remaining beam tubes where the unperturbed thermal neutron flux is ~4 x 10^{18} $n•m^{-2}•s^{-1}$, the anticipated performance will likely be similar to HANARO or the IRF, that is the perturbed thermal fluxes will be ~2.5-3 x 10^{18} $n•m^{-2}•s^{-1}$.

Table 5: BNCT Facility Performance

Parameter	10 MW MAPLE -Mk2	Medical Therapy Reactor Concept	HFR Petten
Epithermal Neutron Flux ($10^{13}•m^{-2}•s^{-1}$)	26 (4%)*	18	0.33
Total Neutron Flux ($10^{13}•m^{-2}•s^{-1}$)	30 (4%)	20	0.38
Epithermal / Total Flux	0.85	0.91	0.87
Total Neutron Current to Flux Ratio	0.72	0.71	–
Treatment Time (min.)	~6	8	434
Gamma-to-Epithermal Neutron Flux Ratio	0.006	0.007	~0.1

* statistical uncertainty (one standard deviation)

V. SUMMARY

AECL is continuing to develop MAPLE technology to meet Canadian and international requirements for high-performance research reactors. The main current focus is on developing the IRF concept to support the evolution of CANDU technology and generate neutrons for basic and applied materials science. AECL is also developing a standardized MAPLE research centre for neutron-beam applications, radioisotope production, and materials testing.

REFERENCES

The original paper had 10 references. If desired, please contact the authors.

Problems and Solutions

by Keith Weaver[1]

Introduction

The terms "problem" and "solution" are too familiar, in many ways. I suggest they are so familiar to us as words and as ideas that we make insufficient attempts to understand what they mean in some important contexts.

It is almost a truism that an effective scientist or engineer is one who works on problems that have been defined well and carefully. Someone who doesn't work in this manner risks wasting time, effort and money. And yet, it is still all too common to find problem statements couched in terms that describe the result being sought rather than in terms of the difficulty, shortcoming, weakness or failing that brought about the need for problem solving activity in the first place. In other words, although everyone recognizes in an abstract way that a problem and a solution are different, in specific instances the distinction is sometimes lost. How often does one hear the question "What problem are we trying to solve?" Not often enough? How often does one hear the answer "We have to produce a better X?" Too often?

Good problem definition is an important step. The need to define the problem should be a reminder to focus, to analyse, to think and to judge. Too frequently, this step resembles more a ritual that is carried out rather mechanically. The more specific and precise one can be about the problem at hand, the more obvious the possible solution methods are likely to be, and the more clearly one is likely to be able to foresee the characteristics of the desired outcome. Against all this, it is puzzling that there should be so little good, practical advice available on problem definition.

What Problem?

To begin, I intend to nail my colours to the mast early by indicating what problem I am concerned with in writing this article. The problem I want to deal with here is, as I see it, the shortcomings that plague the understanding and use of those deceptively simple terms "problem" and "solution", and what can be done to avoid these shortcomings.

A problem should be thought of as something wrong, incorrect or incomplete; as something that doesn't work, should be improved or needs to be modified in some way; as an obstacle to be overcome, a situation to be used to advantage or a circumstance to be clarified. We will come to "solution" later.

It's very easy to think that one is defining a problem when really that is not what's happening at all. Suppose that a problem is stated in terms such as, for example, "a need to have staff work smarter". Can one say that this phrasing has actually articulated a problem? My answer would be "No". Anyone making a statement like this probably is not identifying a real problem. Do they think they are identifying a real problem? Almost certainly yes. So what's happening?

Consider carefully the words "a need to have staff work smarter". Doesn't this come closer to being a description of a solution? (The common understanding of "solution" is good enough for now. There will be more on "solution" later.) If staff worked smarter, then we could... what? Overcome the problem we have because they are presently not working smarter? But this just leads us back to an undefined problem, the solution to which is for staff to work smarter. Maybe there is a need to remove obstacles that are presently preventing or hindering staff from working smarter. But this is really the same as before: there is some obstacle in our way, some problem, but we don't know what it is because we haven't stated it.

Now consider things in a somewhat more positive light. Suppose that "a need for staff to work smarter" is actually viewed as a solution. What might the problem be? One statement of the problem corresponding to this solution might be something like "We appear to have too much work" or "We appear to be processing work too slowly", or "We appear to be making too many mistakes". Once one makes statements like this, statements that come closer to identifying what is actually wrong, than it can be seen almost immediately that "a need to work smarter" is one possible response, one possible solution to this problem. But it is only one response of many. What about other possible responses? How was this particular response chosen? We don't know that, because no basis, no criteria for the choice have been stated. It may seem to be a random choice, but people don't really function like that. More likely, it was the result of a pre-judgement.

If the problem and its solution were indeed prejudged in some way, then one can expect the solution to be "contaminated". That is, it will probably contain unexamined judgements as to the true nature of the problem. "A need to work smarter" might describe a problem that someone has diagnosed as follows: "We

[1] Keith Weaver is a nuclear safety analyst in his day job, and he has committed, at least once, all the errors alluded to in this article.

appear to be making too many mistakes, and the cause of these mistakes is inadequate commitment of our workers to the job." It should be clear that in order to arrive at a cause and effect assessment like this, one must have faced and answered the questions "Are we really making too many mistakes?" and if so, "WHY, are these mistakes being made?".

When viewed in this light, the formulation "We have to work smarter" describes, in effect, one way of getting around a problem rather than describing the problem itself. It is tempting to fall back on buzz phrase terms, and describe it as a solution looking for a problem. The situation is actually worse than this, however, since what we really have is a solution masquerading as a problem. What has happened here is that one solution out of possibly many has been allowed to take control of the situation (or has been imposed onto it by someone's prejudices or assumptions). If work goes ahead on this basis to find ways of "working smarter", it is unlikely that the real problem will be solved, for the simple reason that it hasn't been identified.

Whose Problem?

Somebody always has to take ownership of a problem. If this doesn't happen, then there is no obvious direct interest in seeing that the problem is dealt with. The interest of all problem owners is not always the same, and is not always straightforward. Leaving political games aside, the owner of a problem may have a number of interests in finding a solution. One interest may be ordinary working necessity: he or she may have been assigned the problem and he or she had better solve it if he or she wants to avoid The Big Boot. Another interest may be professional pride. A third interest may be personal or intellectual interest. A fourth interest may be entrepreneurial drive or commercial necessity. In an actual situation, it may be some mixture of these or others.

Is it important to know who owns the problem and why they want it solved? Well, yes. Unless everyone involved knows who owns a problem, unstated assumptions about ownership can arise. If the problem and its solution is entirely contained within one person's sphere, things can be relatively simple. The problem owner is also solely responsible for providing the solution. In the case of either success or failure, the garlands or The Boot know exactly where to go. If, as is more likely, the problem is big enough that more than one person is involved, then one or more people may be working on one or more parts of the problem. When a problem is divided up like this, guess what happens? Each person is now working on a sub-problem, and this sub-problem has to be defined just as though it were a "problem". There are now interfaces and communications to worry about as well. Through all this, the original problem owner still owns the basic problem and will still be hunted down by The Big Boot if things don't work out.

A good example of a problem being distributed among several people is a situation common to the nuclear business and elsewhere: the need to have contract research carried out. We sometimes have a problem that needs input in the form of research data. In these situations, things can become quite interesting.

Before a research project can be commissioned, some statement on the nature of the application problem should be available. (Whether this always the case, I leave as a question for the reader.) But the researcher who will eventually be doing the research work will also have to identify the research problem. It should hardly need stating that the application problem and the research problem are closely related. Before the research begins, it is very desirable that the researcher should understand at least the general nature of the application problem. At the other end, when the research has been completed, the applications engineer has to have a good appreciation of the research results in order to apply them intelligently, or even correctly. This is the main reason why things become more interesting: because now we have more than one problem loose, and the problems are related. This means there should be more than one problem owner, and it also means that there are actually two interfaces: one interface relates the applications problem to the research problem, and the other relates the research solution to the applications solution.

Leaving the problem owner to his woes, I want to turn now to considerations of what is meant by a "solution".

What Solution?

Once the nature of the real problem is known, one can concentrate on the solution. Right? Wrong.

Few problems are so pure that they have only one solution. There are usually a number of possible solutions, and for each solution there may be several ways of getting there. Let's say that you are working on windshield wiper design. You need a new wiper for a new car model, and the design you have come up with was shown in tests to perform poorly at speeds greater than 60 mph in moderate rain. In talking to a colleague, you learn that a new type of rubber has just been developed and that it has properties quite different from those of your present wiper blade. The more you think about it, the more it seems that your solution is at hand. It looks like your troubles are over. Alas, it may be that they are just starting.

In fact, you have probably just fallen into an old trap.

The trap, in this case, was a solution looking for a problem. Since there are usually many possibilities that will offer solutions to a problem, the question is "How does one choose among them?" One good way is to try to determine what characteristics your ideal solution might have before you begin trying to find specific, real-world, non-ideal solutions. This approach has two salient advantages.

The first advantage is that it leaves the problem solver in control. The characteristics of an ideal solution are those things that would counteract, rectify or avoid what is wrong. So, setting out to identify the characteristics of an ideal solution, i.e. putting right what is wrong, is not easy to do if one can't say what is wrong. This approach, therefore, encourages good problem definition. Not all the solutions that can be imagined or desired will be possible or acceptable. An ideal solution has certain characteristics that are dictated by constraints, by the preferences of the problem owner, by an understanding of what it is that needs to be corrected, and sometimes by the ways that are available to arrive at a solution. What one shouldn't do as a matter of regular practice is to let one solution method dictate, *a priori*, the nature of the solution that will be provided. (This is the trap noted earlier.) The trap can be a subtle one, and can result in a solution method hijacking the entire problem solving exercise. The problem solver becomes a sort of acquiescent observer, and is no longer in effective control. It's far better to let the dictating go the other way: if one has ideas on the kind of solution that is ideally wanted or needed, they will probably point toward a preferred solution method and can offer criteria or a basis for choosing among alternative solutions.

The second advantage is that with a list of the characteristics of the ideal solution, formulated early in the exercise, one has something to look back on and to judge the actual solution against, once it has been arrived at.

Resolving a Problem

Although this picture of things is more complicated than one might have desired or thought necessary, eventually we find the answers we need, and we can set about solving our problem. Assume that we have now reached the state where a successful research programme has been completed, and the results passed to the customer. The work looks excellent and the customer is happy. All that remains to be done now is to apply the results and solve the problem. Sounds too pat, doesn't it. You're way ahead of me.

Before going any further, it is worth pondering the meaning of those three words "solve the problem". What does it mean when we say we are "solving a problem"?

This sounds like a perfectly obtuse question, but in fact some reflection should indicate that it is a good question and one very much worth answering carefully.

It should be clear that it is not easy actually to make a problem "go away", or even to understand what that expression might mean. If part of our problem is ignorance or uncertainty, then by dispelling that ignorance or uncertainty it may be possible to prove that either some supposed problem never actually existed, or that the perceived problem was not what we supposed, but was actually something else. The first of these is not really solving the perceived problem, since the end result was to show that there never was a problem in the first place. In the second instance, we may have made the current situation easier by showing that the problem lay elsewhere. But the problem has not "gone away". It has just "moved", and it may (or may not) still be of concern.

Recall that I have characterized a problem as something wrong, something missing, something that doesn't work, etc. With this in mind, consider the question of carrying out and using the results of some piece of nuclear safety research.

The application of our research may lead, for example, to changes in hardware that alters some boundary condition such that the appearance of the problem is shifted to a different set of conditions. To choose a fanciful case, our research might result in the construction of a larger containment vessel than was currently in place. This may mean that the original set of conditions under which significant potential for harm arose, have now been substituted for another set of conditions. In this case, those conditions that gave rise to a specific problem, to something that was wrong, have been shifted into another domain or counteracted somehow, but they have not been "removed." Alternatively, our research may indicate that the best way to resolve the problem is to avoid some set of conditions of concern. This could be done through procedural means, through engineering fixes that give warning when the conditions of concern are about to arise, or through automated avoidance or preventive means. In these cases, one has found various ways of avoiding the problem, but in no real sense has one actually made the problem "go away". One view of some problem solutions is presented in the accompanying figure.

What this figure seems to imply is that there may be very few, if any, instances in which "solving a problem" actually means that the problem "goes away" in a meaningful sense. (Whether the problem does appear to "go away" or not, may come back once again to that critical definition of what the problem is. If a problem does appear to "go away", should this be a warning about a badly defined problem?) We may be able to prove that a problem never existed, that our view of things was distorted by incorrect information or by lack of information and that as a result we diagnosed a perceived problem but not a real one. In many other instances, "solving a problem" may mean finding ways to avoid it, to contain it or otherwise to live with it. In some cases, a hardware change may make a problem "go away" because the source of the problem is removed. Chances are that we are just replacing one problem with another. But often we are dealing with physical phenomena that have certain characteristics, and these characteristics impose constraints or limitations that have to be lived with or otherwise dealt with. In general, neither these characteristics, nor the constraints they impose, can be just made to "go away".

Some examples of "solutions" to problems in a nuclear context are as follows. The more serious aspects of limiting doses to the public following an accident are achieved by building a concrete cylinder around the reactor and most of its associated equipment. This could be viewed as imposing a physical constraint that will help avoid releasing fission products. A second example involves avoiding flux tilts of various kinds. The solution to this problem is a procedural one; rules are formulated on how a reactor should and should not be operated. Perhaps the best known "solution" of all is the ASME boiler and pressure vessel code. This solution is not the result of having found a way to prevent pipe and vessel failures under any conditions. Rather, it involved finding out the properties and characteristics of various materials (the limitations that have to be respected), and then laying down a set of rules on materials choice and designs to ensure that we will stay well within those limits and out of harm's way.

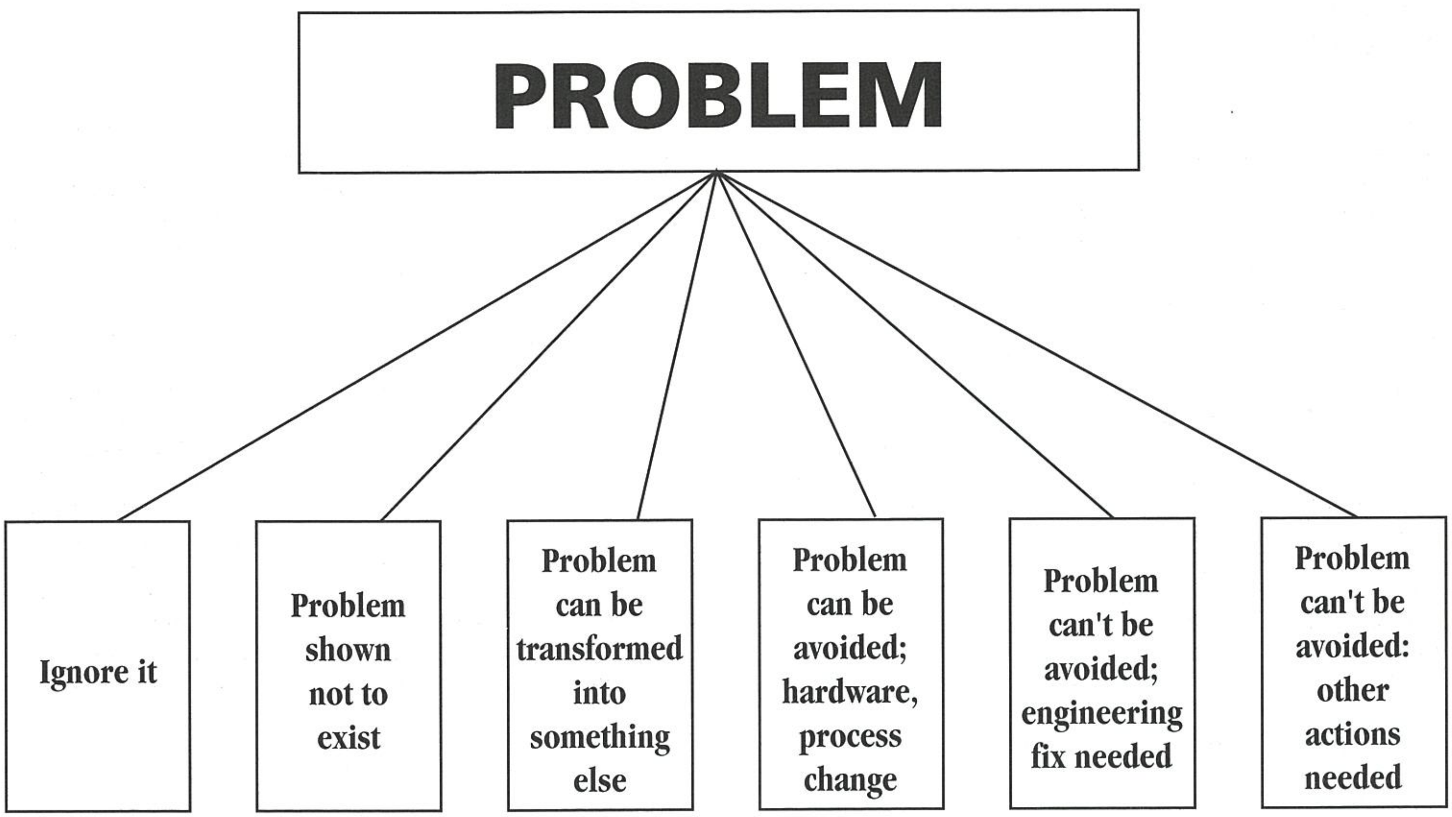
Maintaining Problems in "Resolved States"

How much effort would you put into maintaining a problem in a resolved state, after you had put the solution in place? Probably none, if you thought that you had made the problem "go away". Is it reasonable to presume that a problem will be scared away by your solution, and that it will stay away forever after?

If, on the other had, the "resolution" of a problem means that some way has been found of containing, shifting or avoiding it, and it has not been somehow "permanently disposed of", then there will probably be a need to put in place some measures to ensure that the problem does not recur. Such a recurrence might take place for any of a number of reasons. Some other apparently unrelated change might be made that moves one back, unwittingly, into an undesirable set of operating conditions, or which extends the range of undesirable operating conditions such that they now include some part of your desired operating states. A recurrence might also take place because the original research results are lost or forgotten, because the understanding of the results or their significance has become blunted, or because the role of the results in formulating a procedural or other barrier between you and the problematic region is forgotten.

A problem may recur because of poor documentation, or because of a failure to maintain adequate knowledge and expertise in the area of competence where the problem arose. There may be a loss of context, resulting in the original concern being distorted or over-ridden. There may be others.

Another cause may relate to the main topic I have been discussing in this short article: a failure to understand clearly enough just what those innocent-looking words "problem" and "solution" mean in a particular instance.



GENERAL news

Building a Culture of Excellence

Deep River Science Academy Celebrates 10th Anniversary

by Paul Cowie

Ten years ago, two concerned AECL scientists conceived the idea of an educational institute that would give achieving students the chance to experience professional research and development. Today, the Deep River Science Academy is still going strong, with campuses at three locations across Canada. Recently, co-founder John Hardy, director of AECL's TASCC facility, looked back on the achievement and forward to reaping its fruits.

One summer, early in the history of the Deep River Science Academy, John Hardy recalls receiving a phone call from an AECL Public Affairs officer. Hardy was told the Public Affairs office was becoming swamped by Science Academy students looking for information on AECL to take back to their schools, and that if he could keep the students from going in one at a time, Public Affairs would gladly send them all a customized package of materials. Hardy laughs, When these kids get turned on, they make fantastic ambassadors for science.

These kids are the talented and curious high school students from across Canada who for the last ten summers have been turning on to scientific research and development, much of it nuclear, at the Academy's three campuses: two – Deep River, Ontario and Whiteshell, Manitoba – associated with AECL's Chalk River and Whiteshell laboratories; the third at the Okanagan University College in Kelowna B.C. By 1996, over 400 students had taken part in professional research projects under the guidance of scientists or engineers and undergraduate tutors, gaining educational credits through a combination of science theory and hands-on experience. An ambitious concept, but the masterminds behind it all had even loftier goals.

The Early Years

In the mid-1980s, Hardy and Alistair Miller (AECL project manager, Heavy Water Production Processes) brainstormed creative solutions to deal with a decline in federal funding for nuclear research and the need to awaken public interest in the situation. They discussed the need to nurture a national science culture that would ensure a real commitment to science and technology in Canada. Their solution: give our country's brightest students the chance to experience what Hardy describes as the thrill of research – in the process developing a culture for the future that understands and values scientific pursuits.

So how did it become a reality"

A fledgling Board of volunteer directors was created, initially for a single campus at Deep River, Ontario, that would use the facilities of nearby Chalk River Laboratories and the Petawawa National Forestry Institute. In the early struggle to secure funding, one far-sighted gesture was enough to ensure that the Academy saw the light of day: the Deep River Town Council, to Hardy's amazement, offered at $25,000 line of interest-free credit. "We were proud to draw only $17,000 of that credit in the first year, and at the end of the year, our Board presented the town council with the money back – I've never seen so many surprised faces in my life", said Hardy. "We've never had to borrow money again."

The early years saw major contributions of time and experience from people like Jack Gray, retired Renfrew County superintendent of education. Jack was our first principal and a powerhouse in delivering the school's educational component, says Hardy. As the Academy continued to expand (to Whiteshell in 1993 and Kelowna in 1994) regional boards were created to meet the new challenges, such as raising $200,000 annually from corporate and government sponsors across the nation. Meanwhile, awards recognizing the Academy's achievement have continued to roll in, including a Conference Board of Canada (Ontario) Award for Excellence in Business-Education Partnerships, a Prime Minister's Award for Teaching Excellence (Jack Gray), and a Manitoba Sustainable Development Award of Excellence.

School a Big Event in Their Lives

For Louise Young, current principal of the Whiteshell campus, the ultimate success of the program is the process of transformation she observes taking place each summer as students overcome their self-doubts and realize they have the capacity to make meaningful contributions to science at the highest level. It's a very concentrated course of study, says Young, all day long the students are either performing lab work, writing reports or listening to lectures or tutorials. By the time of their oral presentations (of their project results) they're just glowing with confidence.

It's this all-out commitment to learning that also impressed industry observer Barry Garbutt, Dean of Applied Sciences at Winnipeg's Red River Community College, who attended this year's Whiteshell grad: I saw three or four students in tears, hugging each other and I thought, This is more than a school, it's a big event in their lives. Garbutt believes the Academy's concept is similar to an apprenticeship model, in which students receive the theoretical knowledge they require at the time they need to use it: Perhaps this is significant, perhaps we see there an opportunity to provide education in a very different way – without course numbers for example – giving the theory as the student gains the practice.

Currently, 80 students are accepted each year to the Academy, after a lengthy recruitment process which begins with application forms being sent to science teachers and guidance counselors across Canada. The number of students may rise to well over a hundred if a fourth campus, being considered for the Atlantic region, opens in 1998.

In whatever way the Academy decides to expand, its achievements over the past ten years have already exceeded its founders expectations. Post-graduate tracking indicates that over 90% of Academy students go on to university studies in science or engineering, with many winning scholarships and proceeding to graduate work. As he reviews student biographies each year, Hardy says he is always staggered at the potential of the young people before him: Most of them are talented in so many ways – they play musical instruments, they're sports stars, they organize charity work – these are go-getters, our future leaders. When Academy students return home, he says, they remember their experiences and keep in touch: Eventually in their careers they will form a network of excellence among the research community. It's a start to the culture we've tried to create.

Obituaries

BOB KEATING

Canada's leading nuclear representative in Korea for many years, Robert K. (Bob) Keating died in Oakville, October 20, after a four month bout with cancer.

Bob began his career with Atomic Energy of Canada Limited in 1966 after graduating from Nova Scotia Technical College and was assigned as a design engineer, attached to Canadian General Electric Company, working on the Port Hawkesbury Heavy Water Plant. Two years later he moved to the Bruce Heavy Water Plant and subsequently became senior project engineer and then head of plant projects with the then Chemical Company of AECL.

In January 1980 he began a two-year term as executive assistant to Jim Donnelly, then president of AECL. At the end of 1981 he moved to marketing and sales in AECL International and was responsible for overall coordination of a major bid to Mexico.

Later that year he began his long association with Korea as proposal director for what was then termed Wolsong B. The next year (1982) he became Director, Sales and Proposals - Korea. That expanded in 1985 to Director - Asia, the Pacific and Latin America. In 1989 he moved to the Seoul, Korea office where he played a pivotal role in winning the contract for Wolsong 2 and, later, for Wolsong 3 and 4. According to former AECL president, Don Lawson, Bob essentially set AECL's (and Canada's) strategy in Korea and won the confidence of senior people in the Korea Electric Power Corporation.

He returned to Canada in 1991 and the following year was assigned Vice-President - Atlantic Region for AECL. Then, two years later, in 1994, he returned to Korea as Vice-President - Korea.

Bob was an active member of the Canadian Nuclear Society and attended almost all of the annual CNA/CNS conferences, usually bringing visitors from Korea and other countries.

He was buried in New Brunswick but a memorial service was held in Oakville on November 12 when many of his colleagues and friends from Sheridan Park and other parts of the nuclear community gathered to remember him.

ARA MOORADIAN

Another of Canada's nuclear pioneers has passed away. Dr. Ara Mooradian, a former executive vice-president of Atomic Energy of Canada Limited, died in Deep River on October 4 of lung cancer.

Ara joined AECL at the Chalk River Nuclear Laboratories in 1950 in the chemical processing group where he worked initially on plutonium separation. Subsequently he was a key member of the team that developed the fuel for NPD and Douglas Point which became the basis for the current designs of CANDU fuel. In 1963 he was appointed Director of the Development Engineering Division which was responsible for the ongoing evolution of fuels for both power and research reactors.

In 1966 he moved to the Whiteshell Laboratories in Manitoba as Managing Director, becoming Vice-President of the site in 1969. Two years later (1971) he was appointed Vice-President of the Chalk River site and in 1977 took on responsibility for both laboratories. In 1978 he was appointed Executive Vice-President, Research and Development.

Ara was elected a Fellow of The Royal Society of Canada, a Fellow of the Chemical Institute of Canada and a Honourary Fellow of the Royal Australian Chemical Institute. He was awarded an Honourary Doctorate of Science from the University of Manitoba, was an associate member of the former Science Council of Canada and served as president of the Chemical Institute of Canada. In 1980 he was awarded the W. B. Lewis Medal by the Canadian Nuclear Association.

Ara was active in whichever community in which he lived and served as the first Mayor of Deep River in 1958. Following his retirement in 1987 he continued to be active in professional affairs and was appointed to the Science Advisory Committee to the Director General of the International Atomic Energy Agency in 1988.

DR. GORDON STEWART

A long-time medical director at Atomic Energy of Canada Limited's Chalk River Nuclear Laboratories, Dr. C. Gordon Stewart died in Deep River, November 20.

Gordon was twice chairman of the International Commission on Radiological Commission (ICRP), the body that has set the radiation protection standards followed by almost every country, and was the only Canadian to be appointed to that position.

He served for many years on the Reactor Safety Advisory Committee established by the Atomic Energy Control Board in 1956 where he participated in the development of the basic Canadian nuclear safety concepts. He was also very much involved in the drafting of the first health and safety regulations issued as part of the Atomic Energy Control Regulations in 1960.

Before joining AECL he had served in the Royal Canadian Navy as a Surgeon Lt. Commander.

Gordon was an avid outdoorsman and spent much of his free time in the woods surrounding Deep River, his home for over 40 years.

A New Publication

A 50 YEAR VISION

In the spring of 1996 the International Nuclear Societies Council issued a 70 page document entitled A Vision for the Second Fifty Years of Nuclear Energy , the results of a three-year study involving many individuals from the member societies of the INSC. The study concludes that nuclear technology will be essential to provide energy and that its use in health care, in the food industry and in manufacturing will continue to grow. It predicts that nuclear science and technology will be commonly accepted.

A world-wide organization, the International Nuclear Societies Council represents nuclear societies in 37 countries having a total membership of over 50,000. The INSC committee which prepared the study was chaired by Dr. Masao Hori of the Atomic Energy society of Japan and the document was edited by Dr. Stanley Hatcher of the Canadian Nuclear Society. It was published by the American Nuclear Society and is being distributed by all of the member societies of the INSC.

The study notes that in fifty years the world's population will double, with most of the growth occurring in developing countries. As these nations strive to achieve a quality of life closer to that of industrialized countries the world will need substantially more energy and global energy demand will more than double over the next 50 years. Although the use of fossil fuels, which today supply 80% of the world's energy, will be constrained by environmental concerns, it will continue to grow. Even with expansion of hydroelectric power and renewables there will be a shortfall and the only available energy option is nuclear. With technology available today there will be ample uranium and thorium to fill such energy demands.

The use of nuclear science and technology in the health care field is predicted to continue to grow in imaging for diagnostics and for therapy. Radiation sterilization of medical supplies is expected to become universal.

Irradiation is a proven method of protecting food from insect infestation, bacterial decay and spoilage. The study predicts that in fifty years irradiation of many foods will be considered as necessary and desirable as pasteurization of milk is today.

Nuclear energy as a source of energy will require large investments in financial and human resources. The study examines strategies needed to achieve the vision. It reviews the evolution underway in the design, construction and operation of current nuclear power plants. Continuing cost reductions will be necessary to ensure that nuclear power remains competitive and a "Henry Ford" type of mass production may be needed.

By the middle of the 21st century the demand for energy will likely make recycling an attractive option. Fast reactors offer the promise of breeding and offer the assurance of sustainable and economic nuclear fuel supply for centuries to come.

Copies of **A Vision for the Second Fifty Years of Nuclear Energy** *have been distributed to each CNS Branch and are available from the CNS office in Toronto.*

Change at Gentilly 2

As part of the recent organization changes at Hydro Quebec, Gentilly 2 has a new director.

Denis Pelletier has been named Directeur Production - thermique et nucléaire and in that post will be director of Gentilly 2 as well as of Hydro Quebec's few thermal plants. He was formerly Vice-president of the Manicougan Region.

M. Pelletier replaces Roger Emard who is, reportedly, taking early retirement.

No other changes at Gentilly 2 had been announced as of the end of November.

Darlington Licence Renewed

Following its public meeting in Oshawa on November 28, the five-member Atomic Energy Control Board announced that the Operating Licence for Ontario Hydro's Darlington Nuclear Generating Station had been received for a period of two years, to 30 November 1998.

The Board also announced renewal of the Operating Licenses for the two reactor fuel manufacturing facilities operated by General Electric Canada in Toronto and Peterborough for two-year terms, to 31 December 1998.

Other renewals were for waste management facilities at the University of Alberta and at the Pickering NGS site.

The Board deferred its decision on a renewal of the Operating Licence for Pickering Nuclear Generating Stations A and B.

CNS news

BRANCH NEWS

The following article is based on the report on CNS branch activities prepared by Ben Rouben, CNS 1st vice-president and chair of Branch Affairs, for the November 1996 meeting of the CNS Council.

Most of the Branches are well into their programs for the season.

Bruce

The Branch Executive for 1996/97 is composed of:

Chair - Program Coordinator	Eric Williams (Bruce A)
Secretary - Past Chair	Karl Mika (Bruce B)
Treasurer	Glenn Sutton (Bruce B)
Social Coordinator	Stephanie Hunn (Bruce A)
Stakeholder/Public Relations	Patrick Moran
Advisor	Juris Grava
(Bruce A Business Development)	

This year's Branch program had a very good start on Oct. 1 with a seminar, followed by a social hour and BBQ. The guest speaker was Mr. Ken Talbot (Director, Pickering Division, Ontario Hydro), who spoke on "Pickering's Return to Excellence". The activity was held at the Bruce Nuclear Power Development's Information Centre. The seminar attracted an impressive attendance of 62, and 35 stayed on for the social hour.

The Branch held a second seminar on October 10 with Dr. Jerry Cuttler (AECL)(and past-president of the CNS) speaking on "The Chernobyl Legacy - 10 Years Later".

The following meetings are planned for November and December:

- 1996 Nov. 12, seminar by Mr. Michael Mirsky, "Competing in a Deregulated North American Energy Market"
- 1996 Dec. 5, seminar by Dr. Murray McQuigge, on "The Nuclear Role of a Medical Officer of Health"

The Branch is planning to hold ten meetings in 1997. The first two are:

- 1997 Jan. 7, seminar by Mr. Jim Burpee, General Manager, Bruce Nuclear
- 1997 Feb. 6, seminar by Dr. David Whillans (Ontario Hydro) on "The Health Effects of Radiation"

The Branch continues to pursue the establishment of an Education Grant with local high schools. Considerable work has been done, and the Branch looks forward to the first awards being made in fall of 1997.

Chalk River

Branch Chair Bob Andrews withdrew from the Chairmanship of the Branch. Many thanks are due to Bob for his volunteer efforts on behalf of the CNS. The Branch organized excellent programs under his leadership.

The new Branch Executive is composed of:

Chair	Helen Griffiths
Past Chair	Aslam Lone
Vice-Chair	Jeremy Whitlock
•Treasurer	Bryan White
•Secretary	Ravi Jategaonkar
•Communications	Al Rose

Tentative plans for Branch seminars are as follows:

- 1996 Nov. 21, seminar by John McManus, of the AECB, on the new Nuclear Safety and Control Act.
- A seminar in 1997 January with a guest speaker from Nordion.

Darlington

The Branch Executive met on Sept. 25 to discuss finances and program. Some of the ideas being considered for activities are:

- a talk on the design/safety/licensing of the MAPLE reactors.
- a trip to Port Hope - Zircatec or Comenco
- a talk on the CANDU 9
- a talk on food irradiation
- a social evening (Branch dinner), perhaps around the Oshawa General Hospital nuclear unit
- a repeat tour of Clarkson
- a talk by someone from WANO or INPO
- a Council meeting at DNGS in the spring of 1997.

Golden Horseshoe

The Branch Executive for 1996/97 is composed of:

Chair	Pierre Gérard
Vice-Chair	Hassan Basha
Secretary	Dave Kingdom
Treasurer	Robert Léger
Propaganda (WebMaster)	Simon Day

The Branch continues to be the curator of the CNS home-page on the World Wide Web. Visit the CNS at
http://www.science.mcmaster.ca/cns/www/cns/cns.html.

Manitoba

Branch Chair Morgan Brown has communicated with Branch members to ask for volunteers to serve on the Branch Executive for 1996/97.

The Branch is planning to hold its Annual General Meeting on November 13, with a wine-and-cheese party to celebrate the 31st anniversary of WR-1 and a talk by Bob Lidstone (AECL) - and perhaps others - on "Whiteshell's WR-1 Organic-Cooled Reactor". Morgan sends these "familiarization notes" prior to the talk:

November 1 will be the 31st anniversary of first criticality of WR-1, so I've proposed a little trip down memory lane. WR-1 was an organic-cooled, heavy-water-moderated vertical-tube research reactor that operated successfully until 1985, when it was shut down for economic reasons. It is interesting to note that the outlet temperature for one loop of WR-1 was 400C (a CANDU is limited to 310C) and the organic pressure was 2 MPa (10.5 Mpa in a CANDU). Of course the coolant was flammable, so this may be the reason no organic CANDU was ever built (I stand ready to be corrected)."

Morgan is also following through with his plans for a calendar. Here are his words on the subject:

I'm planning to get the first "Nuclear Canada Calendar" published - 150 copies. This year will be low-tech - a black and white calendar with a card backing with one picture (WR-1, no less). I've put as many Canadian nuclear events as I could find onto the calendar (with a few international ones too), along with major CNS conferences. The cost? Well, it will cost ~$3 each to produce them, so I expect the calendars will cost a little more than that. If people like them and there is sufficient demand, then next year's will be a little snazzier (one picture/month?, some colour?).

Morgan notes that the Manitoba Branch has recorded several of the Branch seminars on video. The following videos are available:

- 1994 Oct. 3, Mr. Keith Dinnie (OH), "Pickering: A Risk Assessment Study"
- 1995 Jan . 15, Mr. Ralph Hart (AECL), "Options for the CANDU 9"
- 1995 Feb. 27, Mr. Merle Griebenow (Neutron Technology Co.), "Boron Neutron Capture Therapy for Treatment of Cancer"
- 1995 Mar. 10, Dr. Agnes Bishop (AECB), "The Changing Role of the AECB in Canada and Overseas"
- 1995 Apr. 24, Mr. Robert Nixon (AECL), "Global Opportunities for AECL"

Morgan has been very active, and has also continued his initiative of presentations in schools. He sends the following entertaining report on his latest foray:

I took an afternoon off to visit Pinawa Secondary School, to present a brief introduction of nuclear energy to two classes of Grade 8 students.

The classes went well, although 40-minute periods seem too short to cover much (I don't THINK the kids found 40 minutes too long!). After a brief introduction on radiation, I cut to the fission process itself. I had an overhead of the process (a slow neutron coming into a uranium nucleus), but thought I'd try getting the kids to act out a nuclear fission.

We moved some tables back, and then I got someone to be my fast neutron. I also got 4 kids, coupled in pairs, to be my heavy hydrogen nuclei. These "nucleons" put their hands on their partners' shoulders, symbolizing the bonds between the nucleons. The remaining kids (~10) I assembled into a nucleus of a uranium atom, and their arms were again the interactive forces amongst the nucleons. I told them that there were two main forces in a nucleus - the positive charges of the protons trying to force the nucleus apart, and the attractive forces amongst all the nucleons. I then took the "fast neutron", bumped him or her against both heavy hydrogen nuclei, thus slowing him/her down to enter the uranium "nucleus". The "nucleus" then split apart, and I got at least one of the nucleons to run off quickly as a fast neutron.

So, did the skit work? One class co-operated well and seemed to enjoy it, the other class was a little less interested and co-operative (did they think it geeky?). I believe it was reasonably fun to do, and was not too chaotic (maintain control of the class!). I then went back to the overhead of a uranium fission, explaining it again and using the class members as examples of the various particles involved. It is also important to explain that the nucleus splitting gives off lots of heat, as well as some more neutrons.

The other comment is that it is very useful to have a Geiger counter with various radioactive sources to play with (U ore, Coleman lantern mantle, radium-painted clock face, etc.). Let the kids play with the meter a bit before and after the class. Also, the section of fuel channel with a mock-up fuel bundle was very useful."

Ottawa

The Branch Executive for 1996/97 is composed of:

Chair	Mohamed Lamari (613) 520-2600 ext.1760
Past Chair	Jeff Lafortune (613) 563-7242
Secretary	Lindsay Patrick (613) 237-3270 ext. 5117
Treasurer	Fred Boyd (613) 592-2256
Program Director	Robert de Wit (613) 992-5113
Special Project Coordinator	Sadok Guellouz (613) 562-5800 ext. 6291

The Branch Executive held its first meeting on Friday August 30. Branch Chair Mohamed Lamari reports tentative plans were made as follows for the upcoming season:

- Organize three technical seminars, with the first scheduled for 1996 October
- Hold the traditional annual Branch dinner
- Support the Ottawa Regional Science Fair
- Establish an award for "Best Exhibit in Nuclear Science and Technology" at the Ottawa Regional Science Fair
- Establish and organize a series of seminars for High-School students in the Ottawa region, which will replace the educational field trip.

Pickering

The Branch has scheduled a seminar for November 12. The guest speaker will be Gregory Kane, U.S. nuclear consultant who is assisting Ken Talbot in Pickering's drive to return to excellence.

Sheridan Park

On September 25 the Branch presented a seminar by Mr. Ian Lindsay, Cernavoda Project Manager, AECL Sheridan Park. The title of the talk was "Cernavoda - A Success Story". The Abstract was as follows:

Europe's first CANDU reactor, Cernavoda in Romania has reached 75 percent of full power and is producing 475 MWe of electricity. It is expected to reach full power this month. Come and hear from the Cernavoda Project Manager Ian Lindsay about how we got there and future plans for this plant".

On Oct. 23 the Branch presented a seminar entitled "The Irradiation Research Facility (IRF) - AECL's New Research Reactor", by Mr. Bill Bishop, Project Manager of the IRF Project. The Abstract for this talk was as follows:

AECL has developed the concept for a national Irradiation Research Facility (IRF) to replace the neutron irradiation capabilities of its NRU (National Research Universal) reactor. Such a facility would provide a dual-purpose research reactor for (i) irradiation test facilities for CANDU advanced fuels and material development, and (ii) advanced materials research for Canadian and international scientists.

The Branch is also planning the following activities:

- 1996 Nov. 5, seminar by Mr. Paul Lafrenière (Hydro-Québec), "The Hydro-Québec Perspective on Operating a Single-Unit Nuclear Power Plant: A Business".

This talk will examine the areas of production, reliability of production, safety, bus bar costs, and plant life management.

- 1996 Nov. 19, seminar by Mr. Pierre Lahaie (Nordion), "Nordion's Isotope Business and the Maple Reactor Project"
- 1996 Dec. 3, Annual Branch Meeting and seminar by Dr. Stan Hatcher, "Vision for the Next 50 Years of Nuclear Energy"

Toronto

The Branch Executive for 1996/97 is composed of:

Chair	M. Stephen Rogers	(416) 592-2799
Vice-Chair	Ross Rock	(416) 592-4349
Past Chair	Greg Evans	(416) 978-1821
Treasurer	Jeremy Edward	
Student Affairs	Juliette Ling	

Further Hearings on Disposal Concept

The federal Environmental Assessment Review Panel held four additional days of hearings in its Phase II from November 18 to 21 in Toronto. These were intended to hear technical comments on additional information submitted since the basic Phase II hearings last spring.

Each day began with a presentation by AECL or Ontario Hydro on a particular technical subject. AECL provided comparisons between its "Second Case Study " and its "Reference Case".

The Reference Case assumed the use of titanium containers each holding 72 fuel bundles, placed vertically in bore holes in a vault in low-permeability rock. The Second Case Study assumes the use of copper containers placed horizontally in high permeability rock. Because of the horizontal placement the amount of fuel that can be stored in a given vault is reduced by a factor of two. Nevertheless, with other savings the cost per bundle would be about 15 to 20 % higher for the Second Case Study over the Reference Case. The calculated radiation dose to a member of the "critical group" would be less for the Second Case Study (and much less than that required by the Atomic Energy Control Board).

Ken Smith, speaking for the Canadian Nuclear Society, made one the few "pro-nuclear" presentations to the hearing.

Phase III hearings to conclude the Panel's review will be held in various locations from Saskatchewan to New Brunswick from mid January to mid March, 1997.

NEWS OF MEMBERS

ANS Awards Amares Chatt

Dr. Amares Chatt, professor in the Department of Chemistry at Dalhousie University in Halifax and director of the SLOWPOKE 2 facility, was presented with the Radiation Science and Technology Award by the American Nuclear Society at its winter meeting in Washington D.C. in early November.

The award is granted for outstanding contributions to the development and advancement of applied radiochemistry through specialized applications of neutron activation analysis and for the effective international dissemination of these techniques.

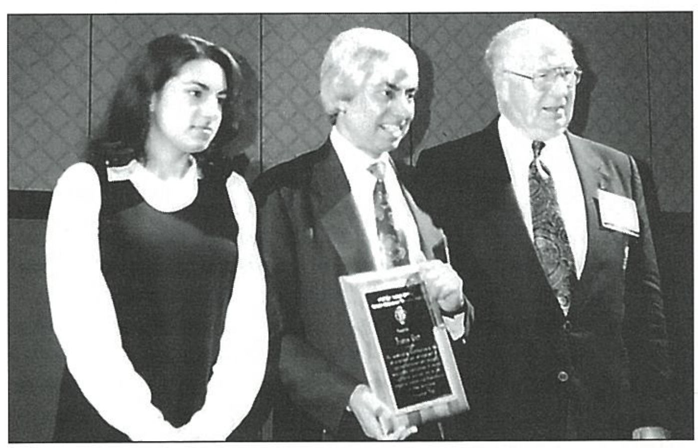
Dr. Chatt presented two invited papers at the meeting:

- *Status of Neutron Activation Analysis in Developing Countries*
- *On the Trail of Short-Lived activation Products*

The latter was specifically related to the award. It deals with a method of cyclical irradiation in the Dalhousie University SLOWPOKE followed by rapid counting. Biological, environmental and geologic samples containing high amounts of salts can be conveniently analyzed for trace elements by the technique.

The award consisted of an engraved plaque and a cheque for $1,000.00.

This adds one more to the long list of awards won through work associated with SLOWPOKE reactors.



Dr. Amares Chatt (centre) poses with his daughter and Dr. Bob Jarvis following his receipt of the ANS Radiation Service and Technology Award.

CNS Comments on New Act

Last April, the Minister of Natural Resources, Anne McLellan, introduced in the House of Commons, Bill C-23, the proposed new **Nuclear Safety and Control Act.**

That Bill went through two reading in the House and was referred to the Standing Committee on Natural Resources for review. The Committee held meetings in September and invited interested groups to present comments.

The Canadian Nuclear Society responded to that invitation and submitted a short brief. Three representatives appeared before the Committee on September 8 to present the document.

The CNS brief supported the objectives and general structure of the proposed Act but urged for clarification in several clauses, especially where it implied that regulations should ensure zero exposure or risk. A clause of some concern would require designated workers at a nuclear facility to be on duty regardless of a strike or lockout. It is understood the Committee recommended a modification to that clause.

The Committee has completed its review and returned the Bill to the Minister who is expected to table it for third and final reading soon, possibly before the end of 1996. It is likely that Canada will have a new nuclear law by early 1997.

CANDU Safety Course Popular

Over 90 persons attended the **CANDU Reactor Safety Course** and presented November 25 to 27 at the Sheridan Park Conference Centre in Mississauga, Ontario. The course was organized by the Nuclear Science and Engineering Division of the Canadian Nuclear Society under the chairmanship of Dr. V. S. (Krish) Krishnan of AECL Sheridan Park.

The numbers surprised the organizers, who had planned on about 30 based on previous courses. It was not clear what caused the large response but it appeared that many of the attendees, who came mostly from AECL and Ontario Hydro, had recently become involved with safety issues.

Most of the lecturers came from AECL with one from Ontario Hydro and one from the private sector.

Given the response it is likely that the course will be offered again next year.

FROM STEAM TO SPACE

edited by Andrew Wilson

published by the Canadian Society
for Mechanical Engineering

This book chronicles contributions of mechanical engineering to Canadian development. It consists of over 300 pages of essays, photographs and memoirs, covering aspects of mechanical engineering in Canada from the early 1800s to the present time. There are three contributions from Phil Ross-Ross, formerly at AECL Chalk River and one of the founding members and early president of the Canadian Nuclear Society.

price: $50.00 for hardback (limited numbers); $25.00 paperback (all taxes, shipping & handling included)

HEAT AND MASS TRANSFER IN SEVERE NUCLEAR ACCIDENTS

edited by J.T. Rogers

published by Begell House, Inc.
79 Madison Ave. NYC, NY, 10016

This 300 page volume contains ten lectures, 38 papers, and summaries of discussion from the seminar sponsored by the International Centre for Heat and Mass Transfer held in Turkey in 1995. The objective of the seminar was to bring together scientists and engineers involved in heat and mass transfer aspects of severe accidents in nuclear power plants.

price: $107.50 (US) plus $9.00 shipping and handling

IAEA YEARBOOK 1996

published by the International Atomic
Energy Agency (292 pp. 72 figures)

This eighth edition concentrates on developments in nuclear science and technology beginning with an extensive review of the Chernobyl accident ten years later. The parts cover; technical cooperation programs; nuclear techniques in health; nuclear safety review; waste management; and safeguards.

available from the IAEA and through local booksellers.

price: 500 Austrian schillings.

CALENDAR

1997

February 10-11

CNA/CNS Winter Seminar
Ottawa, Ontario
contact: Ms. Sylvie Caron
CNA/CNS
Toronto, Ontario
Tel: 416-977-7620 Ext. 18
Fax: 416-979-8356
e-mail: carons@cna.ca

March 14-15

22nd Annual CNA/CNS Student Conference
Fredericton, NB
contact: Lisa Lang
University of New Brunswick
Fredericton, NB
Tel: 506-453-4520
Fax: 506-453-3591
e-mail: f0vx@unb.ca

March 23 - 26

Advances in Fuel Management
Myrtle Beach, SC
contact: Dr. Paul Turinsky
North Carolina State Univ.
Rawleigh, NC
Fax: 915-515-5115
e-mail: turinsky@eos.ncsu.edu

April 6 - 11

4th International Conference on Methods and Applications of Radioanalytical Chemistry
Kailua-Kona, Hawaii
contact: Sylvie Caron
CNS office
Toronto, ON
Tel: 416-977-7620 ext. 18
Fax: 416-979-8356

April 10 - 11

CNS/Chinese Nuclear Society Joint Symposium on CANDU Technology
Beijing, China
contact: Ed Price
AECL Sheridan Park
Mississauga, Ontario
Tel: 905-823-9060 Ext. 3066
Fax: 905-823-3160
e-mail: pricee@candu.aecl.ca

April 14 - 18

5th International Topical Meeting on Nuclear Thermal Hydraulics, Operations and Safety
Beijing, China
contact: Ken Talbot
Pickering NGD Ontario
Ontario Hydro
Pickering, ON
Tel: 905-839-1151

April 24 - 25

Course on Two-Phase Flow and Heat Transfer
contact: Dr. M. Shoukri
McMaster University
Hamilton, Ontario
Tel: 905-525-9140 ext. 24288
Fax: 905-528-4952

May 13 - 16

CRPA Annual Conference
Victoria, BC
contact: Wayne Greene
Vancouver, BC
Tel: 604-822-4218
Fax: 604-822-6650
e-mail: greene@safety.ubc.ca

June 1 - 5

ANS Annual Meeting
Orlando, Florida
contact: American Nuclear Society
La Grange Park, Illinois
Tel: 708-352-6611
Fax: 708-352-6464

June 1 - 5

Embedded Meeting 2nd International Topical Meeting on Advanced Reactors Safety
contact: Dr. Rusi Taleyarkhan
Oak Ridge, TN
Tel: 423-576-4735
Fax: 423-574-0740
e-mail:
zrt@cosmaill.ornl.gov

June 8 - 11

CNA/CNS Annual Conference
Toronto, ON
contact: Sylvie Caron
CNA/CNS
Toronto, ON
Tel: 416-977-7620 ext. 18
Fax: 416-979-8356
e-mail: carons@cna.ca

August 17 - 21

International Conference on Neutron Scattering
Toronto, ON
contact: Dr. W.B.L. Buyers
AECL Chalk River Lab.
Chalk River, ON
Tel: 613-584-3311
Fax 613-584-1849

September 22 - 24

5th International CANDU Fuel Conference
Toronto, ON
contact: Dr. J. Lau
AECL - SP
Mississauga, ON
Tel: 905-823-9060 ext. 4531

September 30 - October 4

NURETH-8, 8th International Topical meeting on Nuclear Reactor Thermal Hydraulics
Kyoto, Japan
contact: Dr. Jerry Cuttler
AECL - Sh. Pk.
Mississauga, ON
Tel: 905-823-9060 ext. 2556
Fax: 905-855-0945
e-mail: cuttlerj@spkb.candu.aecl.ca

September ??

Nuclear Simulation Symposium
TBA
contact: V.S. Krishnan
AECL
Mississauga, ON
Tel: 905-823-9060 ext. 4555

October 5 - 10

Global '97 International Conference on Future Nuclear Systems
Yokohama, Japan
contact: Dr. Jerry Cuttler
AECL - Sh. Pk.
Mississauga, ON
Tel: 905-823-9060 ext. 2556
Fax: 905-855-0945
e-mail: cuttlerj@spkb.candu.aecl.ca

October 6 - 10

International Conference on Mathematical Methods and Supercomputing for Nuclear Applications
Saratoga Springs, NY
contact: Dr. M.R. Mendelson
Knolls Atomic Power Lab
Schenectady, N.Y.
Tel: 518-395-7046
Fax: 518-395-4422

October 14 - 18

2nd International Conference on Isotopes
Sydney, Australia
contact: Dr. Clarence Hardy
Australian Nuclear Assoc.
Peakhurst, NSW, Australia
Tel: 61-2-9579-6193
Fax: 61-2-9570-6473
e-mail:
cjhardy@ozemail.com.au

November 16 - 20

ANS Fall Meeting
Albuquerque, New Mexico
contact: American Nuclear Society
La Grange Park, Illinois
Tel: 708-352-6611
Fax: 708-352-6464

November 16 - 18

4th CANDU Maintenance Conference
Toronto, ON
contact: D. Iafrate
Ontario Hydro
Darlington, ON
Tel: 905-697-7496

November ??

International Conference on Effects of Radiation on In-Reactor Corrosion
TBA
contact: V. Urbanic
AECL-CRL
Chalk River, Ontario
Tel: 613-584-4676

1998

May 3

11th Pacific Basin Nuclear Conference
Banff, Alberta
contact: Ed Price
AECL Sheridan
Tel: 905-823-9060 ext. 3066
Tel: 613-584-3311
Fax: 613-584-1849
e-mail: pricee@candu.aecl.ca

June 7 - 11

ANS Annual Meeting
Nashville, Tennessee
contact: American Nuclear Society
La Grange Park, Illinois
Tel: 708-352-6611
Fax: 708-352-6464

June 14 - 18

12th International Symposium Zirconium in the Nuclear Industry
Toronto, Ontario
contact: G.D. Moan
AECL
Mississauga, Ontario
Tel: 905-823-9060
Ext. 3232

June 21 - 24

3rd CNS International Steam Generator and Heat Exchanger Conference
Toronto, Ontario
contact: R. Tapping
AECL-CRL
Chalk River, Ontario
Tel: 613-584-8811
Ext. 3219

September ??

CNS Annual Conference
TBD
contact: Sylvie Caron
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Toronto, Ontario
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Contents

Cover Illustration

The illustration on the cover is an artist's rendition of the Qinshan III site in China with two CANDU 6 units.

(Photo courtesy of AECL)

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