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- Climate Change 2 Conference
- Nuclear Power: Obstacles and Solutions
- Advanced Pressure Tube Sampling Tools
- CNS 7th International CANDU Fuel Conference
- Canadian CANDU Fuel Development Programs
- Plant Control System Upgrades

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Cover Illustration

The photograph on the cover shows a recent view of the Qinshan 3 project in China.

(Photo courtesy of Atomic Energy of Canada Limited)

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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.
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EDITORIAL

An Embarrassment

Before proceeding with the comment to match that heading we wish to congratulate the organizers of the two conferences that are covered in this issue: the *7th International Conference on CANDU Fuel* and the *Climate Change 2 Conference,* that were held last fall. Again they demonstrated that CNS volunteers are among the best, if not THE best conference organizers in the world-wide nuclear community. As a comparison, the Winter Meeting of the American Nuclear Society, while larger in attendance number, paled in comparison on the basis of structure, content, operation, social aspects and general organization, despite the large paid staff of that organization.

Now, to the "embarrassment", with the emphasis that this is a very **personal** comment and should, in no way, be attributed to the CNS or any of its officers or council members.

The topic is the MAPLE project. As readers know, the two small MAPLE reactors being built at the Chalk River Laboratories are to be dedicated to producing radioisotopes, primarily for medical diagnosis. They are owned by MDS Nordion, which is the world's pre-eminent supplier of such radioisotopes but are being built by, and are to be operated by, Atomic Energy of Canada Limited. As noted in the short report in "General News" they are now more than two years behind schedule.

The sad story of the reasons for that delay can be found in the records of the various hearings of the Canadian Nuclear Safety Commission. Repeated failures of the shutdown system were reported in a series of CNSC hearings dealing with the project. Initially the "excuse" was dirt in the mechanism combined with very small clearances. The design was modified but further failures occurred. Because of this, questions were raised, especially by Commission members, about Quality Assurance but AECL representatives to the hearings insisted that their QA program had been reviewed and minor deficiencies corrected. Surprisingly, CNSC staff agreed. However, after hearing the same story many times, the non-technical members of the Commission raised questions and doubts.

Following the CNSC hearing in December 2001 the Commission approved AECL proceeding with the commissioning of the two reactors, with a number of conditions. But Commission members still noted their concern about the project and, especially, about the apparently inadequate communication between CNSC staff and that of AECL.

As an observer, we ask, how is it that an organization which can construct large, complicated projects half way around the world, on time and on budget, can not manage a small project on its own campus?

The potential losers in this mess are MDS Nordion, who have already lost some business because of concerns of reliability of supply, and Canada, which has been the pre-eminent country in the production and use of radioisotopes.

Fred Boyd

IN THIS ISSUE

First of all, to match our current publishing schedule of January, April, July and October, this issue has been numbered Vol. 23, No. 1. For anyone counting that means there were only three numbers in Vol. 22.

The content of this issue is drawn largely from two successful conferences held by the CNS in the fall of 2001, the **7th International Conference on CANDU Fuel,** held in Kingston, Ontario last September, and the **Climate Change 2 Conference,** held in Toronto in October. There are short reports on each of these along with some selected papers. From the former we reprint two national overview papers: **Canadian CANDU Fuel Development Programs** and **CANDU Fuel R & D in Korea.** From the latter we have just one paper, **Technology and Climate Change,** which is somewhat longer than our usual selections but provides a good overview of the topics covered at the Climate Change 2 Conference.

There are two other papers drawn from previous conferences, which are still relevant and, in our view, interesting: **Nuclear Power: Obstacles and Solutions,** and **Advance Pressure Tube Sampling.** Then, as an experiment, we include a short paper that is intended to be the first of a small series, on **Plant Control System Upgrades.**

The section on **"General News"** contains items that we found interesting and hope you will also, and which you may not have seen elsewhere.

Even though the section on **CNS News** is longer than it has been in recent issues it still does not fully reflect this very active society. (In that regard we always welcome news of members, branches or other activities related to the CNS.)

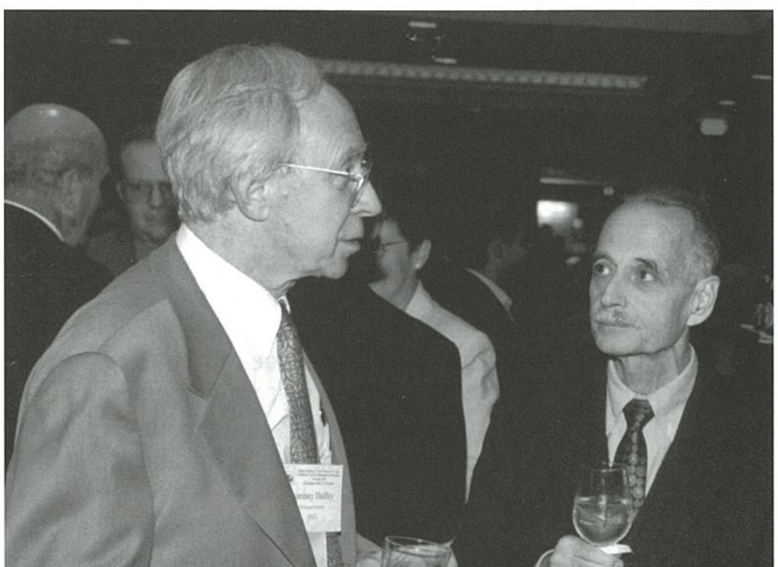
There is a page on **Books,** an updated **Calendar**, and, of course, the always intriguing **Endpoint** from Jeremy Whitlock.

Let us know your thoughts, comments, whatever, on the publication, and, your contributions are always welcomed.

Climate Change 2 Conference

Second conference on climate change and technology brings different disciplines closer together

Conference chair Kris Mohen (left) and Program chair Duane Pendergast confer during the Climate Change 2 Conference in Toronto, October 2001.



Romney Duffey (AECL) and Jan VanErp (ANL) share thoughts during the Climate Change 2 Conference in Toronto, October 2001.

In late October 2001, representatives of many different disciplines came together in Toronto, Ontario, for the second time to share their knowledge and approach to the challenge of climate change. Delegates to the *Climate Change 2 Conference: Canadian Technology Development* held October 3 - 5, 2001, compared views on how to minimize the emission of greenhouse gases, which are considered to be the cause of climate change, or remove them from the atmosphere.

Although largely organized by the Canadian Nuclear Society the role of nuclear energy was muted, with only two papers directly related to that topic. The diversity of subjects covered is exemplified by the titles of the sessions: *Greenhouse Gas Technology Development and Energy (the opening plenary); Sources of Energy and Material; Energy Services and Enabling Technologies; Technology to Salvage and Sequester the Products of Energy Use; Societal Issues and Technology Development.*

The Conference began with a reception on the evening of October 3, at which Jay Ingram, from the *TV Discovery Channel,* talked about "Controversy and Climate Change".

Ingram, noting that the controversy over the reality of climate change is not resolved, spoke about the approach he had taken to the subject. He selected several of the leaders of the public discussion and asked them to describe the basic rationale for their belief that climate change was or was not real. He followed their responses with some questions to establish the credibility of the key sources on both sides of the debate, their breadth of vision, and their openness to the contrary arguments. On these grounds he suggested to the audience that they follow James Hansen on the pro-global warming side, and Richard Lindzen on the con side, as people who make predictions that can be tested. He commented that this would facilitate following the arguments put forth by experts

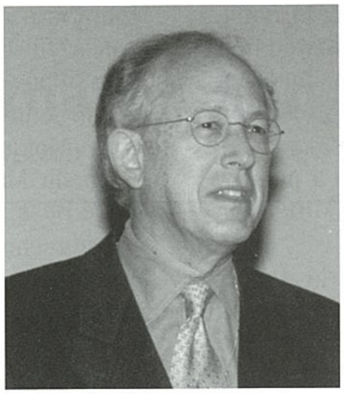
The actual sessions were opened with a short address from the federal Minister of the Environment, David Anderson, by telephone from Ottawa since parliamentary matters had prevented him attending in person.

The opening plenary session included four overview papers:

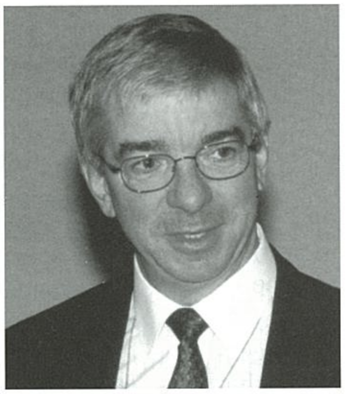
• *Human Energy Use and the Carbon Cycle* by

Stuart Smith, chair of the National Round Table on the Environment and the Economy

- *Technology and Climate Change* by Robert Morrison, David Layzell and Ged McLean
- *Canada's Kyoto Commitment* by David Oulton, Climate Change Secretariat, Natural Resources Canada (presented by Don Strange)
- *Technology Development and Deployment: Climate Change Initiatives,* by Graham Campbell, Director General, Natural Resources Canada.



Stuart Smith



Graham Campbell

In his opening paper, Dr. Smith spoke about the "Carbon Cycle", the movement of carbon from the atmosphere to organic (living) matter and back to the atmosphere, which, he said, "could be considered as the basic infrastructure for life itself". Since the industrial revolution, he commented, the cycle has been grossly unbalanced because of the release of carbon, which had been deposited over millions of years, through the burning of fossil fuels. This, he noted, had led the "vast majority of scientists" to believe it would lead to "climate change". Therefore, he stated, "climate change is primarily an energy problem, not a pollution problem". Greater efficiency is not enough, he claimed. There are, he contended, just three ways forward:

- develop and use energy sources other than fossil fuels
- use fossil fuels such that carbon dioxide (CO_2) does not escape to the atmosphere
- find ways to remove CO_2 from the atmosphere and permanently sequester it

We cannot wait, he asserted, before making substantial investments in research on these three paths.

The presentation by Bob Morrison provided a comprehensive overview of the many issues in climate change and the potential role of technology to reduce the concentration of greenhouse gases (GHG) in the atmosphere. *The paper is reprinted in this issue of the CNS Bulletin.*

Don Strange made the presentation on Canada's Kyoto Commitment. He reviewed the commitments Canada had made at Kyoto and noted that the gap between Canada's GHG emissions and its Kyoto commitment had widened. However, the ratio between GDP and GHG had decreased. He referred to the CoP meeting in Bonn in the summer of 2001 and the (then) upcoming further meeting in Marrakech.

Graham Campbell, who had been co-chair of the Technology Issues Table for the climate change studies, spoke about technology solutions for minimizing greenhouse gas emissions. Public, private, academic partnerships are needed, he claimed. The federal government has announced a number of initiatives: the Climate Change Action Plan ($500m); the Climate Change Action Fund 2000 ($150m); the Sustainable Development Technology Fund (initial $100m); extension of the Technology Early Action Measures (TEAM) ($13m per year); and the Green Municipal Enabling and Investment Funds ($125m).

The luncheon speaker the first day was Allen Amey of Climate Change Central in Alberta. Amey described his organization as a public / private corporation set up to lead Alberta in dealing with climate change issues. Although observing that climate change was on the "back burner" after the events of September 11, he pointed out that it had very pervasive consequences: health, economic, scientific, generational, ethical. He noted that Alberta's emissions of GHG were greater than had been predicted and commented that putting a price on CO_2 would be very costly for his province.

The first afternoon had two parallel sessions on: "Sources of Energy Material" and "Energy Services and Enabling Technologies" with papers covering a variety of topics, such as: a review of natural gas resources; green heat from grass biofuels; an integrated manure utilization system; high pressure injection of natural gas [into geological reservoirs]; GHG free transportation through fuel cell technology.

The conference banquet that evening was supposed to feature comedian David Broadfoot but, unfortunately, he took ill just as dinner was about to be served and was rushed off to hospital. Fortunately, it was just a mild attack and he was released the next day.

The morning of the second day was devoted to two more parallel sessions of papers on specific topics under the titles of: "Technology to Salvage and Sequester the Products of Energy Use" and "Societal Issues and Technology Development". The former included papers on: biological sinks; geological storage of CO_2; enhanced anaerobic digestion; and, life cycle assessments; while the latter had ones on: economic factors; and overall philosophy on climate change. Luc Gagnon of Hydro Quebec presented some interesting graphs on life cycle emissions of GHG and of energy input / output. (See Fig. 1). The paper by Douglas Lightfoot, from the McGill Centre for Climate and Global Change Research on "Climate change is an energy problem" provided a historical context. He noted that the level of CO_2 in the earth's atmosphere had oscillated around 250 ppm for tens of thousands of years but in the last century had risen to about 370 ppm and was predicted to rise to 550 ppm by the middle of this century, primarily due to our use of fossil fuels.

Peter Harrison, deputy minister at Natural Resources Canada, gave the luncheon talk on the second day. He reviewed Canada's position at the CoP6 meeting in Bonn, stating that a compromise was necessary but insisted that the government's support for nuclear energy had not changed. "Kyoto was just a beginning", he stated, and urged continued effort on climate change.

The last afternoon began with four papers in a plenary session on "Establishing Sustainable GHG Mitigation Technology", followed by a panel discussion.

Allan Glasgow outlined initiatives at Ontario Power Generation to reduce GHG emissions with emphasis on energy efficiency. Paul Fauteux of Environment Canada provided an "inside" view of the negotiations at Kyoto and subsequent CoP meetings. Canada did obtain credit for significant "sinks" in its forests, he pointed out. We must engage the USA, he commented. Robert Page of Transalta Corporation began by noting there was no "quick fix". Critical of Canada's stance in international meetings he stated "we are a long way from being ready for the Kyoto agreement". Graham Campbell (NRCan) gave a government perspective on technology developments. The largest R & D effort is in CO_2 capture and storage and referred to a recent report issued by his department on that topic.

The balance of the afternoon was devoted to a spirited discussion led by a panel of the afternoon and other speakers with active involvement of the audience.

Although there were many different viewpoints the general attitude coming from this final discussion was that there is a need to minimize the emissions of greenhouse gases to the atmosphere and all of the technologies described or referenced in the conference have a role.

The conference was organized by a committee chaired by Kris Mohan, with Duane Pendergast, Dan Meneley, Corneliu Manu, Ben Rouben, Lori Harding, Kwok Tsang, Dave Buss, Elizabeth Zariffeh, Denise Rouben.

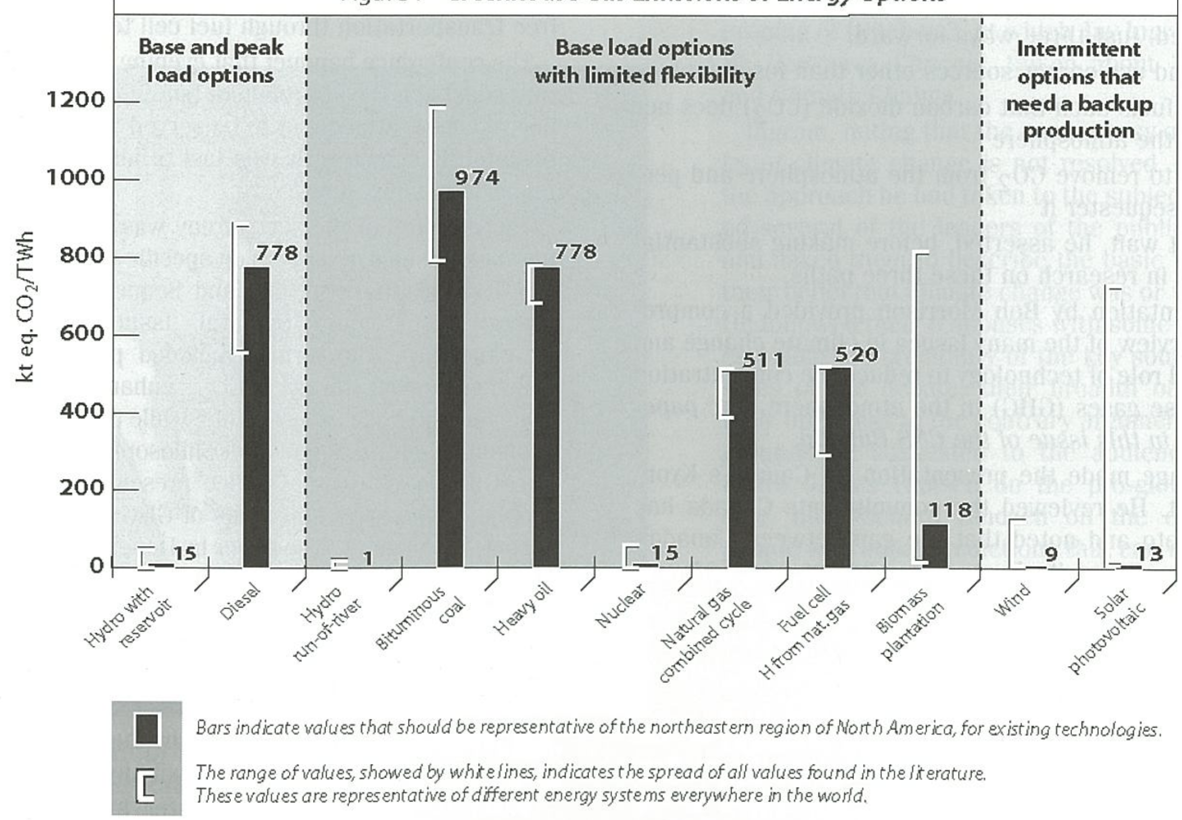
The technical program committee was chaired by Duane Pendergast, with Richard Damecour, Nigel Fitzpatrick, David Layzell, Bernard MassÈ, Ged McLean, Dan Meneley, Holly Mitchell, Robert Morrison, Claudia Wagner-Riddle.

Other organizations involved were: BIOCAP Canada, Canadian Hydropower Association, Canadian Hydrogen Association, Integrated Energy Systems (UVic), CRUISE (Carleton University, Canadian Society of Agrometeorology, Electric Vehicle Association of Canada, Canadian District Energy Association.

A number of organizations provided financial assistance: Bruce Power, Computare, NRCan, CNA, Ontario Power Generation, Stuart Energy, Babcock Wilcox Canada, AECL, Alcan, Cameco, Wardrop Engineering, Thermodyne Engineering, IESVic, OCI, Power Workers' Union, Azure Dynamics, Koch Engineering, Special Electronics & Designs, Nu-Tech Precision Metals, B.C. Research, Alberta Irrigation.

Proceedings of the conference are available from the CNS office and will be on a special conference Web site.

*Figure 1 - **Greenhouse Gas Emissions of Energy Options***



from Luc Gagnon, Hydro Québec

Technology and Climate Change

by Robert Morrison[1], David Layzedl[2] and Ged McLean[3]

Ed. Note: *The following paper was the major one of the opening plenary session at the Climate Change 2 conference held in Toronto, Ontario in October 2001. Although longer than most papers that have been reprinted in the CNS Bulletin it provides a thorough overview of the issues discussed at that conference.*

1. Introduction

This paper provides a context for assessing the needs for technologies to reduce the concentration of GHG in the atmosphere. It looks at sources, sinks and trends for GHG, in the world at large and in Canada, and at efforts to develop new technologies to achieve the goals of climate change policy.

Technology development is one of many approaches to reducing emissions and absorbing GHG from the atmosphere. Initiatives to address a range of other factors will be needed, including regulation, efficient markets and pricing, emissions trading, education and information, demonstration, voluntary commitments and public involvement. New technologies will be deployed in conjunction with these initiatives, and will be conditional on them for success. Investments in new technologies must be harmonized with the implementation of existing technologies. New technologies will be more successful if they can also achieve non-climate goals, such as better air quality or reduced soil erosion, especially in developing countries, which have more immediate priorities. A broad spectrum of coordinated policies will be required.

Because of the lead times needed to deploy technology and the slow replacement rate of many energy systems, most emission reductions in the timeframe of the 1997 Kyoto Protocol (2008 - 2012) will be achieved by technology that already exists. Beyond Kyoto, more ambitious reduction targets will be required. The IPCC estimates that in order to limit GHG concentrations in the atmosphere to two times the pre-industrial values, emissions from fossil fuels will have to be reduced from the current rate of 6 Gt C per year to about 2 Gt C per year *(IPCC 1995).* (Additionally about 1.6 Gt C is released from land use changes and deforestation, but a net absorption takes place on land, as discussed below). Kyoto only reduces emissions from the industrial countries by 5%, leaving other countries free to increase. Even the modest Kyoto targets now look difficult to achieve.

Thus the development of new technologies is well matched to the need for further reductions beyond Kyoto, in both scope and timing. In the long term, new technologies will influence very strongly the possibility of achieving acceptable atmospheric concentrations of GHG.

We look here at sectors where new technology may be most needed. In general these will be areas where emissions are large, or growing rapidly, or both. It doesn't follow that a given investment in new technology for these areas will necessarily have a bigger economic or environmental return, but they certainly merit close attention as potential markets.

One approach to emissions reductions is to decouple emissions growth from economic growth, especially in the faster growing sectors. This means ensuring that new equipment, buildings and processes are especially energy and carbon efficient. It may be more effective to design high efficiencies into new systems than to retrofit old ones. This strategy addresses the growth problem directly - it cuts emissions off at the pass.

1 CRUISE (Carleton Research Unit for Innovation on Science and Environment) Carleton University

2 BIOCAP Canada

3 Institute for Integrated Energy Systems, County of Victoria

The Kyoto GHG reduction targets essentially mean reducing the GHG emissions that are projected to occur in the 2010 period under business-as-usual scenarios by an amount equal to the growth between 1990 and 2010 plus the committed reduction from 1990 levels. That is, if a country has committed to reducing emissions by 6% from 1990 levels, and if growth under a business-as-usual scenario for the 1990 to 2010 period is 30%, it must reduce emissions by 28% from the projected business-as-usual 2010 levels. This is a daunting task.

We also review current areas of focus for technology development, to see if there are any obvious gaps and opportunities. Expenditures on R&D are a proxy for meaningful activity in this area, but it will be years before one can assess the returns to R&D investment, in either commercial or emissions terms. R&D is always a risk, but risk management processes can be applied.

Emissions from fossil energy use are the main source of the GHG problem, and CO_2 is the most important GHG, but other GHG, and other factors affecting GHG concentrations, must also be kept in mind. Overall management of the biosphere, and the development of biological and geological sinks to store carbon, can have a significant impact over the longer term.

Without trying to pick winners, we focus in this paper on transport, electricity and biomass as sectors of interest, both because of their potential for contributing to climate change policy goals within Canada, and also because of our own research interests.

2. Factors Affecting GHG Emissions and Concentrations

The amount of GHG emissions from human activity will depend on the combined effect of a series of factors. First is the amount of activity in a particular sector as measured, say, for buildings by square meters of floor space to be heated and cooled, for transport by passenger- or tonne-kilometers, for industry by value added. Each activity can usually be carried out through a variety of sub-activities or modes - travel modes, types of buildings, different industrial processes, etc. The contribution of the different modes, which comprise the structure of the sector, can vary between countries and regions and over time.

The activity measures grow in response to population growth and to the desire for economic improvement. They are also responsive, to varying degrees, to energy prices. They are not easily limited, and governments are reluctant to tamper with them because of the economic and political consequences. The high-growth activities are particularly difficult to contain. This leaves open the option of shifting among sub-activities, say from cars to buses, or from single to multi-unit dwellings, but even here the tendency in many sectors seems to be toward more energy-intensive modes: bigger houses and cars, more urban sprawl. The other factors described below are more amenable to both policy and technology developments.

Second is the energy intensity of the sub-activity: how much energy does it take to heat the space or move the freight, in energy units per unit of activity, Joules per m^2, or per tonne-km. It is the output, the energy services, rather than the energy itself that is the desired product here, and if the service can be obtained more efficiently, so much the better. Striving for better efficiency (and its inverse, lower energy intensity) is clearly a fruitful area for technology development.

However efficiency gains are not necessarily used to reduce emissions. In the vehicle sector, efficiency gains have been used to increase vehicle weight and performance rather than reduce emissions. And the money people save on reducing emissions in one area, say better insulation, they can spend on energy intensive areas like jet vacations.

Third is the carbon intensity of the energy. How much carbon is emitted per unit of energy, in units of tonnes C (or CO_2) per Joule of energy consumed? Reducing the carbon intensity will often involve switching to lower-carbon, renewable carbon or non-carbon fuels, which may require significant technology development.

A fourth factor influencing net emissions will be our ability to capture carbon, and other GHG's such as methane, from processes that would otherwise emit them, and to make use of them or store them in sinks. In many cases this means removing carbon from fossil fuels before they are burned, or CO_2 from combustion flue gases. In other cases it means removing the CO_2 associated with deposits of natural gas. It generally means that one needs access to large, and ideally concentrated, streams of CO_2, so capture opportunities tend to be matched to large point sources

Fifth, through photosynthesis, plants can remove CO_2 directly from the atmosphere at existing or elevated concentrations, and build a carbon stock in the form of energy-rich biomass. By changing the way the biosphere is managed, one can build and preserve biosphere carbon stocks thereby creating a net sink for atmospheric carbon. While many of the management 'technologies' are well known, opportunities exist for new technologies that will enhance the ability to create and preserve biosphere carbon stocks. Equally, if not more important, is the need for tools to verify that these changes in biosphere management or these new technologies do, in fact, result in the quantifiable transfer of greenhouse gases out of the atmosphere.

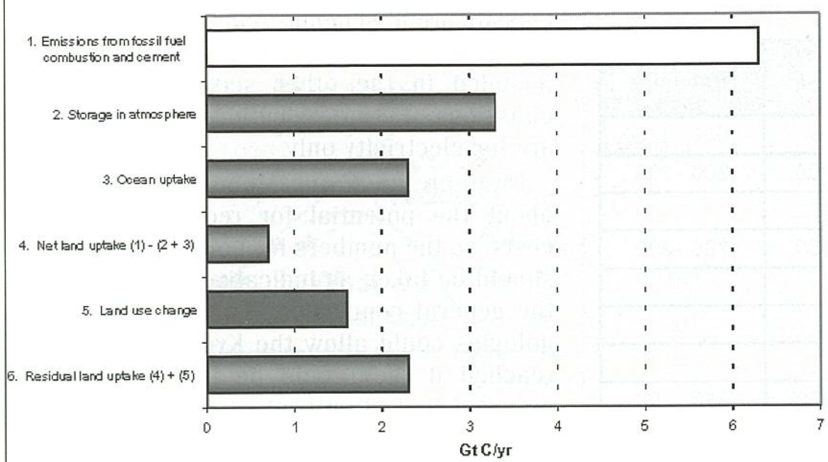
3. Natural Cycles

Looking at GHG emissions in the context of the natural carbon cycle, the picture presented by the IPCC *(IPCC 2000)* is as follows, in units of Gt C per year:

This deals with CO_2 alone. Other gases would alter the picture somewhat, but since estimates of emissions and removals of other gases are much less reliable, that data is not presented here.

About half of the anthropometric CO_2 emissions remain

Graph 1 Annual Man-Made GHG Fluxes, 1989-1998
(Billions of Tonnes C per Year)



Source: Summary for Policy Makers, IPCC Special Report on Land Use, Land Use Change and Forestry (LULUCF), IPCC, 2000

in the atmosphere. The other half is absorbed, mainly in the oceans. Even with man-made emissions of about 1.6 Gt C per year from the forest sector (primarily from burning forests to clear land in the tropics) the overall biomass sector is still a small net sink due to the natural carbon uptake. This suggests that in the absence of the man-made forestry emissions, biomass would be a significant net sink. This sink effect represents the small difference between overall emissions and overall uptake in the natural carbon cycle, which are each about 100 Gt C per year.

4. World Energy Use and GHG Emissions

The International Energy Agency recently published its outlook on global supply and demand for the period 1997 to 2020 *(IEA 2000a)*. The report assumed 'business-as-usual', and made a number of predictions, including:

Energy Use. World primary energy use is expected to continue growing over the next few decades by about 2% annually (close to its historic rate), or by about 57% from 1997 to 2020. This is the result of annual population growth of 1%, economic growth of 3%, and an annual decrease of energy intensity by 1%. Carbon emissions are expected to grow slightly faster than energy use, implying that carbon intensity will increase over this period.

Energy Use by Regions. Different regions and sectors evolve at different rates. Primary energy use will grow at 1.7% in the OECD countries, and at 2.7% in the developing countries, which will account for 68% of the increase in world energy use from 1997 to 2020. Transition economies are expected to grow at 2%. This will mean a shift in energy use and emissions. The OECD contribution, currently 54% of primary energy and 51% of CO2 emissions, will decline to 44% and 40%, respectively, by 2020, whereas the developing country contribution is expected to increase to make up the difference. The transition economies are predicted to remain at about 10% for both primary energy and CO_2 emissions.

Energy Use by Sources. In terms of sources, oil is expected to retain its 40% market share, reflecting its importance in transport. International trade in oil and gas are expected to increase sharply while the share of natural gas in the energy market increases from 22% to 26% by 2020. Coal is expected to decline from 26% to 24% of global energy supply, although its consumption is predicted to increase significantly in absolute terms. India and China are expected to account for two-thirds of the increase in coal use, mainly for electricity. The overall share of fossil fuels increases slightly to about 90% of the global energy supply.

Of the remaining 10%, nuclear is predicted to decline slightly to 5% while hydro continues at about 2% (hydro's share of electricity production is similar to nuclear's but its share of primary energy is less because it is rated at the equivalent of 100 % conversion efficiency, whereas nuclear is at 33%). Non-hydro renewables will grow rapidly, at about 2.8% annually, but will represent only about 3% of the market by 2020. Biomass consumption for energy use (largely in the developing countries at the present time) is expected to decline in favour of commercial fuels, while becoming more commercial itself.

Energy Use and Emissions by Sector The most rapidly growing sectors are expected to be electricity at 2.7% and transport at 2.4%, increasing their shares of the market from 17% to 20% by 2020, and from 28% to 31%, respectively. The bulk of the increase will be in developing countries. End-use sectors other than transport grow at 1.8%.

A recent model of sectoral energy growth suggests that industrial energy use peaks in countries having a GDP of about $10,000 per capita and declines slowly above that *(Medlock and Soligo 2001)*. Residential and commercial use overtakes industry in countries with GDPs between $10,000 and $25,000 per capita, the level of the richest countries today. The model predicts that transportation will continue to grow, becoming the biggest sectoral user of energy in countries with GDP per capita levels above $25,000.

A study of sectoral GHG emissions among 14 OECD countries *(Schipper et al 2001)* indicates that activity levels are likely to be the main source of differences in emissions, followed by utility carbon intensity and energy intensities. Activity levels are related to GDP, but at the same level of GDP, activity levels in different sectors can vary significantly among countries. The US has the highest per capita emissions, due to a combination of high activity in transport, residences and services (e.g. floor space),

Table 1 World GHG Emissions and Reduction Potential (Millions of Tonnes of C Equivalent per Year)				
Sector	Historic Emissions 1990	Emission Growth 1990-95 (%)	Reduction Potential 2010	Reduction Potential 2020
Buildings	1650	1	700-750	1000 - 1100
Transport	1080	2.4	100 - 300	300 - 700
Industry	2300	0.4		
energy			300 - 500	700 - 900
material			200	600
Industry - non CO_2	170		100	100
Agric CO_2	210	n/a		
non-CO_2	1250 - 2800	n/a	150 - 300	350 - 700
Waste	240		200	200
CFC	0	1	100	na
Energy supply, conversion	-1620	1.5	50 - 150	350 - 700
Total	**6900 - 8400**		**1900 - 2600**	**3600 - 5050**

Source: Summary for Policy Makers of the Mitigation Report, IPCC, Third Assessment Report, WGIII, Accra, February-March 2001

high energy intensity in industry, transport and appliances, and high carbon intensity in the electrical utility sector. Canada has similar characteristics, except that its utility carbon intensity is low, and its climate is colder. Japan has lower emissions due to low activity in transport services, and low energy intensities for industry and residences, but its absence of natural gas consumption in the fuel mix increases emissions to some degree.

Activity levels, as noted above, are difficult targets to address for both policies and technologies. Energy intensities, via efficiency, and carbon intensity, via fuel switching, are more amenable to intervention, as are the management of biomass and the use of sinks.

Among sectors, energy demand growth in transport and electricity is difficult to tackle with policy and pricing initiatives. The services these sectors provide are seen as essential to the economy and to modernization programmes. Large infrastructures are in place. The cost of energy is generally a small part of the overall cost of these services, and the price elasticity is low in the short term. Competitive alternatives to oil in transport will not be easy to implement widely or rapidly. We'll hear more about the longer-term possibilities later. For electricity there is a range of possibilities for using zero carbon fuels, such as hydro, other renewables and nuclear, or less carbon intensive fossil fuels, notably natural gas. In both sectors, efficiency improvements all along the fuel chain are a major source of hope for reducing emissions.

Emissions and Potential Reductions. For the world, the 1990 emissions and estimates of the reduction potential for different sectors are given by the IPCC *(IPCC 2001)*. The units are tonnes of carbon equivalent, or tonnes Ceq (multiply by 3.67 for CO_2 eq) per year.

Buildings presumably refer to what other classification schemes call Residential and Commercial. Energy supply and conversion is included in the other sectors for historic emissions. Future reductions in this category are for electricity only.

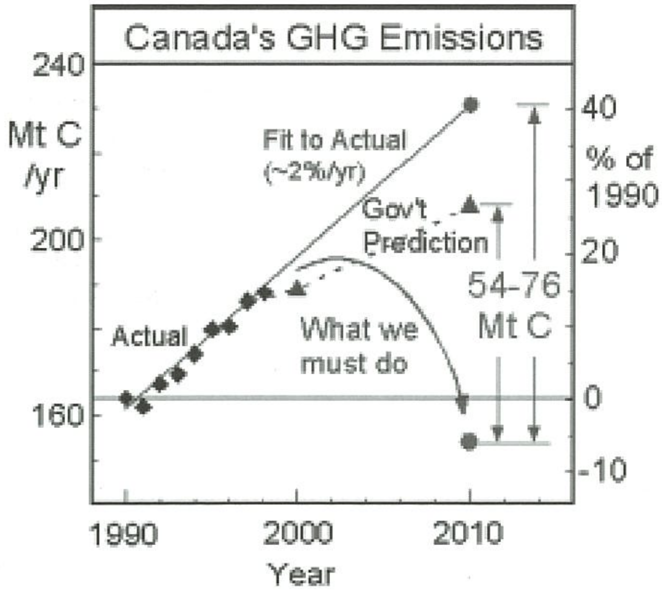
There are great uncertainties in all sectors about the potential for reduction, and the costs, so the numbers for potential reductions should be taken as indicative only. However, the general conclusion is that existing technologies could allow the Kyoto targets to be reached if they could be fully deployed, a prospect that at present seems unlikely.

According to the IPCC, the most promising areas for global GHG reductions in absolute terms are buildings and energy efficiency in industry, and most initiatives in these areas should result in net negative costs. They may be undertaken independently of climate change goals, on a "no regrets" basis. Most of the potential for efficiency gains in buildings are in the industrialized countries. The next most promising in absolute reduction terms are material efficiency in industry, along with agriculture, transport, and energy supply/conversion, with a wide range of costs. Transport and industry can achieve savings up to about 50% of the 1990 emission levels, but transport is growing very quickly.

The IPCC suggests that about half of these reductions can be obtained at negative cost, that is they should provide net economic benefits. Most of the other half should be available at net costs up to \$100 per tonne Ceq, or about \$27 per tonne CO2 *(IPCC 2001a, p. 4)*, although some options range up to net costs of \$300 per tonne Ceq, or \$80 per tonne CO2 *(IPPC 2001b, p. 28 and Table TS.1)*. Taking 2 000 Mt Ceq in 2020 as half of the total reductions that might be achieved, the cost at \$100 per tonne Ceq would be about \$200 billion per year.

The IPCC also sees carbon capture and storage, and biomass management, as important factors. The Second Assessment Report estimated that about 60 to 87 Gt C could be sequestered in forests by 2050, and another 23 to 44 Gt C in agricultural soils. Costs range up to \$20 per tonne C in some tropical countries and up to \$100 per tonne C in non-tropical countries *(IPCC 2001b, p. 43)*

A recent IEA study *(IEA 2000b)* also looks at technologies to reduce GHG. With R&D funds scarce, governments have a key role in stimulating a longer term approach: reducing barriers to acceptance, developing efficient markets and correct price signals, leading by example, covering some of the risks, providing information, accelerating the availability of new technologies and supporting their uptake. Several technologies have taken off faster than anticipated a decade ago, and show signs of further



Graph 2. Canada's GHG emissions from 1990-98 (diamonds) and its Kyoto target (lower circle) for the 2008-2012 commitment period. The extrapolation of the actual emissions gives a business-as-usual projection (upper circle) that is higher than the federal government prediction (triangles).

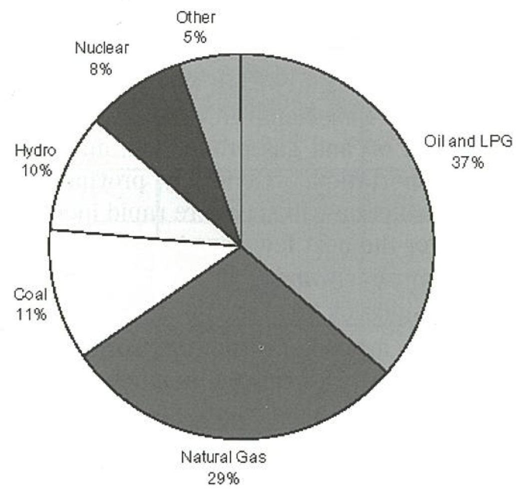
promise: wind turbines, community energy, gas-fired power plants, hybrid gasoline-electric vehicles, windows and lighting, and rooftop photovoltaics. The IEA study outlines, by way of example, some technologies that would benefit from further investment in R&D. A number of these would lower GHG emissions in their subsector by 20% or more: industrial processes and separation (membranes, etc.), electric-hybrid vehicles, fuel cell vehicles, biofuels, gas-fired power plants (especially if replacing coal-fired plants - this would be enough to reach Kyoto targets for many countries), nuclear energy, and stationary fuel cells. In many cases the technology exists, but R&D can help to lower costs in order to achieve commercial deployment.

In conclusion, while GHG emissions come from a very broad range of human activities, it seems that major sources of growth in emissions will be the developing countries, and that transport and electricity will be the high-growth sectors both there and worldwide. The growth of coal-fired power plants in developing countries is itself a major factor, as they are expected to cause about one-third of the global growth in emissions over the period to 2020.

5. CANADA's GHG Emissions

Past, Present and Future Emissions. Although Canada represents a small fraction of overall world GHG emissions, our GHG emissions are high in per capita terms. The Implementation Strategy *(NCCP 2000b)* explains this high use as the result of weather extremes, large land

Graph 3 Energy Demand in Canada by Fuel Type, 1997



Source: Canada's National Climate Change Process, Canada's National Implementation Strategy on Climate Change, October

mass, high population growth rate, and resource-based, energy-intensive, export-oriented industries. It would be interesting to have a measure of the contribution of these factors, as well as that of a suburban lifestyle that uses land and buildings extensively, with its attendant needs for transport, building space, etc.

In 1997, total GHG emissions for Canada were 682 million tonnes of GHG, in CO_2 equivalent. CO_2 represented 76%, or 518 million tonnes *(NCCP 1999)*. Energy represents about 79% of the total. Agriculture and forestry contribute about 10% of the 20% non- CO_2, mainly methane and N_20, and almost none of the CO_2. The other 10% of non- CO_2 comes mainly as methane from the fossil fuel industries and from landfill, and as N20 from specific industrial processes.

For consistency with the IPCC figures, we convert Canadian GHG numbers into tonnes of carbon or carbon equivalent, t C or t Ceq. Total GHG emissions from Canada in 1997 were thus 186 Mt Ceq, up from 164 Mt Ceq in 1990. This represents an increase of 13%, due to growth in economic activity, population, energy exports and consumption. Over 50% of Canada's oil and gas is exported, and this trend will continue. Energy intensity has improved in the overall economy, but economic growth has outstripped efficiency gains by a factor of two (better than the world at large, where the ratio is three to one).

Total GHG emissions for Canada in 2010 are conservatively projected to be 27 per cent above 1990 levels, at 208 Mt Ceq, , in a business-as-usual scenario. GHG emissions in 1990 were 164 Mt Ceq, the Kyoto target is 154 Mt Ceq, so the gap is 55 Mt Ceq., or 33 per cent of the 1990 level.

In fact, if a linear regression is fit to the reported emissions from 1990 to 1998, an extrapolation of this line would predict that 2010 emissions would be over 230 Mt C per year, or about 76 MtC/year over the Kyoto target

(Graph 2). Therefore, if the 1990's are indicative of 'business as usual' conditions, Canada's emissions gap would be equivalent to +46% of the nation's 1990s emissions.

Energy Use by Regions. Alberta and Ontario are by far the biggest GHG emitters, each with one-third of Canada's total emissions. Emissions growth is fastest in Alberta, mainly through oil and gas production, and in BC, mainly through transportation. Generally, provinces involved in fossil fuel production will see more rapid increases in GHG emissions over the next few decades.

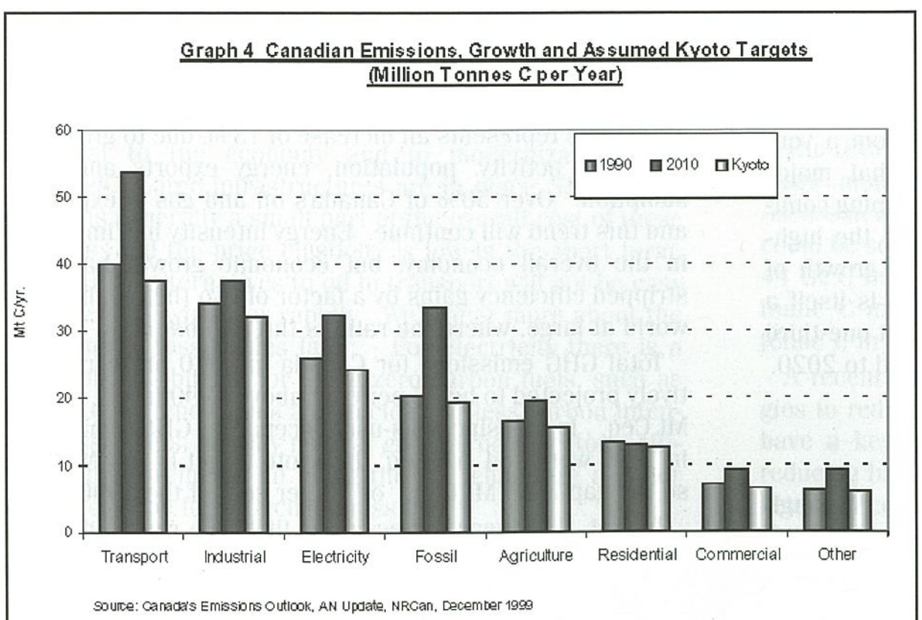
Energy Use by Source. The Strategy shows energy demand in Canada by fuel type for 1997:

Canada's fuel mix differs from the world average in that oil's share is slightly lower, coal is much lower, and natural gas and hydro are significantly higher. Nuclear's share in Canada is slightly higher than the world average, but lower than the average for the OECD, where it provided 29% of energy supply for electricity in 1995.

In terms of GHG emissions by fuel type, oil and gas are by far the main sources in Canada. In projections, natural gas almost catches up to oil by 2020. Growth in oil emissions is mainly due to transport, and in natural gas to electricity generation, especially after 2010. Coal's share of emissions is declining, due to the gradual replacement of its share in electricity generation by gas, although it continues to grow in absolute terms.

Canada's fuel mix, with a high proportion of low- or non-carbon fuels, decreases its emissions relative to other industrialized countries. While Canada can still make gains by changing its fuel mix, our high emissions are due to other factors.

Energy Use and Emissions by Sector. GHG emissions by sector for 1990 and projected for 2010 are shown in Graph 3, along with assumed Kyoto targets for sectors, *(NCCP 1999).*



For illustrative purposes, the Kyoto targets shown for each sector are simply the 1990 levels minus the 6% for Canada's overall commitment. Of course different targets may be assigned to different sectors.

Transport and fossil fuel production are the biggest absolute contributors to GHG emissions growth, because they are growing most rapidly in absolute terms, and in percentage terms also. Emissions from fossil fuel production will be up 64% from 1990 to 2010, due in part to oil sands development, and those from transport up will be up 34%. Transportation is already up 17% from 1990 to 1997. Gains in vehicle efficiency have been used to increase vehicle weight and performance rather than reduce fuel consumption. Truck traffic is up sharply, in part due to increased international trade.

As in other OECD countries, 80 - 90% of energy use in passenger transport is by automobiles and light personal trucks. Canada's large distances increase the emissions from transport, notably for air travel and freight, compared to the OECD average. The other large OECD countries, the US and Australia have similar patterns. However, it is interesting that average car trip distances in Europe and the US are about equal, but the number of trips per day in the US is double that in Europe *(Schipper et al 2001).*

Electricity and industry are next in absolute size of emission growth, partly due to the large absolute size of the sector emissions to begin with, partly due to growth, especially for electricity.

Agriculture is fairly large in emission terms, although growing slowly. This category includes forestry, although the majority of the emissions are associated with CH_4 and N_2O emissions from fertilizer use in cropping systems and from farm animals and their manure. Interestingly, the residential sector is shrinking on its own, despite the growth in stock, presumably because of buildings standards, and perhaps also because consumers are, in fact, sensitive to price signals and incentives, although seemingly more so in this instance than for personal transport.

The commercial sector's contribution is small. The large size of its gap in percentage terms is due to the rapid projected growth of the service sector, with its need for more electricity-intensive office equipment and for floor space.

Individuals are directly responsible for about 28% of Canada's GHG emissions through transportation, home heating, and electricity *(NCCP 2000a).* Production of consumer goods is not included in this measure. If one normalizes energy use in buildings by both floor space and degree-days, Canada has relatively low energy intensity, because insulating our buildings is a good investment. However, Canada's cold climate (six times more degree days than Australia, where degree days are the number of days where the temperature is less than 18 degrees Celsius, multiplied by the difference between the temperature and 18 degrees Celsius) and the relatively large amount of floor space per capita drive up emissions for buildings *(Schipper 2001)*.

Note that the emissions from Canada by sector are different from those in the world as a whole. Industry and buildings represent a much larger share of emissions for the world, while transportation is clearly more developed in Canada.

This brief survey suggests that energy-using activity levels in Canada are likely to increase. Reductions in emissions must be sought through greater efficiencies, changes in fuel mix, new approaches to energy use and energy systems, and carbon capture and sequestration. Key sectors, because of their size and likely growth, will be transport, fossil fuel production and electricity.

Also, given Canada's vast land area and the relatively large size of its agriculture and forestry sectors, biomass has a unique contribution to make as both a source of renewable energy and a sink for emissions. However, a greater reliance on agriculture for the production of bio-based fuels and other products could increase the already significant GHG emissions associated with this sector. New technologies are required to enhance agricultural production while reducing GHG emissions.

Table 2 GHG Emission in 1998, Reductions and Growth by Sector

Sector	% of total in 1998	% of reduction under Plan by 2008-2012	% growth to 2010 under business-as-usual
Transportation	25	10	34
Electricity	17	20 inc.oil & gas	25
Oil and Gas	18		65
Industry	15	15	10
Buildings	10	10	9
Ag and Forestry	10	20	18
Other	5		48
International		25	
Total	100	100	27

Source: Canada's Emissions Outlook: An Update, NRCan, December 1999, and Government of Canada Action Plan 2000 on Climate Change

6. Technologies to Reduce Emissions or Enhance Sequestration, and Key Sectors

The Options Exercise and the Technology Table. Canada's national Options Tables Exercise in 1999-2000 looked at GHG technologies for both the near term and the longer term, through a series of consultative "tables". Most of the tables looked at existing technologies that could be implemented in the Kyoto timeframe, from the perspective of the technology users. The Technology Table *(NPCC 1999b)* examined technologies that might be applied beyond the Kyoto timeframe, from the perspective of the technology supply community.

The Technology Table stressed that a sustained commitment to technology development should be made as soon as possible. It outlined the required funding, an annual amount increasing from $100 million to over $500 million over five years, mainly in demonstration, at $300 million/yr and in technology development, at $200 million/yr. This would help meet the targets for Kyoto and beyond, reap ancillary benefits, and position Canadian companies for international competition in GHG technology.

The Table proposed options in four areas pertaining to Canada's innovation system for GHG technologies: knowledge infrastructure, including human resources, demonstration and commercialization, the export business climate, and linkages and partnerships. It stressed the need to find the right regional balance for actions across Canada.

The Table discussed 25 groups of promising technologies for GHG mitigation in six broad categories to illustrate some of the possibilities, not to select a definitive set for investment. In so doing, they looked for technology areas where there was an emerging Canadian capability, and ideally both a Canadian and an international need. The categories were:

- Fossil fuel supply
- Energy production, mainly electricity and biomass
- Energy end-use, mainly fuel cells, buildings and transportation
- CO_2 management, notably geological sinks
- Non-energy GHG emissions - cement, agriculture and wastes
- Enabling or crosscutting technologies, including hydrogen.

In all, the Table identified about 1300 specific technologies for consideration. They also carried out some detailed studies of countries and sectors where Canada's would find good export markets for its GHG technologies. Proposed funding for most of the 25 illustrative technologies was in the range of $5 - 30 million per year.

In the 25 groups, there is some consideration of the likely cost range, and also of the likely market. However, it is difficult to do this systematically across activities that are so different in nature, in potential, and in stages of development, and of course with longer term R&D there are many uncertainties. What one would want, ideally, is a chart that shows for each technology the potential for emissions reduction in different timeframes, and the cost per tonne of carbon saved. What one gets is a fairly broad range of both costs and reduction potential, as with the IPCC and IEA studies. Decisions must inevitably be made under conditions of uncertainty. R&D can help to reduce that uncertainty.

Canada's Action Plan 2000. This Plan *(Government of Canada 2000),* draws on the Options Process. It involves new expenditures of $500 million plus $625 million already announced, to be spent over the next 5 years, building on $850 million that the government of Canada has already spent. The total reduction from the initiatives outlined in the Action Plan is expected to be one-third of the Kyoto Gap. The remaining two-thirds will be achieved by measures yet-to-be-announced.

Action Plan 2000 targets key sectors that contribute 90% of Canada's emissions: transportation, energy (oil and gas, and electricity), industry, buildings, forestry and agriculture, international, and future solutions.

Table 2 shows some aspects of the Plan. The first column *(NCCP 1999)* shows the percentage contribution of each sector to Canada's total GHG emissions in 1998. The second, *(Action Plan, Chart, p.4),* shows the percentage contribution of each sector to the total reductions under the Plan. The third *(NCCP 1999)* shows the expected growth from 1990 to 2110 under a business-as-usual scenario.

A useful comparison can be made between the first and second columns. Transportation, electricity, and fossil fuels, fast-growing sectors, make contributions to reductions that are much smaller than their share of total emissions. Agriculture and forestry make larger contributions than their share, through biomass

management and sinks. International mechanisms, through which Canada can obtain emission reduction credits for projects undertaken in other countries, are expected to pick up 25% of the total. Thus almost half the reductions in the Plan are due to international mechanisms or sinks. Comparison of the second column with the third is also interesting. The higher growth areas are not the strongest candidates for reductions, so that their growth is less restrained. This is especially significant in light of our belief, noted above, that emissions growth under the business-as-usual scenario is likely to be much higher than the government's projection.

Proposed Actions in Action Plan 2000 by Sector. Given the time frames and the time lags to deploy technology on a large scale, almost all the reductions to 2010 will depend on technology that is ready or almost ready for deployment today. Technologies that still require development, and that could be deployed after 2010, are indicated below under technology as a sector in its own right. The Plan's proposed areas of focus are as follows:

- *Transportation:* Fuel efficiency, new fuels, fuel cells, efficient freight, urban transportation.
- *Energy (Fossil fuel production).* CO2 capture and storage, efficiency, (building on the Weyburn experiment with CO2 disposal, and on coal bed methane, and working with the Regina centre which coordinates Weyburn and encourages R&D.)
- *Electricity.* Reduce barriers to trade (to allow more use of lower carbon and renewable sources) , develop lower carbon sources, e.g. renewables, and CO2 capture and storage. Purchase and subsidize renewables,
- *Industry.* CIPEC, reporting, benchmarking, efficiency audits, incentive to exceed code requirements by 25%. Renewables (biomass, solar hot water, ground-source heating), metal recycling, concrete roads.
- *Buildings.* Near term, retrofit. Long term, build to higher efficiency. Standards for appliances. Upgrade the Model Energy Code.
- *Government Ops.* Try to reduce by 31%. Create the market. Retrofits, fuel switching, renewables.
- *Agriculture and Forestry.* Emissions from these sectors are mainly from non-energy sources. Proposed measures in the Action Plan, focussed on agriculture, include nutrient management, livestock management, soil management and demonstration farms.
- *International.* Office for Clean Development Mechanism and Joint Implementation set up within DFAIT.
- *Technology (Future)* - R&D: find new ideas through discovery competitions, develop through basic university research and support their advancement. Collaborate: develop networks and technology road maps, national forum; Market Technology: support business environment for innovation, showcase Canadian technology to domestic and international markets.

7. Specific Sectors

A. Electricity

Current Situation Decisions on developing new technology to achieve climate change goals for the electricity sector will depend on the sector's characteristics. The share of Canada's electricity that comes from fossil fuels is relatively low, about 27% in the year 2000 *(Statscan 2001),* due to the high share of hydro (61%), but also to the nuclear share, currently about 12%. Fossil fuels contribute about 27%. The bulk of this is from coal. About 90% of the coal consumed in Canada is used to generate electricity. Half of this is consumed in Alberta, and a quarter in Ontario.

As hydro and nuclear are effectively GHG emission-free (some hydro projects release methane from flooded reservoirs, but the overall effect is believed to be fairly small), the share of Canada's total GHG emissions that comes from the electricity sector is also relatively low - about 17%, versus 35% for the OECD countries on average, 34% for the world. Countries such as France, Switzerland, and Sweden also have low emissions from electricity due to various combinations of hydro and nuclear sources.

Nonetheless, in absolute terms, per capita GHG emissions from Canada's electricity sector are high because of our large per capita consumption of electricity, the highest in the world except for Norway and Iceland, which have extensive hydro resources and small populations. Canada's per capita electricity consumption is about 20% higher than the US, and double that of Germany, Japan, the UK or France.

In 1994, the breakdown of electricity production by source was 61% hydro, 19% nuclear and 20% fossil, mainly coal. Since then, the nuclear share of Canada's electricity has fallen, and the fossil share has increased, due to the shutdown of eight Candu nuclear units in Ontario in 1997, and the construction of a number of natural gas plants.

Fuel Mix The GHG emissions from a 1000 MW coal plant operating at 80% capacity factor (e.g. at 100% of its output for 80% of the time) will be about 5.6 Mt of CO2 per year, or 1.5 Mt C per year, and about half that from a natural gas plant. These are the target amounts that can be reduced or eliminated by using lower-carbon or non-carbon sources. They are significant in terms of meeting Canada's Kyoto targets.

The most effective near-term route to emissions reduction in the electricity sector would be a shift in the fuel mix as new plants are brought on line to replace existing capacity or to meet new demand growth. Since power plants involve large capital investments and generally operate for 30 years or more, decisions on the type of technology and fuel for each new plant have long-lasting implications. Each new plant is a major opportunity to influence the future fuel mix. In turn, the fuel mix of Canada's electricity sector will largely determine utility carbon intensity, and will have a large impact on GHG emissions from this sector. However, plants built to supply new demand growth are likely to be fairly rare in Canada in the next decade due to a combination of slow demand growth and, in some areas, excess capacity. A current estimate of electricity demand growth over the next few decades is about 1.7 per cent *(NRCan 2000)*.

The current trend is to favour natural gas plants for new and replacement capacity. To the extent that they displace or replace coal plants, they would reduce emissions. To the extent that they replace or displace nuclear, hydro, and other renewables, they would increase emissions.

Another immediate opportunity for a shift in fuel mix in the electricity sector would be the re-start of the nuclear units in Ontario. Four of the nuclear units at Pickering are being restarted over the next year or two, and two at Bruce are expected to follow shortly thereafter. If these plants, representing about 3700 Mwe of generating capacity, return to service and run at reasonable capacity factors, fossil and nuclear electricity will again achieve a better balance.

Further development of Canada's hydro resources could contribute to the reduction of emissions in neighbouring provinces and in the US. In some cases new transmission capacity may be required. Investments in R&D on hydro development, and its environmental impacts, and on the stability and efficiency of transmission systems, can further enhance the effectiveness of Canada's main source of electricity.

Increased interprovincial trade could displace higher cost plants with lower cost ones, probably increasing the use of hydropower in Canada. Higher electricity exports to the US are also a possibility (Goodale 2001), including those from plants dedicated for this purpose. Exports would favour hydro plants and also some nuclear plants, as both compete in the market on the basis of their fuel and operating costs, which are very low. Since US fossil plants contribute to air pollution in Canada, exports of GHG-emission-free Canadian power would have the ancillary benefit of better air quality for both countries.

In the medium term, the replacement of coal-fired plants in several provinces with lower-or non-carbon alternatives, or the development of sinks that can absorb the carbon from coal plants, could make a significant contribution. Coal reserves are abundant and low-cost. The normal remaining life for existing coal plants in Canada varies from 5 to 30 years *(NPCC 2000d)*. New plants are more readily equipped for capture and storage than existing ones.

Efficiency While the fuel mix can be shifted with existing technologies, the development of more efficient, lower-cost, lower-carbon alternatives is needed to enhance the reduction potential over the medium and longer term. Improvement in end-use efficiencies, such as industrial processes, motors, appliances, lighting, sensors and controls, will also be very important, but we do not have space to address them here. Of course, improvements in the efficiencies of fossil-fired plants would be welcome in their own right.

The most pressing need is R&D to reduce the costs of lower-carbon alternatives, including the costs of carbon capture and storage, in order to help them compete in an increasingly integrated and competitive electricity market.

Greater use of combined heat and power can contribute to greater efficiencies, where thermal and electrical loads can be matched. The development of other renewables, notably wind power, can contribute in some regions, although the contribution is expected to be small in overall terms. Intermittent renewables will require back-up capacity. Biomass can contribute to local economic development, where a reliable supply can be maintained. For nuclear energy, the challenge is to lower the capital costs, while maintaining high safety and reliability standards, and take full advantage of developments in instrumentation and control.

The Electricity Options Table *(NPCC 2000d)* concluded that the most important single step to reduce emissions in the electricity sector would be the establishment of a value for the carbon in carbon emissions. The IEA has drawn similar conclusions *(IEA 2000)*. The Table cited three related policy issues that must be resolved: the impact on competitiveness, the allocation of the burden among regions and sectors (not easy given the distribution of fossil fuel use for electricity in Canada), and access to international mechanisms.

Such a move to a real cost for carbon, whether through taxes or emission trading, would internalize the costs of climate change. It would favour low and non-carbon renewables, and help to create a least-cost route to reducing emissions. And it would allow a clearer picture for investors deciding on which technologies are likely to achieve the best return in the medium term.

B. Transportation

Emissions from transportation are currently at 40 Mt C (148 Mt CO_2) equivalent and are expected to rise to 53 Mt by 2010 under a 'business as usual' scenario. In order to achieve the Kyoto targets, transportation sector emissions will need to be reduced by 28% to achieve pre-1990 levels. The transportation sector is the largest contributor to GHG emissions. However the sector itself represents a diverse array of technologies and practices, from individual use of automobiles to the commercial airline industry. As such, no single prescription for achieving Kyoto targets is possible. To illustrate this point, 44% of transportation emissions are from personal light duty vehicles, with the remaining emissions from commercial transportation including trucking, rail, air and marine vehicles.

Options for GHG emission reduction in transportation are many. Transport Canada conducted an 'Options Table' to consider viable scenario's for GHG reduction in 1999 *(Transport Canada 1999),* and other jurisdictions have engaged in similar activities *(IWG 2000).* These generally agree on defining four approaches to GHG reduction in transportation:

1. Policy and encouragement of voluntary measures to make more efficient use of existing transportation technologies
2. Economic mechanisms (taxes, feebates etc.) to encourage efficiency and the transition to lower GHG technologies and practices
3. New incremental technology to improve the efficiency of transportation technology.
4. Complete redesign of transportation technology with new energy technologies based on zero carbon content (zero carbon energy sources).

While there is an obvious emphasis on the technology of energy supply, storage and conversion for transportation, it should be understood that all four avenues for mitigation rely extensively on new technological developments that were not available ten years ago. In particular, many plans for enforcing policy measures or deriving enhanced efficiency through better planning are dependent upon the widespread availability of information technology.

Transportation services are an integral part of the fabric of Canadian society. The coupling of transportation with both cultural practice and economic activity make the true impacts and costs of any mitigation strategy almost impossible to quantify. Furthermore, the global nature of transportation technology makes major technological change within Canada alone a virtual impossibility. The cost of developing a 'Canadian only' technology solution is simply too high. Rather, the global need for transportation technologies that do not emit GHG's represents a huge opportunity for Canadian Technology to take the world stage, and Canada is recognized as a leader in the field of zero emission energy technologies.

Any discussion of modifications to transportation technology must also note the coupling between GHG emissions and other emissions that contribute to local air quality, particularly in urban centers. Given the profile of health care on the current political agenda, local air quality issues may present a more compelling and more urgent need, which Canadians will appreciate and respond to. While in most cases reduction of smog gas emissions accompanies reduction in GHG emissions, this in not always the case. It is possible we will face the undesirable position of two environmental concerns competing with each other for different policy and technology alternatives.

The Kyoto accord outlines a schedule for emissions reductions in the 2010 - 2020 timeframe. There is little chance of introducing widespread zero emission vehicle technology within the next ten years, particularly when much of that technology is still in the development stage and there is no legislation to force its adoption. Zero emission vehicles coupled with sustainable energy sources present a laudable goal for technology development, but free market decisions to replace existing technology are influenced by many factors other than environmental correctness. A personal decision to replace a car or a business decision to upgrade a fleet of vehicles must also consider cost, quality of service and availability - all areas where new technologies have either inferior performance compared to existing alternatives or are simply unproven. Who will reward the pioneers?

Efficiency

Efficiency improvements in our existing transportation technologies are often cited as a vital mechanism for reducing GHG emissions. Transportation technology has been steadily increasing efficiency at about 0.75%/yr for at least the past ten years. However, the push for efficiency is also coupled with demand for increased quality of service from vehicle drivers. In the light-duty vehicle sector these efficiency improvements are translated into increased power and expanded 'hotel loads' on vehicles. In commercial transport the drive for efficiency is to reduce costs and increase the gross carrying capacity of the combined transportation fleet (fuel economy has remained relatively constant, but the cars are getting larger [cite]). Improving technical efficiency alone will not stem the growth in transportation utilization. During the period between 1990 and 2010 the number kilometers per year for the combined fleet is expected to increase from 265 billion Kilometers to over 400 billion Kilometers. Doubling the efficiency of conventional vehicles is simply not possible.

However, quite apart from technical efficiency, it is nonetheless possible to improve the efficiency of the utilization of the overall vehicle fleet and by so doing achieve significant GHG reductions. Policies that encourage high occupancy vehicles, scheduling programs to plan efficient vehicle routings, modifications to road surfaces to reduce losses are a few examples of myriad policy options which, if adopted, have potential to reduce GHG emissions. These measures are attractive in that they do not demand significant technology change, can be applied to the existing vehicle fleet and generally offer a zero cost or very low cost means of achieving emission reduction. However, it is difficult to guarantee the adoption of voluntary policies and the potential unintentional impact of such practices is also difficult to assess.

The transportation table estimates that feasible measures to improve efficiency, not including price mechanisms or other direct economic tools, could produce a 10 Mt reduction in emissions by 2010. The cost of these measures is negligible.

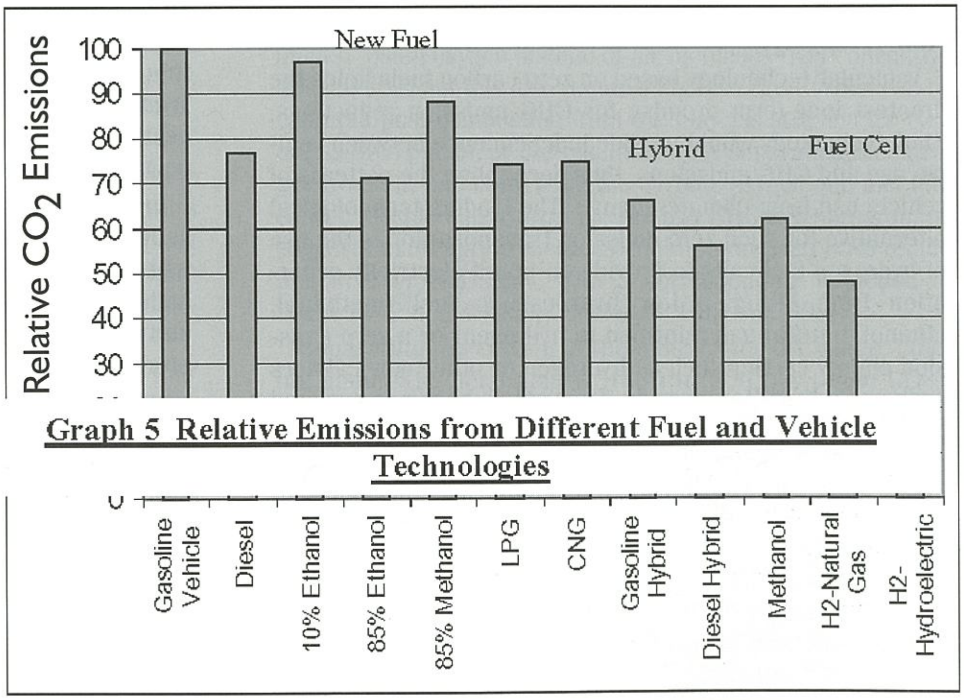
Incremental Technological Change

While there is no question of the need to modify transportation utilization patterns through policy and education, it remains a necessity to deploy new technologies that produce lower emissions while delivering an equivalent service. Our current transportation technology is based entirely on the coupling of hydrocarbon fuels with internal combustion engines to produce work. Near term technology alternatives for each of these two components are emerging.

Fuel substitution with lower hydrocarbon fuels provides one avenue for transition toward a lower emission technology. Starting with gasoline-ethanol blends that run in conventional engines and moving toward progressively lower hydrocarbon liquids produced from natural gas (methanol) and biomass (ethanol) sources, there is the possibility of an incremental movement toward lower hydrocarbon fuels. In the case of ethanol production, the magnitude of the greenhouse gas benefit is largely dependent upon the nature of the biomass feedstock that is used to produce the ethanol. Feedstocks like starch from energy-intensive, nutrient demanding crops such as corn produce a fuel with net GHG emissions that are only marginally better than gasoline. However, production of ethanol from agricultural or forest residues (lignocellulosic biomass) or from biomass grown with minimal inputs may have a much better GHG benefit. The challenge is that conversion of lignocellulosic feedstocks to ethanol requires the use of emerging technologies that have yet to be implemented on the large scales (and economics) needed to serve the transportation sector.

Therefore, at the present time and state of technology, there are difficulties with fuel substitution as a strategy for GHG reductions in the transportation sector. The net emission reduction achievable with fuel substitution is in most cases modest (see Graph 1), so even complete substitution of existing fuel with one of these low emission alternatives would probably not produce the necessary level of emission reductions required to achieve the Kyoto targets. Furthermore, although most of these fuel substitutes are liquid fuels, it does not follow that they can be easily integrated into the existing fuel distribution infrastructure without major new improvements. Gaseous fuels present an even larger challenge, particularly in the off-road industrial transportation sector. Some Canadian technologies for fuel substitution stand out. In particular, Westport Innovations have developed a natural gas injector technology for use with Diesel engines and are focused on deploying this in new diesel engine applications. This is a world-leading technology that can be extended to allow diesel engines to operate directly on Hydrogen as the infrastructure for that fuel develops.

Difficulties with scenarios for fuel substitution include estimating the cost of infrastructure replacement, the identification of policy and market mechanisms to persuade consumers to switch to new fuel technologies (fuels beyond very light gasoline blends require engine modifications) and the possible land use implications of some options (in particular ethanol from 'fuel crops' such as corn). However, the Transportation Table was able to develop a package of



Graph 5 Relative Emissions from Different Fuel and Vehicle Technologies

scenarios around fuel substitution that lead to a predicted 0.5 Mt reduction (only 4% of required reduction to achieve Kyoto targets) at a cost of between $25 and $50 per tonne.

An alternative to fuel substitution is to replace the existing combustion-only vehicle drivetrain with a hybrid gasoline-electric system. Using such approaches, the fuel infrastructure does not change, but the vehicles are able to achieve dramatic performance improvements through the combined use of short-term energy storage in electro-chemical form and the efficient operation of small internal combustion engines. In the 2000 Tour du Sol, which showcases new vehicle technologies, hybrid electric vehicles achieved 55% GHG emission reduction compared to conventional vehicles over a 500 km test in identical conditions. This has led some researchers to conclude that the Kyoto commitment could be met by a transition to such hybrid vehicle technology (Patterson 1999, Patterson 2000).

This technology is most promising for both near and long term development. However, the technology is being developed by major automakers in the global context and there is little Canada can do to accelerate either its development or introduction to the comparatively small Canadian market. Furthermore, the technology is barely beyond proof of concept stages and it is difficult to imagine substantial quantities of hybrid vehicles being made available in the short term [Toyota recently announced plans to increase Prius production]. Finally, it should be noted that hybrid vehicle technology currently is only being developed for light duty vehicle applications. Undoubtedly there will be hybrid powertrain developments for commercial vehicles, but the success of the hybrid automobile is due largely to the short trip length and particular duty cycles that characterize urban driving conditions. Long haul transportation involving large tonnage vehicles may not be amenable to similar emission reductions through the application of hybrid powertrains.

New Technology

Vehicular technology based on zero carbon fuels holds the greatest long-term promise for GHG emission reductions. Such technology would provide independence between vehicle use and GHG emissions, thus decoupling the patterns of vehicle use from climate change. The leading technological alternative for such zero emission transportation is the use of hydrogen fuel cells to provide on-board electricity generation from either a low hydrocarbon fuel (methanol, ethanol, natural gas reformed to hydrogen) or a zero emission energy carrier such as hydrogen or other new carriers such as Sodium Borohydride. The vehicle becomes powered by electricity with the attendant performance improvements that accompany that transition, but without the impediments imposed by storing energy in batteries. Fuel cell vehicles will achieve equivalent performance (performance, cost, duty cycle) to conventional fueled vehicles, but with huge emission reductions. The extension of the hybrid electric vehicle to include a fuel cell engine is an exciting possibility for technology development.

GHG emission estimates from fuel cell powered vehicles resort primarily to emissions produced in vehicle manufacture and fuel production. Again referring to figure 1, emissions from fuel cell powered vehicles are estimated to be between 38% and 85% lower than conventional vehicles. One advantage of fuel cell vehicles is the opportunity to exploit very large economies of scale through multiple applications of the same technology. Canadian fuel cell and hydrogen production technologies lead the world. Ballard Power systems, Global Thermoelectric, Xcelsis, Hydrogenics, Greenlight Power, Powertech labs, Dynetek, Stuart Energy, Hydrogen Systems, Cellex and others are among the leading names in this industry - all are Canadian. Canada is furthering the development of these technologies through significant R&D funding initiatives led by the National Research Council of Canada, and an industry focus group 'Fuel Cells Canada' is playing a major role in coordinating the early demonstration and distribution of these technologies to point the way for future development. Even so, the technology is new and untested and there remain significant challenges to both proving performance and developing the necessary support infrastructure (from refueling stations to diagnostics and maintenance). These issues push the realistic time frame for implementing zero emission fuel cell vehicle technology into the 10-15 year timeframe.

Conclusions On Transport

To summarize the foregoing, transportation is the largest single sector for GHG emissions, not a surprising fact given the role of transportation in both domestic and commercial activities of Canadian society. Although there is a wide array of short-term measures, which could reduce GHG emissions at low or even negative costs, the total reduction in CO2 emissions from these is estimated to be about 10 Mt in 2010. Extending the scenario to include feasible fuel substitution and new vehicle technologies, the Transport Table concluded that emissions reductions of up to 40 Mt in 2010 at a cost of $5/t may be possible. Even this most optimistic scenario leaves the Canadian Transportation sector short in emissions reductions, suggesting that price controls may be necessary if the transportation sector is to achieve Kyoto targets.

In the longer term, it is possible that new technical innovations, particularly with respect to hydrogen technologies, will introduce transportation technology that produces no emissions during use or production of fuel (manufacturing and salvage of transportation technology will still likely produce emissions).

8. Biomass Management and Sinks

Sinks, both geological and biological, have an impressive potential capacity for storing carbon, as well as some other very attractive features. Obviously a lot of R&D work has to be done, both generic and site-specific, before sinks could be implemented on a large scale, but there seems to be significant near- and long-term benefit in pursuing technologies relating to the capture and storage of carbon, with an emphasis similar to that accorded other GHG mitigation approaches.

Sinks could allow the continuing use of coal, which is abundant and cheap, and also of oil and natural gas. Some sink activities may be paid for by the economic revenue generated, for instance enhanced recovery of oil or enhanced coal bed methane extraction. Even when sinks result in a net cost, many of them seem to fall within the cost range of competitive options. Over time, carbon emissions are likely to take on an economic value in all cases, i.e. there is no escape from the costs. Sinks are probably easier to implement politically than measures that restrict economic activity or options, as they pose less of a threat to core goals such as economic growth. However, they are not without their critics. Their permissiveness for continuing use of fossil fuels is a double-edged sword, as it can be seen as inducing complacency and encouraging growth in GHG emissions, which might then be difficult to control. This perception provides some of the rationale for opposition to the inclusion of sinks in Kyoto accounting schemes. Other concerns relate to the security or permanence of these carbon stores, and the difficulties in quantifying and verifying the carbon stock changes that are associated with the 'additional activities' taken to create the sink .

From Minister Anderson's recent statement *(Anderson 2001)*, Canada's policy on sinks is that you account for carbon stored or disposed when that event happens, and you account for carbon released when it is actually released. That makes sense. How much of the uptake should be ascribed to human activities, and hence credited in the Kyoto accounts, and how much should be regarded as natural is obviously a thorny question, which will likely be decided politically. Biomass uptake allows for CO_2 to be taken directly from the atmosphere. Geologic disposal requires a fairly concentrated stream of CO_2, so it is best matched to large point sources, like fossil-fired generating stations which, according to the IEA *(Wallace 2000 at p.3)*, are responsible for about 33% of global CO_2 emissions, although less than 20% of emissions in Canada.

Geological Sinks. The major geological sinks include deep saline aquifers, depleted oil and natural gas reservoirs (mainly gas), coal beds where CO_2 can displace methane (coal bed methane or CBM), and oil reservoirs where enhanced oil recovery (EOR) is possible through CO_2 injection *(Wallace 2000; Legg 2000; Gunter 1998; Reeve 2000)*. Oceans are considered to be a large potential sink for further carbon sequestration, in the order of 1000 Gt C. Costs for the UK were estimated at about $21 per tonne C, exclusive of compression. Ocean sequestration would require access to sites at depths of 3 000 metres, and transport both overland to the coast and thence to the deep ocean site, which are long distances for most Canadian sources of carbon emissions. It would raise issues of environmental impact around the injection site, and the security with which the gas could be contained. Since Alberta and Ontario produce about two-thirds of Canada's GHG emissions, and since there are ample land-based storage opportunities in Canada, Canada is not pursuing ocean disposal as a near-term option, although we participate in some international studies *(Gunter, 1998; Reeve, 2001)*.

Estimates of storage potential vary widely, pointing to a need for a more thorough inventory of sites and their potential. Globally, aquifers and depleted reservoirs seem to have a potential in the hundred Gt C range. Coal beds and EOR are in the tens to hundreds-Gt C range. Coal bed methane is particularly well suited to countries that have abundant coal and little natural gas, like China and India, as it could be seen as a method of coal gasification.

Compared to annual global anthropometric GHG emissions in the 5 Gt C range, these storage capacities are very large. For EOR, the retention time is believed to be perhaps as short as tens of years, whereas it is of the order of 100 000 years or more for the other options.

In Alberta, recent estimates for storage potential are in the range of 5 Gt C (20 Gt CO_2) for coal beds, depleted reservoirs, and aquifers, and 16 Mt C for EOR. Alberta's annual emissions are in the 55 Mt C range, about a third of Canada's total. This suggests that there is enough geologic capacity to dispose of Alberta's entire emissions for many years to come. The challenge is to develop and prove the safety, environmental impact and cost effectiveness of this approach. A current EOR project at Weyburn Saskatchewan will result in the storage of about 0.5 Mt C per year for the next decade or so.

According to Gunter *(Gunter 1998)*, capture and sequestration in Alberta could get to about 10 Mt C per year in 2010, or about one-fifth of Canada's required reduction (Kyoto Gap), although achieving this goal in that time frame would be a major challenge.

Concentrations of CO_2 in flue gas range from 4% for natural gas combined cycle plants to 14% for pulverized coal plants. Using oxygen instead of air increases CO_2 concentrations to 90% but this also requires high energy. Carbon can be captured post-combustion from the flue-gas streams for coal or gas-fired plants, or pre-combustion by separating the nitrogen from air, and converting the carbon, oxygen and fuel into carbon dioxide and hydrogen. The IEA GHG R&D programme suggests that capture methods could produce an 80% reduction in CO_2 emissions, with a corresponding reduction of about 10% in generating efficiency *(Wallace 2000)*.

Separating the carbon is the most expensive stage, costing about $10 per tonne C ($30 to $50 per tonne CO_2). However, the in the case of EOR and CBM, the revenue stream from the enhanced oil or methane recovery may result in a net benefit, or negative cost. Transportation through pressurized pipelines and geological storage should each add less than a dollar per tonne C. Overall, capture and storage will add about 1.5 - 3 US cents per Kilowatt-hour to the cost of electricity. Prices for electricity in the OECD countries in 1998 were in the range of 7 - 14 US cents per kwh for domestic use, and 4 - 9 cents per kwh for industrial use *(Wallace 2000)*, so the additional cost is not negligible.

For Canada, Reeve *(Reeve 2000)* notes the potential for overall capture and storage costs as low as $7 per tonne C. Reduction to about $5 per tonne C would allow widespread deployment, and would offer Canada continuing use of coal, which can be supplied at the equivalent of $2 per barrel of oil. Three-fourths of the point sources in Western Canada are for electricity generation. About 0.4 Mt C per year could be stored in oil reservoirs and used for EOR at a net cost of about $4 per tonne C, while 10 Mt C per year could be stored in deep coal seams or aquifers at $10 per tonne C. The limit is the amount of CO_2 available, and competition from other options, etc., rather than storage capacity.

Technological requirements in this area are for better assessments of geologic potential, field tests to determine fate of CO_2 injected, as is being done at Weyburn, cost reductions for CO_2 separation technologies, and more experience in the use of hydrogen for turbines. *(Reeve 2000, Wallace 2000; Ampere 2000)*. Also required are assessments of regulation, tax and royalty frameworks, an inventory of sources and sites, and institutional development for communication, financing and management of projects *(Reeve 2000)*.

Biological Sinks Through photosynthesis, plants have the ability to use the sun's energy to remove CO_2 from the atmosphere and create a biomass (i.e. the plants themselves), which is both a carbon and an energy store. When the plant material is burnt, consumed by animals or dies and decays, the C in the biomass is returned to the atmosphere, thus completing the biosphere C cycle.

Canada is one of the very few developed countries of the world where our GHG emissions from fossil fuels (ca. 180 Mt C/yr) are dwarfed by the flow of C through our biosphere (est. at >2800 Mt C/yr). Although Canada is home to only 0.5% of the world's population, the nation is steward to approximately 10% of the world's forests. That forest resource, and Canada's vast agricultural lands have allowed this country to provide about 5% of the world's fibre products and 2.5% of global grain production.

Currently, Canadian agriculture is a major source of non-CO_2 emissions (about 10% of the total) and there is a question about whether our national forest stocks are currently increasing or decreasing. However, managing GHG emissions and biosphere C stocks has never been a priority for Canada's agriculture and forestry sectors and many opportunities exist for decreasing agricultural GHG emissions while increasing the amount of C which is taken up and stored in forests or in agricultural soils.

Some of the management strategies or 'technologies' for C sequestration are well known and could be implemented with appropriate incentives. For example, use of low-till agriculture as an alternative to plowing, improved pasture management, more optimal use of fertilizers, or changes in crop rotation strategies are all known to increase soil C reserves. In forestry management, changes in harvesting strategies, prompt replanting after harvest, pre-commercial thinning of forests, fertilization, planting trees on abandoned agricultural lands and improved fire and pest control will all work to increase C stocks.

There are also a number of new technologies, which could be developed to enhance the ability of the Canadian biosphere to take up and hold atmospheric carbon. For example, crop plants could be selected with root systems or silage that decompose more slowly. Given that most crops have a tonne or more C per hectare in below ground biomass at the end of each season, and given that there are more than 30 M hectares of cropland in production in Canada every year, the opportunity is significant. In forestry, selection of tree seedlings for replanting that grow 20-30% faster than average, or that are resistant to insect pests could have a major impact on Canada's carbon economy in coming decades.

A major technological issue for using biosphere C sinks involves the need for cost-effective tools to quantify and verify carbon stock changes and associated non-CO2 GHG emissions. The biosphere C stock is Canada is very large and measuring the C stock changes that occur with additional activities can be a challenge since the background levels are both high and variable. New instruments and measurement strategies are currently under development for the rapid quantification of soil C content, forest biomass, N2O and methane emissions. Measurement and modeling tools are also being developed to scale the site specific measurements to regional and national levels.

These measurement and verification tools are perhaps the most important technologies that need to be developed for large-scale implementation of biosphere C sequestration. The return on the investment should be very high since changes in biosphere management in Canada should be able to take up and hold many tens of millions of tonnes of C per year. At $100 per tonne, the opportunity is in the billions of dollars per year. In addition, there are cobenefits associated with many C sequestration technologies including enhancing biodiversity, sustainable forestry and agriculture, soil conservation, rural development and new products for farmers.

Through biosphere C management, Canada should be able to increase the 'minimum monthly balance' in its 'national C account'. It should also be able to divert a portion of this additional biomass to provide some of the energy, chemicals and materials that are now derived from fossil fuels. Canada has a major opportunity here. For example, the residual biomass from Canada's current agriculture and forestry sectors (i.e. 44 Mt C/yr) has an useable energy content of about 1.6 exajoules, an amount equivalent to over 20% of the energy that Canada extracts from all the fossil fuels consumed in this country in a year *(Layzell, 2001)*.

Full biosphere C management will require the development of a plethera of new process engineering and biotechnologies that will facilitate the movement towards a new, bio-based economy. This represents a major thrust in laboratories around the world, but especially in the USA where the primary driver is 'energy security' rather than GHG emission reductions *(Lugar and Woolsey, 1999)*.

9. Conclusions: Outstanding gaps and opportunities for Canada

- Canada's GHG emissions continue to grow. The current Action Plan address only one-third of Canada's Kyoto Gap, and half of those reductions are through sinks and international credits. Also, the Gap is likely to be larger than projected in government documents.
- Technology development clearly has a role to play in meeting commitments for the post-Kyoto period, which are likely to more stringent, through greater efficiencies, changes in the fuel mix, new approaches to energy systems, and the capture and sequestration of carbon.
- Given the projected increases in Canada's already high use of energy, and the likelihood of further growth with energy exports and tar sands development, carbon capture will be important for Canada.
- Canada has a very large landmass with extensive forests and agriculture, so biomass management must be important. It provides a general and diffuse capture mechanism. But agriculture (and to a lesser extent, forestry) represents a significant source of GHG emissions in Canada, so if we are going to look to these sectors for enhanced C sinks, or for a source of biomass energy, we will need the technologies and management strategies to produce this biomass carbon stock with few or no emissions of non-CO_2 GHGs.
- A big technology challenge for biosphere C sinks is related to the need to quantify and verify the increases in C stocks and to show that these increases are associated with 'additional activities'. It is also imperative to show that the C stocks (geological or biosphere) will have reasonable permanence, or at least that subsequent decreases in C stocks can be readily quantified.
- Transport is a large and growing sector, - so efficiencies and fuel switching will be important. While it will take time to make changes to the infrastructure, the longer term focus should be on lower carbon fuels, including hydrogen.
- Electricity underlies our economy and will continue to grow, though not as fast as in the developing countries. Development aimed at developing lower-or non-carbon sources, and in particular reducing their costs, will be essential, as will the development of lower-cost capture and sequestration options. .
- Buildings - Commercial and institutional buildings seem to have more promise for emission reductions at lower cost than residential.
- Oil and gas production is a large and growing source of emissions. Solutions needed, including carbon capture and sequestration.
- Given the large scale of Canadian energy use (absolute and per capita) and GHG emissions, demand management and efficiency have to be major considerations in all sectors.
- While technology development is fundamental in climate change policy, implementation will require major changes in attitudes and behaviour, individually and collectively.
- Canada can make a contribution to world climate change technology in many areas based on our knowledge and experience, especially in oil and gas production, carbon capture and sequestration, biomass, transport, alternative fuels, including hydrogen, and in the generation, transmission and use of electricity. We should continue to invest in longer term development in these areas.
- In the near and medium term, it will be important to improve mitigation by enhancing efficiencies, educating the public, using energy wisely, and lowering the overall carbon content. Stronger incentives will be required, through price mechanisms (taxes or trading schemes), and regulatory action and standards. In the longer term, given the pressures of population and economic growth, and increasing demand for energy services (mobility, floor space, products, information), new systems will be required, emphasizing sequestration on the one hand, and low or non-carbon energy sources and systems on the other. Canada is well positioned to move toward a non- or low-carbon hydrogen/electricity system, and to develop both biomass and geological sequestration.

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Copies of the Program and REgistration Form have been sent to CNS members with e-mail addresses. Further information can be obtained at the website of the Canadian Nuclear Association <www.can.ca> or from Lise Marshall, e-mail: marshall@can.ca, telephone 613-237-4262.

Nuclear Power: Obstacles and Solutions

by Ralph S. Hart

***Ed. Note:** In the following paper, which was presented at the CNS Annual Conference in June 2001, Ralph Hart provides an excellent overview of the several new designs of nuclear power plants being proposed around the world. Ralph, a former senior engineer at Atomic Energy of Canada Limited, now has his own company, R.S. Hart & Associates, in Carlisle, Ontario.*

Abstract

Nuclear power has a history extending over more than 50 years; it has been pursued both for military power applications (primarily aircraft carrier and submarine propulsion) and for commercial power applications. Nuclear power has benefited from many hundreds of billions of dollars in research, development, design, construction, and operations expenditures, and has received substantial attention and support world-wide, having being implemented by most developed countries, including all of the G-7 countries, and several developing countries (for example, India, China, and Republic of Korea). In spite of this long history, massive development effort, and unprecedented financial commitment, nuclear power has failed to achieve commercial success, having captured less than 5% of the world's primary energy supply market.

There are many factors contributing to the stagnation/decline of the commercial nuclear power business. These factors include: non competitive economics, lengthy construction schedules, large and demanding human resource requirements, safety concerns, proliferation concerns, waste management concerns, the high degree of government financial and political involvement necessary, and the incompatibility of the available nuclear power plant designs with most process heat applications due to their temperature limitations and/or large heat output.

An examination of the obstacles to deployment of nuclear power plants of current design suggest a set of requirements for new nuclear power plants, which may overcome or circumvent these obstacles. These requirements include: inherent characteristics that will achieve reactor shutdown under any postulated accident condition; the removal of decay heat by natural and passive means; no safety dependence on operator actions and tolerant to operator error, and malicious or incompetent operator action; and, economic viability in relatively small unit sizes.

Many innovative reactor technologies and concepts are under consideration around the world. Several of these innovative concepts are capable of satisfying many of the requirements identified. These include the High Temperature Gas Reactors (HTGRs), the Lead-cooled Integral Reactor (LEADIR), the Molten-Salt Reactor (MSR), the BREST fast reactor, and the accelerator driven Energy Amplifier. All of these designs have high temperature capability, (core outlet temperature in the range of 650° C to 900°C).

This paper reviews the current obstacles to nuclear power deployment, proposes a comprehensive set of requirements for future nuclear power plants that may serve to overcome the obstacles identified, and discusses five innovative reactor technologies/concepts that are capable of meeting most of the requirements identified.

1 Introduction

Nuclear power has a history extending over more than 50 years; it has benefited from many hundreds of billions of dollars in research, development, design, and construction expenditures; it has been pursued both for military applications (primarily aircraft carrier and submarine propulsion) and for commercial applications (primarily electricity production and to a limited degree, for icebreaker propulsion); and it has received substantial world-wide attention and support, having being implemented by most developed countries (including all of the G-7 countries) and several developing countries (for example, India, China, and Republic of Korea). In spite of this long history and massive effort and financial commitment, nuclear power has failed to achieve commercial success, having captured less than 5% of the world primary energy supply market; this fraction continues to drop as alternate electricity supplies (currently dominated by combined cycle natural gas facilities) are rapidly deployed, while nuclear construction continues to decrease and operating nuclear plants are retired.

There are several factors contributing to the stagnation of the commercial nuclear power business. These include: economics, lengthy construction schedules, large and demanding human resource requirements, safety concerns, proliferation concerns, waste management concerns, the high degree of government financial and political involvement necessary, and the incompatibility of the available nuclear power plant designs with most process heat applications due to their temperature limitations and/or large heat output.

However, the major alternative energy sources to nuclear power (primarily coal and natural gas) have substantial negative environmental impacts, principally through their release of CO_2 , and the resulting contribution to the "greenhouse effect". Hence, there is an opportunity, and in fact a need for environmentally benign nuclear power systems that overcome the current obstacles to nuclear power deployment. This paper reviews the current obstacles to nuclear power, proposes a set of requirements for future nuclear power plants, and discusses technologies that are capable of meeting these requirements.

2 Obstacles to Nuclear Power Deployment

2.1 Economics

The nuclear power plant designs currently available feature very high specific (cost per megawatt electrical) capital costs; these costs are typically 4 to 6 times greater than those of Combined Cycle Gas Turbine (CCGT) generating units. In addition, current nuclear power plants have high operations and maintenance costs relative to CCGT units, and incur high costs in obtaining and maintaining their operating licenses. These costs are not offset by the relatively low fuel cost of nuclear power plants within an economically competitive time frame. The nuclear power plants now available also have high absolute capital cost as a result of their complex designs and large outputs (in the range of 600 MWe to 1500 MWe).

2.2 Long Project and Construction Schedules

Typical project schedules for current nuclear power plants are in excess of 8 years; this includes the duration of the bid process, and the construction and commissioning period. The latter period generally exceeds 5 years. This compares to project and construction schedules that are typically in the order of 3 years and 2 years respectively for combined cycle gas turbine facilities.

Given the rapid globalization of world markets and the associated uncertainties, it is impossible for utilities and governments to accurately plan their energy requirements sufficiently far in advance to accommodate nuclear power project schedules. In addition, the long construction period required for nuclear power plants imposes a substantial financial burden on the host country and utility, since cash outflow is high, and no income is delivered during the construction and commissioning period. The long project schedule also results in substantial project financial risk; many things can change over the nuclear power project period, including governments, public opinion, the demand for energy, and the host country/utility financial circumstances.

2.3 Large and Demanding Human Resource Requirements

The human resource requirements for all phases of nuclear power deployment, ranging from design and construction to operation and licensing, are very large, and demand extremely high skill levels. Typical staff levels at nuclear power plants currently exceed one person per megawatt of electrical output; many of these people, including operators and maintainers, require specialized skills that take many years of training to acquire. And the human resource requirements are far reaching, encompassing the regulatory and contract service and support organizations. As a result, it is both time consuming and costly for all parties involved to acquire and maintain the staff necessary for the operation of a nuclear facility.

2.4 The Need for Government Guarantees and Commitments

The unique requirements of current nuclear power plants impose substantial obligations on the host government that are largely avoided by competitive energy sources; these include the provision of a dedicated regulatory body, subscription to IAEA safeguards, acceptance of the ultimate responsibility for waste disposal, and acceptance of the ultimate nuclear liability responsibility.

In addition, the relatively long cost recovery period of current nuclear power plants imposes a number of financial commitments on the host government; these may range from sovereign loan guarantees, to the long term guarantee of power contracts, currency exchange rates, and import/export regulations.

2.5 Safety Concerns

There is broad based concern in many publics world-wide regarding the safety of current nuclear power plants. Unfortunately, these fears do have some foundation; a modern Probabilistic Risk Assessment (PSA) for a nuclear plant clearly demonstrates the many ways in which an accident can unfold.

Nuclear power plants are the only non-military devices designed and built by mankind that can have almost instantaneous impacts on health and the environment world-wide in the case of a substantial accident (for example, Chernobyl). Even among natural disasters, only major volcanic eruptions and major meteor impacts have a global effect; others events such as earthquake and tornado have only local effects. Although the impact of the failure of other devices (for example chemical complexes, bridges, and aircraft) may be devastating (for example Bhopal), the effects are localized. Other man-made devices may ultimately have greater negative health and environmental impacts than nuclear power (for example coal plant emissions or car accidents), but these require thousands of the devices to be operated over many years, a situation that publics are relatively comfortable with.

Operator/human error has been a significant and in many cases dominate factor in most accidents that have occurred at nuclear facilities; human error can occur in any phase of nuclear power implementation (for example, design, manufacturing, construction, operation and maintenance).

Public concerns regarding the safety of commercial nuclear facilities, including both power plants and fuel fabrication and reprocessing plants is likely to increase in the future.

2.6 Proliferation and Terrorist Concerns

There are two distinct concerns regarding nuclear proliferation. The first is the possible production on nuclear weapons by rogue state(s), although there is historically a very weak connection between commercial nuclear power plants and the production of military explosives.

The second consideration is the threat posed by fissile material being obtained by terrorist organizations. It is technically easy to build a physically large nuclear explosive device with a high yield (for example, one that would fit within a commercial highway tractor drawn trailer or large truck) utilizing relatively low-grade materials (for example, waste products from a LWR fuel reprocessing plant); highway vehicles are now a favourite explosives delivery method used by terrorists. The IAEA safeguards program would assure that the diversion of fissile material is detected; however there is no international protocol in place covering the actions needed to locate and recover stolen fissile material.

2.7 Waste Management Concerns

There is world-wide public concern regarding the storage, transportation and long term disposal of radioactive wastes, particularly high level wastes. Public opposition appears to be greatest in the case of schemes that permanently bury waste, claiming that nothing can go wrong for thousands or even millions of years. Schemes involving storage in accessible facilities often garner less opposition.

2.8 Incompatibility With Process Heat Applications

The available nuclear power plant designs are not compatible with most process heat applications due to their temperature limitations and/or their large heat output (1, 2). A typical 1000 MWe nuclear power plant of current design produces about 3000 MWth; this is far in excess of amount of heat that which can be economically used by most process heat applications. In addition, the heat, even if taken directly from the reactor cooling system, is at a relatively low temperature (typically under 300° C); this temperature is far below that needed for many process heat applications. Since an increase in the average temperature at which energy is used accompanies industrialization, this disparity will increase as the developing countries increase their industrial activities.

3 Proposed Requirements For Nuclear Power Plants

In order to achieve broad based acceptance and to achieve a substantial share of the primary energy production market, future nuclear power plants must incorporate technologies and design features that overcome the current obstacles to nuclear power deployment.

It is therefore suggested that future nuclear power plants should:

a) Possess inherent characteristics that will achieve reactor shutdown under any postulated accident condition without the use of any active detection or shutdown mechanisms,

b) Provide for the removal of decay heat by natural and passive means, without the use of any active detection or operating mechanism,

c) Have no safety dependence on operator actions and be tolerant of operator error, and malicious or incompetent operator action,

d) Eliminate real and perceived beyond design basis events for which there are not transparent, inherent or passive solutions.

e) Be economically viable in relatively small unit sizes (for example, less than 300 MW th)

f) Provide low environmental impact; plant discharges of all types, including chemicals and radioactive isotopes must be minimal. A comprehensive releases and waste management scheme must be included,

g) Both nuclear power plants and the fuel cycles of nuclear power plants must minimize the need to transport and dispose of radioactive materials, and to incorporate features that satisfy public concerns.

h) Incorporate features that make the diversion of fissile material very difficult, and which facilitate a robust safeguards system.

i) Eliminate the need for fuel reprocessing, at least during the lifetime of the initial plants (new reprocessing technologies may be available in the future),

j) Facilitate relatively low operating, maintenance and security costs: the nuclear power plant must not be substantially more demanding in any aspect of normal operation than modern combined cycle gas facilities.

k) Accommodate a broad spectrum of user requirements, ranging from low temperatures applications (district heating for example) to high temperature applications (thermal-chemical water splitting for example),

l) Facilitate the use of modern assembly line production technologies, with a minimum of on-site construction: hence, the plant must be fully modularized, and designed for ease of transportation and assembly, and

m) Offer a fast and secure construction schedule, competitive with those of combined cycle gas plants; these are currently in the range of 18 to 30 months.

4 Technologies Appropriate to Future Nuclear Power Plants

Many innovative reactor technologies, many of which are capable of satisfying many of the requirements suggested in section 3, are under consideration around the world. The subsections below briefly review four designs that have been suggested; the High Temperature Gas Reactors (HTGR), the Lead-cooled Integral Reactor (LEADIR), the Molten-Salt Reactor (MSR), BREST, and the Energy Amplifier.

Three of these designs (HTGR, LEADIR, and MSR) utilize graphite moderator. Graphite offers excellent neutron economy, very high temperature capability, high heat capacity, and a strong negative reactivity temperature coefficient. The latter is important to achieving inherent reactor shutdown capability in these designs. The coolants used are helium, molten lead, and molten-salt.

Two of the designs (BREST and the Energy Amplifier) are fast reactors, which use fast neutrons rather than thermal neutrons to sustain a nuclear reaction. The Energy Amplifier is unique among nuclear reactor designs since it produces power utilizing an accelerator driven sub critical core.

4.1 The High Temperature Gas Reactor

The high temperature gas reactor has the most extensive experience base; demonstration HTGRs established excellent operating records in the US (Peach Bottom) and in Germany (AVR-15). Commercial HTGRs in the US (Fort St. Vrain) and in Germany (THTR 300), both in the 300 MWe size range, have been shut down.

Current HTGR designs utilize a steel reactor pressure vessel, rather than a post tensioned concrete pressure vessel as used by earlier designs. The pressure vessel diameter of a 450 MWth HTGR is in the range of 4 m (13 ft). Typical helium conditions at the core outlet are 6.2 MPa (900 psi) and 850°C (1560°F).

Both the German and US HTGR based designs utilize the TRISO fuel particles (Figure 4-1). TRISO particles, with an outside diameter of less than one mm, have an uranium or thorium oxide core with four coatings. The silicon carbide coating serves the containment function that is provided by the containment buildings of water-cooled reactors. The porous pyrolytic carbon layer accommodates fission gasses. The pressure retaining capability of the TRISO particle is maintained up to about 1600°C.

HTGR plants based on the German design utilize a "pebble bed" core; TRISO particles, embedded in a graphite matrix, are contained in billiard ball sized "pebbles" which occupy the reactor core volume within a graphite reflector structure; the helium coolant flows upward through the pebble bed. The pebble bed HTGR is refueled on-power; new and recirculated pebbles are added to the top of the core, while irradiated pebbles are removed from the bottom. HTGR plants based on the design developed by General Atomics in the US have a prismatic core, consisting of hexagonal graphite elements that contain the fuel and coolant flow passages. The TRISO fuel particles are contained in a graphite matrix within fuel compacts that occupy vertical wells in the fuel elements (Figure 4-2). The prismatic HTGR is batch refueled off-power.

Current HTGR designs (GH-MHR and PBMR) utilize a direct cycle (Figure 4-3), and achieve an thermodynamic efficiency of about 50% (3).

Inherent shutdown capability is provided in HTGR reactors, primarily by the strong negative reactivity temperature coefficient of the graphite moderator. Passive fuel cooling is provided following postulated accidents by the conduction and radiation of heat from the fuel to the pressure vessel surroundings. This requirement limits the size of HTGRs to about 600 MWth, and currently limits coolant core outlet temperature to about 1000°C.

The HTGR is currently receiving broad based support worldwide. Direct cycle HTGR development is proceeding at ESKOM in South Africa in association with BNFL (pebble bed), and at a consortium consisting of General Atomics, Framatome, Fuji Electric, and nuclear organizations in Russia (prismatic core). A HTGR research reactor entered service in Japan in 1998, and a similar unit went critical in China in 2000. MIT have recently received a grant to cover the initial stages of design and construction of a pebble-bed HTGR research reactor at Idaho Falls in the US. Technologies now available facilitate the design and construction of a commercial direct cycle HTGR.

4.2 Lead-cooled Integral Reactor

The LEAD-cooled Integral Reactor (LEADIR), illustrated in

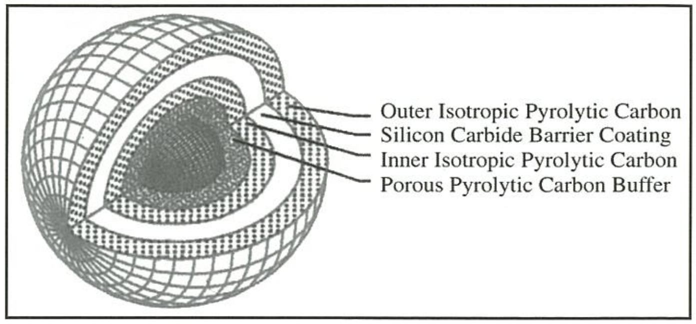

Figure 4-1 TRISO Fuel Particle

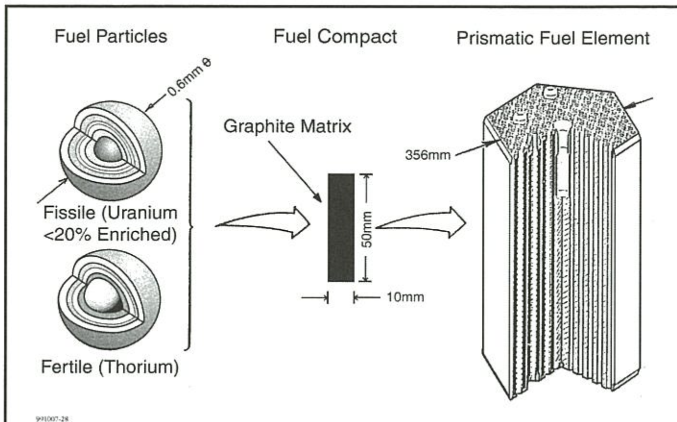

Figure 4-2 Prismatic Fuel Element

Figure 4-2 Prismatic Fuel Element

Figure 4-4, is a 208 Pb cooled, graphite moderated pool type reactor. The reference LEADIR core configuration (4) is similar to the prismatic HTGR core design, utilizing TRISO fuel. Lead, with a boiling point of about 1620°C (2950°F) at atmospheric pressure allows the reactor to operate at the maximum temperatures permitted by the fuel and by the coolant system materials. Graphite is buoyant in the lead coolant; the reactor internal structures maintain the graphite core in the design location. A CO2 cover gas is provided above the molten lead free surface.

^{208}Pb, which constitutes about 54% of naturally occurring lead, is transparent to neutrons; use of ^{208}Pb coolant thereby provides a neutron economy comparable to that of the HTR. The bulk of world experience with lead coolants exists in Russia.

Heat is transferred from the lead coolant to a secondary heat utilization circuit; suitable secondary coolants include helium, CO_2, and supercritical steam. Helium as the secondary coolant allows LEADIR to utilize the same power generation equipment as the direct cycle HTGR. Supercritical steam offers advantages in some process heat applications. As with the HTGR, inherent reactor shutdown of LEADIR is provided by the strong negative reactivity temperature coefficient of the graphite moderator; post accident decay heat removal is provided by conduction and radiation to the reactor pool surroundings. In LEADIR, the primary reactor pool vessel is surrounded by a concentric shield pool vessel, with the annulus filled with steel shield balls and ordinary lead. The outer

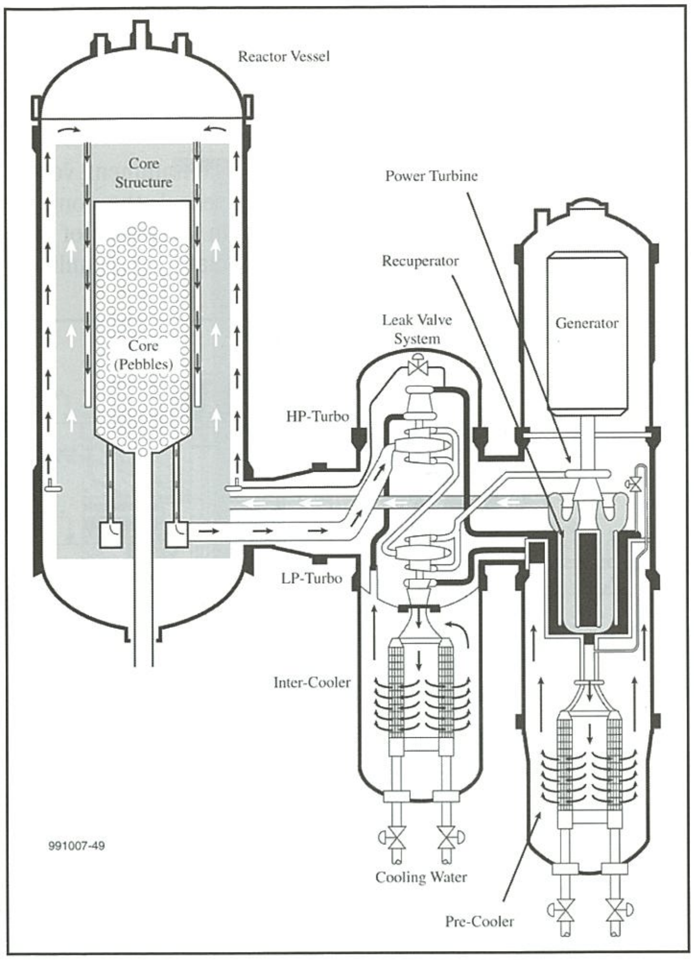

Figure 4-3 Direct cycle HTGR Cross Section

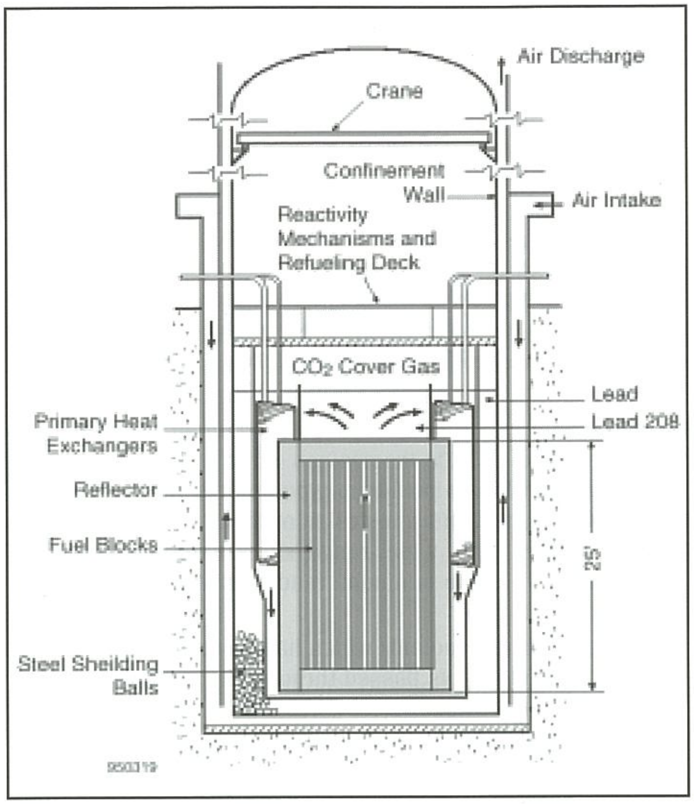

Figure 4-3 Direct cycle HTGR Cross Section

portion of the annulus remains solid during normal plant operation, thereby minimizing heat loss; under postulated accident conditions, this lead melts, promoting natural circulation and heat rejection. The requirement to passively reject decay heat limits the size of LEADIR to about 1000 MW_{th}.

4.3 Molten Salt Reactor

Development of the molten-salt reactor was centered at Oak Ridge National Laboratories (ORNL) in the US (5, 6, 7, 8). The graphite moderated, molten-salt cooled MSR technology facilitates the design of a high temperature pool type reactor.

MSR fuel, as uranium or thorium fluoride, is dissolved in the molten salt coolant. The configuration of the MSR is potentially similar to that of LEADIR, except that the fuel strings are eliminated from the graphite moderator blocks. A helium cover gas is maintained above the free surface of the molten-salt coolant.

The MSR is refueled on-power through the addition of a small amount of uranium fluoride to the coolant stream. Studies indicate that a MSR could operate for a period of thirty or more years without the removal of fission products from the molten-salt coolant.

Heat is transferred from the molten-salt coolant to a secondary heat utilization circuit via heat exchangers.

Inherent shutdown capability is provided in MSR by the negative reactivity temperature coefficient of the graphite, in combination with the thermal expansion of the molten-salt in the core; the latter reduces the fissile content of the core as coolant temperature increases. In the very unlikely event that coolant is lost from the core, it quickly solidifies, and the reactor shuts down due to loss of reactivity. Cooling of the MSR reactor following postulated accidents is provided by conduction and radiation of heat from the reactor pool to the surroundings; this requirement limits MSR size to about 1000 MW_{th}.

ORNL operated a demonstration MSR for 32 months in the 1960s, with very few technical difficulties (9). This reactor, called the Molten-Salt Reactor Experiment (MSRE) produced 8 MWth, and operated with a core coolant outlet temperature of 650°C (1200°F). The fuel salt used in MSRE was $^7Li\text{-}BEF_2\text{-}ZrF_4\text{-}UF_4$ (65-29.1-5.0-0.9 mole %). The principal properties of this salt at 650°C (1200°F) are given in Table 4-1. A comprehensive review of molten salt chemistry is provided in (11).

The MSR can operate as a breeder, utilizing the thorium cycle (10). The ^{233}U produced (by neutron capture in ^{232}Th) is easily removed by bubbling fluorine through the coolant; fluorine scavenges uranium, but does not remove actinides such as plutonium. The MSRE was the world's first reactor to be fueled with ^{233}U.

Operation of MSRE demonstrated practical salt handling in a reactor, and that the salt chemistry is predictable and stable. The nuclear characteristics of MSRE were close to those predicted, and demonstrated by operation to be stable. No significant corrosion was experienced by the MSRE graphite or structural components.

Testing, largely at ORNL, has shown that minimal corrosion

Table 4-1: Principle Fuel Salt Properties

Density	2.3 g/cm3	141 lb/ft3
Specific Heat	2 x 103 J/kg-°C	0.47 BTU/lb-°F
conductivity	1.3 W/m-°C	0.83 BTU/h-ft2-°F
Viscosity	29 kg/h-m	19 lb/h-ft
Melting Point	434°C	813°F

occurs between the molten salt coolant and graphite at 700°C. Temperatures up to 1000°C may be viable based on analysis; testing is required. The Hastelloy-N material used for construction of the MSRE reactor structures has been shown to be suitable for temperatures up to 850°C.

4.4 BREST

The BREST 300 is a pool/loop type breeder reactor that utilizes lead coolant. The basic design of the reactor (Figure 4-5) is appropriate to a wide range of reactor outputs. 700 MWth/300 MWe is the minimum reactor size that can sustain a breeding ratio of 1.

The lead primary coolant, which has a core outlet temperature of about 540° C, is passed through the secondary side of the primary heat exchangers. There, heat is transferred to light water passing within the primary heat exchanger tubes to produce supercritical steam, which subsequently drives the turbine-generator. The use of lead as the reactor coolant avoids the requirement for an intermediate circuit operating between the reactor coolant system and the steam generators that is required by sodium-cooled reactors.

The lead primary coolant is circulated by pumps and gravity; the pumps deliver the lead coolant to a chamber at the top of the pool, which has a free surface level about 2 meters above the main pool level. The head thus established serves to promote circulation of the lead coolant

An advantage realised is the slow rate of reduction in primary coolant flow on loss of power to the circulating pumps, which assures excellent fuel cooling during the transition from force-assisted flow to natural convection.

BREST 300 uses a mononitride mixed fuel (UN +PuN) that is compatible with both the lead coolant and the fuel sheath material. The BREST 300 will require refuelling every 5 years when operated at an 82% capacity factor.

4.5 Energy Amplifier Technical Summary

The Energy Amplifier (9, 10) extracts energy from a subcritical core with the assistance of an accelerator. The beam of high energy protons from the accelerator is directed at a spallation target made of lead. The spallation neutrons produced are only slightly moderated by the lead, and are multiplied under sub-critical conditions by the breeding process taking place in the mixed $ThUO_2$ oxide fuel. The concentration of ^{233}U, which is bred from the ^{230}Th, is stable at about 12% (breeding equilibrium).

The reactor is a fast reactor utilizing lead coolant in a pool configuration; a reactor, utilizing fast neutrons rather than thermal neutrons, achieves a high power density and very high burning efficiency for the higher actinides. Circulation of the lead coolant at all power levels is achieved by natural circulation (Figure 4.6).

The output of the reference Energy Amplifier is 1500 MWth. The heat of fission is transferred from the lead to a secondary side circuit via four primary heat exchangers located near the top and the walls of the reactor vessel. The core outlet temperature is in the range of 700°C.

The reactor vessel is housed within a containment vessel that is in close proximity to the reactor vessel; the containment vessel is located in a below grade silo fabricated of concrete which serves to contain the lead coolant in the unlikely

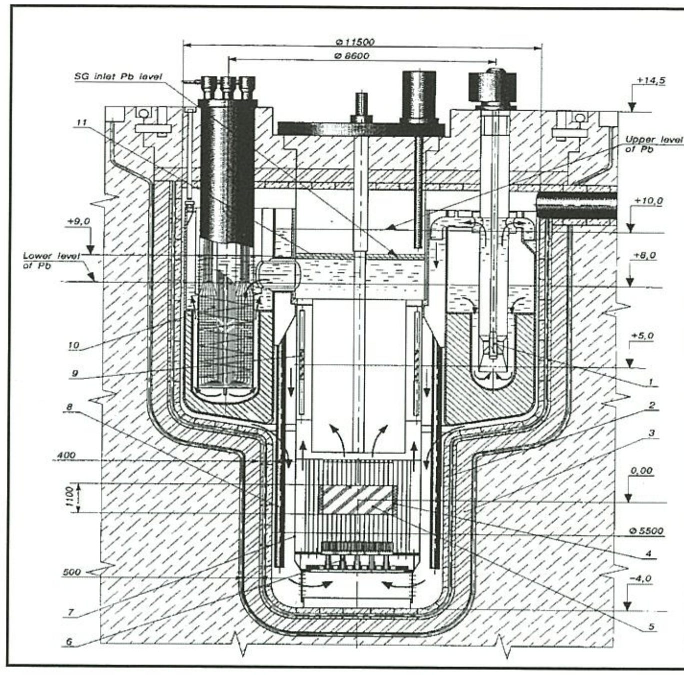

Figure 4-5 BREST Reactor Section

event of a rupture of the reactor and containment vessels. A shield building over the reactor area provides protection from external events.

The passive reactor vessel air cooling system is located in the annular space between the containment vessel and the silo. Heat loss during normal operation is low.

Mixed oxide fuel is used with a very large concentration of ThO_2 . The increase in the fissile content of the fuel during reactor operation compensates for the increased neutron absorption by fission products. Hence neither refueling or fuel shuffling are anticipated during the 5 year fuel cycle.

The accelerator consumes about 25 MWe, and delivers a 10 MW beam when the reactor is operating at full power. The power produced by the reactor is directly proportional to the intensity of the beam supplied by the accelerator. The reactor power, and reactor shutdown, is controlled by regulating the beam intensity.

The Energy Amplifier incorporates a number of important inherent and engineered safety features that substantially reduce the risk of an accident that could lead to radioactive releases from the facility. These include:

- The reactor power is limited to the rated full power condition by the power provided to the core by the accelerator beam; hence there is no potential for power excursions

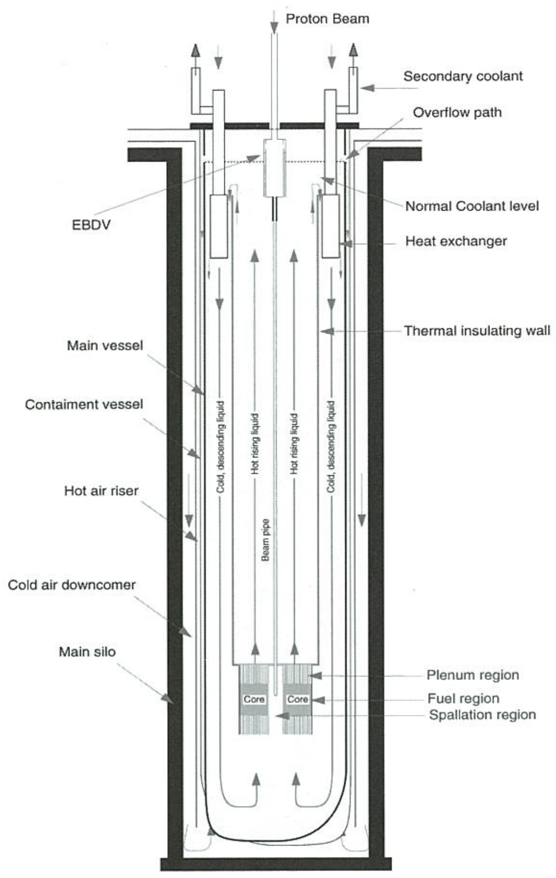

Figure 4-6 Energy Amplifier Section

that significantly exceed the 100% power rating of the reactor,

- The high boiling point of the lead coolant, particularly at the elevation of the core, minimizes the potential for voiding the reactor core, in total or in part; in case of core voiding, the core design features a negative void reactivity coefficient,
- An inherent emergency shutdown capability is incorporated in the design; thermal expansion of the lead coolant within the reactor vessel causes the level of the lead to rise when normal operating temperatures are exceeded, and to overflow into a chamber such that the lead blocks the accelerator beam, thereby causing reactor shutdown.
- A second emergency shutdown system is provided in addition to the above; when allowable operating temperatures are exceeded, the lead, as a result of the increased level in the reactor vessel, enters tubes, forcing B4 C absorbers into the core.
- The normal reactor shutdown system, which consists of removing the power supply to the accelerator, based on appropriate signals is simple and robust.
- A passive decay heat removal system that is passively initiated when the lead coolant exceeds the allowable operating range.

5 Summary

Nuclear power, some 50 years after introduction, has yet to achieve broad based commercial success due to a host of factors, ranging from economics to perceived safety. Innovative reactor technologies currently being investigated have the potential of overcoming many of these factors. In the near term, the Direct Cycle High Temperature Gas Reactor is in a position to significantly alter the nuclear scene by providing relatively low cost energy from small units that incorporate a high degree of inherent safety. In the longer term other technologies (for example lead and molten salt cooled reactors or sub-critical reactors) may be established.

The nuclear industry must respond to the various obstacles that currently prevent the deployment of nuclear power plants, and develop innovative approaches and technologies that can overcome these obstacles. It is not sufficient to sit back and wait for the world to change.

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CNS 7th International CANDU Fuel Conference

Delegates from several countries, including Argentina, Egypt, France, Korea, India, Pakistan and Romania, joined with those from Canada for the 7th International Conference on CANDU Fuel in Kingston last September, 2001. Overseas participants made up close to a third of the total registration.

A welcoming reception, held in the 19th century Kingston City Hall on the Sunday evening, preceded the three days of specialized papers on all aspects of the design, manufacture and performance of CANDU fuel.

The actual conference began with a plenary session on "International Experience and Programs" with overview papers from Canada, India, Korea, and Pakistan. (Two of those papers, from Canada and Korea, are reprinted in this issue of the CNS Bulletin.)

The remaining 2 1/2 days were structured with three parallel sessions in which over 50 papers were presented. Titles of the sessions indicate the range of topics: "CANFLEX Fuel Design and Development"; "Fuel Management"; "Manufacturing and Quality Assurance"; "Fuel Performance Assessment"; "Fuel Safety"; Fuel Designs and Development"; "Advanced Fuel Cycles"; "Fuel Handling; "Fuel Perfomance and Modelling"; Fission Gas Release Modelling".

At the luncheon the first day, guest speaker Rafael Moya, of Ontario Power Generation, gave an overview of the creation and subsequent evolution of his organization with a focus on the nuclear fuel and fuel channel programs. After noting that OPG had been created in early 1999 with the break-up of Ontario Hydro. OPG currently has 24,700 MW of generating capacity, composed of 7,300 MW hydroelectric; 9,700 MW thermal (fossil); and 7,650 MW nuclear (including the 2,000 MW of Pickering A temporarily laid-up). However, the provincial government has decreed that OPG must decontrol 4,000 MW by four years after "open access" and be no more than 35% of Ontario's generation in ten years.

On the fuel side Moya noted that fuel and fuel channel programs had been integrated. Elements of the combined program include: life cycle management; processes for inspection and assessment; auditing; annual review. After two years significant progress has been made and there has been a high level of staff engagement. Continuous improvement will be pursued, he noted in closing.

There were no speakers at the other two luncheons to provide maximum time for the technical sessions. However, delegates had a pleasant break from their deliberations the second evening with a boat cruise through part of the Thousand Islands of the St. Lawrence River which took them to the Royal Military College just outside Kingston for an excellent banquet served in meticulous military manner. There was a dinner speaker, Dave Wren, of Atomic Energy of Canada Limited, who described AECL's "next generation" design of CANDU. (See the paper by Hopwood et al in Vol. 22, No. 3 issue of the CNS Bulletin for a similar description.)

The Conference was organized by a committee chaired by Brent Lewis of RMC with co-chair members: Fernando Iglesias, Erl Kohn, and Mukesh Tayal, and Hugues Bonin, Paul Chan, Leslie Bennett, Bill Andrews, Trish Lewis, Denise Rouben, Bernie Surette.

A number of organizations provided financial or other support: Atomic Energy of Canada Limited; general electric Canada; Hydro Quebec; International Atomic Energy Agency; Ontario Power Generation; Royal Military College; Zircatec Precision Industries.

At the close there was general agreement that this series of meetings every two years should continue and many suggestions were made for the 2003 conference.

Delegates of the 7th International CANDU Fuel Conference, held in Kingston, September 2001, gather on the deck of boat before embarking on trip through the Thousand Islands en route to the banquet at the Royal Military College.

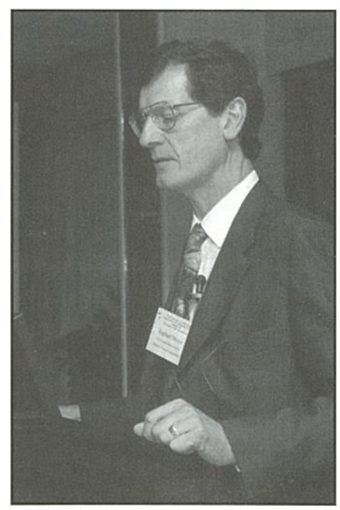
Dr. C. Ganguley from India.

"Official" photograph of delegates.

Mike Notely (right) receives a gift from Brent Lewis, chair of the 7th International CANDU Fuel Conference, in recognition of his pioneering work and achievements in the research and development of CANDU fuel, at the conference in Kingston, Ontario, September 2001.

Huges Bonin asks a question while Conference chairman Brent Lewis looks on.

Ben Rouben, David Brissette and Brent Lewis check a computer presentation.



Luncheon speaker Rafael Moya

Photographs courtesy of Bernie Surette

Canadian CANDU Fuel Development Programs and Recent Fuel Operating Experience

D.S. Cox[1], J.H.K. Lau[2], W.W.R. Inch[1], R.G. Steed[3], E. Kohn[4], N.N. Macici[5], R. Chun[6]

***Ed. Note:** The following paper was the "national" Canadian presentation at the 7th International Conference on CANDU Fuel held in Kingston, Ontario in September 2001.*

Abstract

This paper summarizes the performance and operating experience of CANDU(fuel in Canadian CANDU reactors in 1999 and 2000. The extremely low rate of fuel defects continues to demonstrate that CANDU fuel is performing exceptionally well. Over the 2-year period, the fuel bundle defect rate for all bundles irradiated in Canadian CANDU reactors has remained very low, between 0.011% (suspected defects) and 0.007% (confirmed defects). On a fuel element basis, this represents a rate of confirmed defects of about 0.0002%; this rate is approaching 2 defects per million fuel elements! This successful performance is the result of a number of contributing factors, including a simple and robust fuel design with conservative design margins, reliable and specialized manufacturing processes that have been developed over the years, and fuel operations that conform to the fuel operating limits.

Strong linkages between plant operation, designers, and Canadian fuel research and development programs also contribute to the high performance of the current CANDU fuel. The Fuel Design and Performance program, funded by the CANDU Owners Group, addresses licensing and operational issues that are common to the Canadian CANDU utilities. In addition, AECL's Fuel and Fuel Cycles working group directs R&D to support evolutionary improvements to the fuel products, as well as longer-term R&D for advanced fuel concepts. This paper describes the development programs in 1999/2000.

1.0 Introduction

The impending deregulation of the electricity market in the province of Ontario has created new opportunities, as well as changes in the ownership of nuclear assets in the province. The breakup of Ontario Hydro resulted in the formation of Ontario Power Generation, Inc. (OPG) as the electrical generation utility. In 2001 May, Bruce Power, Inc. finalized a long-term lease arrangement with OPG for the Bruce A and B generating stations. Bruce Power is now the licensed operator of the Bruce A and B stations, and has announced the launch of a program to restart two of the four laid-up Bruce A reactors. Similarly, OPG is in the process of restarting the four laid-up Pickering A reactors, with plans to bring them back into service beginning in 2002.

Bruce Power has joined the other Canadian nuclear utilities (Hydro-QuÈbec, New Brunswick Power, OPG) and AECL as a member of the CANDU(r) Owners Group (COG). The COG organization itself has undergone a re-organization, in response to the competitive and changing environment that the utilities face.

At the beginning of the year 2000, the former Atomic Energy Control Board became the Canadian Nuclear Safety Commission (CNSC), and the Nuclear Safety Control Act came into effect, replacing the former Canadian legislation that governed the safety and operation of nuclear installations.

And earlier this year, AECL underwent reorganization in response to changing market conditions. Two operating units were created, Nuclear Products & Services, and Technology. The main change with respect to fuel activities has been the transfer of several fuel project activities from the former R&D part of the organization to a new Development Projects group, with a mandate to complete development activities and transfer commercially ready technology to the Nuclear Products and Services unit.

Within this changing business and regulatory environment over the last two years, there have been many achievements in the Canadian nuclear fuel community. Two highlights are noteworthy in this introduction. First, OPG achieved closure of the CNSC generic action item (GAI) on fuel condition (GAI-94G02), setting a path forward for the other utilities. This closure has been achieved through the demonstration of an integrated design, inspection and surveillance feedback process for fuel compliance monitoring.

Secondly, a demonstration irradiation of AECL's CANFLEX(fuel design was successfully completed at the Point Lepreau generating station (PLGS). Twenty-four CANFLEX bundles fuelled with natural uranium (NU) were irradiated over a two-year period, beginning in 1998 September. The subsequent in-bay and hot-cell examinations of the fuel have been completed, and confirm that the CANFLEX bundle meets all of the necessary design requirements.

1 Atomic Energy of Canada Ltd., Chalk River Laboratories
2 Atomic Energy of Canada Ltd., Sheridan Park, Mississauga
3 New Brunswick Power, Point Lepreau,
4 Ontario Power Generation, Toronto, Ontario
5 Hydro- Quèbec, Gentilly, Quèbec
6 Power Inc., Tiverton, Ontario

As an update of the previous national paper on CANDU fuel development [1], this paper will first summarize the 1999/2000 fuel performance data for the Canadian CANDU stations. The Canadian fuel development programs in 1999/2000 are then described, first for COG Safety and Licensing R&D, and then for AECL's Fuel and Fuel Cycles working group.

2.0 Fuel Performance in Canadian CANDU Stations

One of the typical measures of fuel performance is the fuel bundle defect rate, which is expressed as the percentage of the bundles in which sheath failure has occurred during irradiation. The means of fuel defect detection, and the convention used to report the number of fuel defects differs among the Canadian CANDU stations. Some stations report the number of suspected fuel defects, and report confirmed defects only after the defects are corroborated by inspection results at the fuel bay. Therefore, depending on the monitoring system that is available at the stations and the reporting convention, the number of suspected fuel defects may be an overestimate, whereas the number of confirmed fuel defects might be an underestimate of the actual number of fuel failures.

Table 1 summarizes the performance data collected for the 1999 and 2000 calendar years. A total of about 116,000 bundles were discharged over the two-year period. Of these, a total of 13 suspected defects were assigned, while 8 were confirmed through inspections. As a percentage of discharged bundles, the suspected and confirmed defect rates are 0.011% and 0.007%, respectively. Because most failed bundles involve only one fuel element, the element defect rate over the 2-year period for all discharged bundles in Canada is on the order of 0.0002% to 0.0004%; this is equivalent to between two and four defects per million fuel elements. The cause of the confirmed defects was split equally between manufacturing flaws and debris fretting. This rate is consistent with the long-term trend of defect rates in the absence of a defect excursion, and is considered to be excellent. This óperating record demonstrates remarkably good performance for current CANDU fuel-both 28-element and 37-element designs.

The trend in average discharge burnup at the various stations is consistent with the long-term averages. A more detailed picture of operation at the Gentilly-2 station is available in these proceedings [2].

Over the review period, fuel performance has not been a concern and has not caused any loss of power generation in any of the Canadian CANDU stations. More than 1.5 million CANDU fuel bundles had been discharged in Canada by the end of 2000.

3.0 COG Fuel Design and Performance Program

The Safety and Licensing program of COG performs R&D to improve the industry's understanding of the design basis for the safe operation of the current generation of CANDU reactors. Specifically, within the Fuel Design and Performance program (formerly the COG Fuel Technology program), R&D is performed to maintain or improve current operating margins. COG-funded R&D is also performed to support the resolution of GAIs raised by the CNSC staff. The focus of these COG programs is to maintain and improve the reliability, economics and safety of the 28- and 37-element NU CANDU fuel bundles in operating stations.

3.1 Fuel Specifications Review

A review of technical specifications for CANDU fuel and documentation of the rationale for the specification limits was completed in 2000. The review identified requirements for updating the specifications, in order to capture new information from R&D, manufacturing, and operating experience. Documenting the rationale for each aspect of the specifications has provided users with an improved understanding, and additional quality assurance in the fuel procurement process. The documentation of the rationale is also necessary for the training of newcomers to the nuclear fuel industry. Under the project, all the technical specifications for fuel materials and components were reviewed, and assessments were documented.

3.2 Post-Irradiation Examination of Fuel

The post-irradiation examination (PIE) of fuel that is of common interest to the Canadian CANDU stations continues to be an important component of the COG fuel program.

The irradiation and PIE of four "special" bundles have been of generic interest. These bundles were specially fabricated (i) with high and low UO2 densities, (ii) with large and small diametral clearances, and (iii) with and without a CANLUB coating. These "special" bundles were all irradiated at PLGS. Bundles with high and low densities and with large and small clearances were examined in the hot cells at CRL, and the results were documented previously [3]. In 2000, irradiated bundles with and without a CANLUB coating were examined to investigate any effect of the CANLUB coating on the fuel chemistry and fuel temperature. The proceedings of this conference provide the details of those results [4].

An investigation into the effect of pressure tube diametral creep on fuel performance was also completed. Two bundles from the Hydro-Quebec Gentilly-2 reactor were destructively examined after discharge from a channel with high diametral creep (about 2.5%). It was found that all performance para-

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meters for the fuel were within the expected ranges, and it was concluded that the pressure tube diametral creep had no measurable impact on fuel performance.

Other ongoing and future generic PIE work includes the examination of

- two long residence bundles (burnup of 400-500 MWh/kgU) to investigate and analyze fuel performance parameters, such as sheath strain, spacer-pad wear, element bowing, endplate integrity and fission-gas release[1]; and
- seven elements from each of two defective fuel bundles that resided near the liquid zone controllers (LZCs), in order to determine whether local power variations caused by LZCs have any impact on fuel performance.

Considerable debate has taken place in the past with regard to the impact of power variations, caused by LZCs, on fuel performance. The above examination is expected to address this issue.

Other work completed in 2000 included a compilation of defective power reactor fuel examination results, with the classification of the root causes and failure mechanisms. This information will be beneficial to the utilities in addressing GAI-related issues and in obtaining closure of the GAI.

3.3 Irradiated Fuel Database

An electronic database of fuel behaviour parameters, including fission-gas release, sheath strain, power-burnup history, etc., has been compiled using the PIE results of CANDU fuel elements irradiated in power reactors and research reactors over the last 30 years. This database is being used extensively for the validation of the fuel behaviour code ELESTRES-IST. The database has recently been updated with additional PIE data from 23 power reactor bundles. The database consists of about 360 cases, about 125 from power reactors, and the remainder from irradiations in test reactors.

3.4 Burnup Uncertainty Assessment

A thorough assessment of the uncertainty in chemically measured fuel burnups was conducted. The uncertainties from the various sources (sampling, chemistry measurements, physics calculations) were combined to determine the overall uncertainty in the chemically measured burnup. Using current methodologies, the overall 1 (uncertainty in burnup for natural UO2 commercial CANDU power reactor fuel is determined to be ±3.4%. The burnup measurement can be biased by -1.4% to 0.5%, depending on the physics code and data library that is used.

3.5 O/U Measurements of Irradiated CANDU Fuel

A procedure has been successfully developed to use coulometric titration to measure the O/U ratios of small samples of irradiated CANDU fuel. Considerable effort has been expended to ensure the reliability of the measurements, which had proven over several years to be challenging to perform. The measurement involves heating fuel samples to 1000°C in reducing atmospheres and recording the amount of oxygen that is released by the sample as a function of time. The reproducibility of the method is excellent.

The technique has been applied to small samples taken from a CANDU fuel element that defected during in-reactor service. In one fuel element, preliminary coulometric titration measurements of samples taken 6 cm from a debris-fretting defect showed that the samples had been oxidized to UO2.044±0.002 at that location. It is planned to make further measurements to quantify the uncertainties associated with this technique, and any possible bias in the results. The proceedings of this conference provide the details of these and other results [5].

3.6 Pore Former Fuel Performance

A project was undertaken with the goal of identifying an amount and type of pore former agent that can be used in CANDU fuel pellets to enhance their dimensional stability in relation to burnup, and to also result in lower gas release. These improvements would reduce sheath strain and fuel element internal gas pressure.

Pore formers are added to fuel pellets to introduce irradiation-stable porosity. The role of this porosity is to accommodate fuel swelling caused by solid and gaseous fission products. The size distribution of the porosity that is introduced must be carefully chosen. The porosity must be large enough to be stable under irradiation (i.e., not eliminated by irradiation-enhanced sintering), and the number of pores and their distribution in the fuel matrix must be such that they can react to local swelling (i.e., several very large pores would be irradiation-stable, but would not accommodate swelling). In addition, the pores in the cooler periphery of the fuel may act as fission gas traps.

The multi-year project was completed in 2000. Experimental pore former fuels were fabricated and irradiated in the test loops of the NRU reactor at CRL. Irradiation variables included the amount and type of pore former, linear power rating and burnup. Six fuel elements with a burnup of about 240 MWh/kgU were examined; the analysis and documentation of that PIE was completed in 1999/2000. The final results of the project concluded that there are potential benefits arising from the use of pore formers, but for the irradiation conditions achieved in this test, the pore size/distribution had little effect on sheath strain and fission-gas release.

3.7 ELESTRES-IST Code Validation

The ELESTRES-IST code is supported by the COG partners as the industry standard toolset (IST) for modelling

1 One of the bundles experienced a significant number of power maneuvers (load following), in addition to being irradiated to a high burnup.

fuel element behaviour under normal operating conditions. Based on the finite element technique, the code combines the features of the ELESIM and the ELESTRES codes. The code contains 11 additional functional features, in comparison with the previous reference version [6]. The code has been extensively verified and is now under validation to qualify it in accordance with the requirements of the Canadian nuclear industry's Quality Assurance program. The interim results of the validation show good agreement with experimental data [7].

4.0 AECL'S Fuel and Fuel Cycle Working Group R&D Program

The focus of these programs is to implement improvements to fuel designs that increase operating margins, and to develop advanced fuel bundles and fuel cycles that will reduce capital and fuelling costs, improve NU utilization, and provide synergy with other reactor systems to improve resource and spent fuel management [8]. The Fuel and Fuel Cycles working group directs these programs within AECL.

The AECL Fuel R&D program is divided into three main activities:

- The development of new fuel bundle designs that can be used for the NU fuel cycle, as well as for other alternate fuel cycles (e.g., the CANFLEX bundle design);
- The investigation of alternate fuels and fuel cycles, such as DUPIC (Direct Use of Spent PWR Fuel In CANDU) fuel, plutonium mixed-oxide (MOX) fuel, thorium fuel, inert matrix fuels, and other alternate fuel cycles; and
- R&D in fuel-supporting technologies to develop features to be deployed in the advanced fuel bundle designs, or to support the maintenance and improvement of fuel design technologies, such as optimized fuel element design for high burnup operation, enhancements in critical heat flux (CHF) performance, and other features.

The following sections provide an update on progress for each of the three main R&D activities.

4.1 CANFLEX Fuel Implementation Program

An overview of the CANFLEX fuel implementation program is given in these proceedings [9]. The CANFLEX design is a 43-element fuel bundle assembly that offers improved operating and safety margins, compared to the standard 37-element fuel bundle, for operating CANDU reactors. The CANFLEX bundle design includes CHF enhancement devices that lead to higher critical channel power (CCP) in a full-length fuel channel, compared to 37-element fuel bundles. The lower heat rating of the CANFLEX fuel elements at current bundle powers leads to lower fuel temperatures. As a result, less free fission-gas inventory is produced under normal operating conditions, compared with the free fission-gas inventory produced in standard 37-element fuel elements at a similar bundle power. Since the early 1990's, AECL and the Korean Atomic Energy Research Institute (KAERI) have pursued a collaborative program to develop, verify and prove a new fuel design that would introduce advanced fuel cycles, such as slightly enriched uranium (SEU), recycled uranium (RU) and others into CANDU reactors, and would provide enhanced performance with NU fuel, through higher operating margins in existing CANDU reactors.

An important milestone for the CANFLEX program was reached in 2000 February, with the successful completion of a two-year demonstration irradiation (DI) of 24 CANFLEX bundles at PLGS [10]. This DI provides a final verification of the CANFLEX design, and is a prerequisite to full-core conversion. The overall verification program for the CANFLEX Mk IV design has included out-reactor flow testing (strength test, impact, cross flow, fuelling machine compatibility, and flow endurance), in-reactor testing, reactor physics tests and analyses, structural analyses, and an industry-wide formal design review.

All activities identified in the Design Verification plan have been fully completed, all issues from the design review panel have been resolved, and all observations from the DI bundle inspections have been formally dispositioned. The CANFLEX Fuel Design manual has been revised to include the final results from analyses, testing and inspections that were completed through the design verification program. AECL's Office of the Chief Engineer has concluded that the CANFLEX Mk-IV fuel bundle design is qualified for implementation in a CANDU 6 reactor. Discussions are underway with utilities in Canada and Korea to quantify the benefits from implementing this new fuel design.

With the CANFLEX-NU design work completed, AECL's development effort is now focusing on CANFLEX-SEU fuel. One of the advantages of enrichments of up to 1.2% in a CANDU reactor is that it allows the flattening of the core flux distribution, which leads to a higher core power for the same-size core. Power flattening is a major benefit, because it can reduce the unit capital cost of new reactors and raise the power output of existing reactors. Using enriched fuel also provides the advantage of reducing the volume of spent fuel, and hence reducing the back-end costs that are associated with spent fuel storage and disposal. It should be noted that RU is a variation of the SEU cycle. RU, which has an enrichment of about 0.9%, is a by-product of reprocessing, and is expected to be a low-cost alternative to conventional SEU. The CANFLEX-SEU/RU work is a joint program by AECL, British Nuclear Fuels Limited (BNFL) and KAERI [11].

Currently, the AECL program for CANFLEX-SEU/RU fuel is focused on developing and implementing design verifications that are necessary to qualify the CANFLEX-SEU/RU fuel bundle [12]. The design verification includes all the tests and analyses that would support the demonstration irradiation of CANFLEX-SEU/RU bundles in a power reactor. Reactor physics simulations have been performed to establish a reference CANFLEX-SEU/RU core design. In the areas of safety analysis, a review of the implications of the use of CANFLEX-SEU/RU fuel in the consequences of all design basis accidents has been performed. The effect of higher bearing pads on dryout power has also been quantified, as a generic CANFLEX feature [13]. Preparations for critical lattice physics measurements in support of CANFLEX-RU fuel are underway, and power ramp tests at extended burnup are also underway in the NRU reactor.

4.2 Alternate Fuel Cycles

The CANDU reactor has the unique flexibility of allowing the use of a number of fuel cycles, because of its inherent high neutron economy. The driver for advanced fuel cycles has traditionally been ever greater improvements in uranium utilization, e.g., the use of 1.2% SEU can yield a 30% improvement in fuel cycle costs and uranium utilization, while reducing spent fuel volumes by a factor of three. However, other potential benefits are also important in pursuing alternate fuel cycles:

- reduced plant capital costs (e.g., the use of SEU to flatten the power distribution in the core and thereby increase the rated output for the same core size);
- simplified plant design; and
- increased operating and safety margins (e.g., lower peak element ratings and higher critical channel power; reduced or negative void reactivity, as required in some markets).

Some of these features are now being designed into AECL's Next Generation (NG) reactor concept. Other reasons for the exploitation of alternate fuel cycles include

- the exploiting of pressurized light water reactor (PWR)-CANDU synergism (DUPIC and civilian MOX fuel cycles that utilize spent or reprocessed PWR fuel);
- the destruction of military plutonium from excess weapons stockpiles (e.g., as MOX fuel);
- the destruction of Pu and actinide wastes (e.g., in an inert-matrix fuel design); and
- the maximization of energy derived from indigenous fuel materials (e.g., thorium fuels in countries without uranium reserves).

AECL has maintained a number of advanced fuel cycles programs, aimed at establishing the technical feasibility of the various advanced fuel cycles. The ongoing research and development programs described in the following section include DUPIC, low void reactivity fuel (LVRF), MOX fuel, and thoria fuel.

4.2.1 DUPIC Fuel

DUPIC (Direct Use of Spent PWR Fuel In CANDU) is a joint project between AECL, KAERI and the United States Department of State to develop the technology to fabricate CANDU fuel from spent PWR fuel, using only dry processes. The DUPIC fuel cycle involves converting PWR spent fuel into CANDU fuel using a dry process called OREOX. By subjecting the PWR spent fuel to repeated oxidation and reduction processes (OREOX), selected fission products that are highly neutron-parasitic can be removed. The resulting powder, when fabricated into CANDU fuel, can be used directly in a CANDU reactor. The OREOX process, which does not separate Pu from the fuel matrix, is highly proliferation-resistant, and provides a safeguard that is not available in conventional reprocessing. The recent project work at AECL has included the fabrication of DUPIC fuel elements at AECL's Whiteshell Laboratories [14]. A total of about four kg of spent PWR fuel was processed into three DUPIC fuel elements, which were then transported to CRL and irradiated in the NRU reactor. One of the three DUPIC elements was discharged after reaching a burnup of 230 MWh/kgHE, and has been examined in the hot cells at CRL. Initial indications are that the DUPIC fuel behaves similar to NU fuel irradiated under similar conditions [15]. The remaining two elements are continuing irradiation to higher burnup targets.

4.2.2 Plutonium Mixed-Oxide Fuel

Because of the high neutron economy in CANDU reactors, twice as much energy can be derived from the plutonium separated from LWR fuel by using it in a CANDU reactor, compared to recycling it in a LWR. R&D activities on MOX fuel (which contains Pu) have been conducted by AECL since 1960, and remain a strategic part of AECL's fuel cycle program. The program includes MOX fuel fabrication development, irradiation testing and PIE, as well as reactor physics and fuel management studies [16]. The irradiation of CANDU MOX fuel to extended burnups continues in the BDL-416 experiment in the NRU reactor. In addition, a new experiment has recently begun, with the objective of investigating the effect of MOX fabrication process variables on fuel performance [17].

AECL is also involved in an important international experiment to assess the potential for using CANDU reactors to disposition weapons-grade Pu from the United States and the Russian Federation. The Parallex experiment has recently begun in the NRU reactor and is described in Reference [18].

4.2.3 Low Void Reactivity Fuel

AECL has recently completed a development program to demonstrate the technical feasibility of the LVRF concept for CANDU reactors. While positive void reactivity is an inherent feature of the current CANDU core, it has been accommodated through several features in the CANDU design, such as two independent fast-acting shutdown systems. As a consequence, the CANDU reactor has an extremely high degree of safety. Nevertheless, some potential reactor markets require zero or negative void reactivity, and AECL undertook a comprehensive development effort to meet those needs. The concept involves incorporating dysprosium (Dy), a neutron absorber, in the central pins of a 37-element or CANFLEX bundle. The amount of absorber, and the level of enrichment in the outer rings of the bundle can be varied to achieve any desired level of discharge burnup and void reactivity reduction [19].

The development program included reactor core physics assessments, fuel design, UO2-Dy pellet fabrication process development, the manufacture of prototype bundles, measurements of reactor physics parameters (void coefficients, temperature coefficients and fine structure flux mapping), thermalhydraulic measurements to determine CHF, benchmarking of the WIMS and ASSERT codes for LVRF conditions, in-reactor performance testing, PIE, and safety experiments to evaluate high-temperature Dy interactions with cladding material. Economic evaluations of the LVRF fuel cycle options were also completed.

Table 1. Confirmed and Suspect Fuel Bundle Defects in Canadian CANDU Stations in 1999 and 2000

Station/Year	No. Suspected Defects	No. Confirmed Defects	Avg. Discharge Burnup (MWh/kgU)	Number of Discharged Bundles
Bruce B				
1999	4	2	–	20550
2000	2	2	–	17602
Darlington				
1999	0	0	206	21300
2000	2	0	207	21200
Pickering B				
1999	2	2	214	12200
2000	3	2	215	5400
Gentilly-2				
1999	0	0	177.3	3864
2000	0	0	177.6	4880
Point Lepreau				
1999	0	0	177	4172
2000	0	0	177	4128
Total	**13**	**8**	**177**	**115,296**

4.2.4 Thorium Fuel Cycles

Over many years, AECL has undertaken an extensive program of thoria fuel fabrication, test irradiations, and fuel management studies of thoria-fuelled CANDU cores, in order to establish the technical feasibility of several thoria fuel cycle options. Recent work has achieved improvements in the thoria pellet fabrication process, as well as the commencement of a new in-reactor test irradiation, in order to provide performance feedback to qualify the improved fabrication processes.

4.3 Fuel Supporting Technologies

AECL continues to maintain a program of technology development to support advanced bundle designs and the deployment of alternate fuel cycles. One technology consists of the development of extended burnup capability to greater than three times the present NU burnup. Currently, several experiments designed for extended burnup operation are being irradiated in the NRU reactor. A review of the existing information for CANDU fuel at extended burnups has been completed [20]. A program has also been initiated to extend the current stress corrosion cracking thresholds to higher burnup, through analytical modeling, irradiation, and power ramp tests.

To complement the development of fuel performance codes for high burnup applications, an investigative program focused on obtaining physical properties of fuels, such as diffusion rates [21], thermal properties, and chemistry [22] is also being conducted.

5.0 Concluding Remarks

Recent operational experience and the Canadian CANDU fuel development programs have been described in this paper. The programs consist of the COG-sponsored Fuel Design and Performance program, and R&D directed by AECL's Fuel and Fuel Cycles working group. The programs cover operational issues that are related to the present 28- and 37-element fuel bundle design, and new products such as the 43-element CANFLEX bundles and alternate fuel cycles. These programs, directly and indirectly, contribute to the excellent fuel performance that has been experienced by the Canadian CANDU stations. These programs also support advanced fuel bundles and fuel cycles that will lead to reductions in capital and fuelling costs, increases in operating margins, and improvements in NU utilization and spent fuel management.

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CANDU Fuel Research & Development in Korea: Current Status and Future Prospects

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Abstract

The current status and future prospect of CANDU fuel R & D in Korea is always subjected to the consideration of domestic and international environments concerning nuclear safety, nuclear waste, non-proliferation and economy in favor of the arguments from public acceptance, international environments, and utilities. Considering that, at the end of 2000, the procurement of additional CANDU units at the Shin Wolsong site was decided not to proceed, the current and future CANDU fuel R & D would be oriented to the safety and economy of fuel and reactor operations rather than the national strategy of nuclear fuel cycle and reactor programs in Korea. Therefore, the current CANDU advanced fuel R & D programs such as CANFLEX-NU fuel industrialization, CANFLEX-0.9% SEU/RU fuel R & D, and DUPIC fuel cycle development in a laboratory-scale will be continued for the time being as it was. But the R & D of CANDU innovative fuels such as CANFLEX-1.2% ~ 1.5 % SEU fuel, thorium oxide fuel and DUPIC fuel would have some difficulties to continue in the mid- and long-term if they would not have the justifications in the points of the non-proliferation, economic and safety views of fuel, fuel cycle and reactor.

1. Introduction

In Korea, sixteen nuclear power plants with 12 PWRs and 4 CANDU-PHWRs are now in operation with a total installed electric-generation capacity of 13, 716 MWe, which accounts for about 27 % of the domestic installed electric-generation capacity in Korea. As shown in Table 1, the installed electric-generation capacity of the 4 CANDU-PHWRs is 2,779 MWe, where it shall be noted that, at the end of 2000, the Korea Electric Power Corporation (KEPCO) decided not to proceed with the procurement of additional CANDU units for Shin Wolsong site. Today, the nuclear industries in Korea are faced with several key challenges to achieve the highest levels of safety, to pursue acceptable waste management option to the industry and general public, to operate within varying political climates, and to tackle all of these within a cost regime competitive with fossil fuel generated electricity.

Since the period of the late 1970s, nuclear fuel design and fabrication technologies have been engaged as one of the important R & D activities in Korea. This paper describes the current status of CANDU fuel R & D in Korea. It also describes the future prospect of CANDU fuel R & D by taking into account "nuclear safety", "nuclear waste", "non-proliferation", "economy", and "not to proceed with the procurement of additional CANDU units" in favor of the arguments from public acceptance, international environments, and utilities.

2. Domestic and International Evironments

Taking into account the domestic and international environment concerning non-proliferation in the Peninsula of Korea, some product development guidelines of the CANDU advanced fuel R & D may be summarized as [1]:

- enhancement of reactor and fuel safety and operation margin,
- reduction of annual production rate of spent fuel volume,
- no involvement and no use of enrichment and reprocessing technologies in Korea,
- to be compatible with existing reactor without major change of hardware,
- improvement of economics by means of reduction of fuel cycle and/or reactor operating costs.

These guidelines for fuel and fuel cycle R & D in Korea have been and will be applied not only for the CANDU advanced fuel R & D but also for the R & D of PWR fuel and others.

The CANDU power plants as shown in Table 1 will be operated at least by the mid of this century, because Wolsong #2, #3, and #4 could be decommissioned by around the year 2048, which is taken account into the initial licensing life time of 30 years and the life time extension of 20 years.

Based on a commercial consideration, KEPCO decided, at the 2000 December,

1 Korea Atomic Energy Research Institute, Taejon, Korea

that the procurement of additional CANDU units was not to proceed for the Shin Wolsong site.

3. Current Status and Future Prospect of CANDU Fuel R & D in Korea

As presented in the 4th International Conference on CANDU Fuel, Pembroke, Canada, 1995 October, a strategical projection of CANDU fuel R & D programs in Korea would be summarized as shown in Figure 1. For the time being, the existing R & D programs of CANDU advanced fuel such as CANFLEX (CANDU Flexible fuelling) - NU (Natural Uranium) & - SEU (Slightly Enriched Uranium) / RU (Recovered Uranium from spent fuel) and DUPIC (Direct Use of PWR spent fuel in CANDU) fuel cycle would be continued as it was. In the next couple years from the late part of 2001, the Korea Institute of Science & Technology Evaluation and Planning (KISTEP) will outline the mid- and long-term CANDU fuel R & D programs for the next 20 years from 2002. KISTEP was established on 1999 February with its main missions of surveying, analyzing, and evaluating Korea's national R & D programs.

3.1 37-Element Fuel

At the end of 1996, Korea's nuclear energy industrial structure was reformed as a follow-up to Korea's national policy, and so KAERI's commercial activities of CANDU fuel fabrication and PWR fuel design transferred to the Korea Nuclear Fuel Company (KNFC). In the KEPCO Nuclear Fuel Co. Ltd. (KNFC), a CANDU fuel fabrication plant with a fuel production capacity of 400 tons of uranium per year was constructed in cooperation with GEC. Since 1998, KNFC has commercially produced all the locally needed CANDU fuel, and also paid attention to improve the productivity by developing advanced manufacturing technologies such as an advanced method of Zr-Be brazing, ECT(Eddy Current Test) for the detection end cap weld discontinuities, and so on.

3.2 CANFLEX 43-Element Fuel

Since the early 1990's, the Korea Atomic Energy Research Institute (KAERI) and the Atomic Energy of Canada Limited (AECL) have pursued a collaborative program to develop, verify, and prove the CANFLEX2 43-element fuel bundle design. The CANFLEX [2] fuel bundle enables the introduction of advanced fuel cycles such as SEU, RU and other fuel cycles into CANDU reactors. The bundle assembly and its critical-heat-flux (CHF) appendages offer higher operating and safety margins than current fuel and the potential of reactor power uprating, which would further increase the economic competitiveness of the CANDU reactor, while maintaining full compatibility with operating CANDU reactors. It enables a higher power to be realized before CHF occurs, leading to a net gain in critical channel power (CCP) typically of 6 to 8% over the existing 37-element NU fuel. The greater element subdivision and the use of two element sizes lower the peak linear-element rating. Therefore, it is well suited for the use of advanced fuel cycles, particularly those that can attain high fuel burnup.

The fuel has been verified through extensive testing by KAERI and AECL and has been critically reviewed under a Formal Design Review. The compatibility of the fuel type with existing reactor systems has been proven through a demonstration irradiation of 24 CANFLEX-NU bundles in the Pt. Lepreau Generating Station (PLGS) at New Brunswick, Canada between September 1988 and August 2000 [3].

3.2.1 CANFLEX-NU Fuel

As a prime example of the results that can be achieved through collaborative ventures between Canada and Korea, KAERI and AECL have, since 1991, jointly developed CANFLEX-NU fuel which could likely counterbalance the adverse effects of ageing within the CANDU heat transport system.

KAERI prepared the CANFLEX-NU fuel design report for use of CANFLEX bundles in Korea and submitted it to the Korea Institute of Nuclear Safety (KINS) on 1996 July, to obtain approval of the fuel design and fabrication method, as part of the Korean licensing process. This approval was obtained from the Korean Government, Ministry of Science and Technology (MOST) at 1999 August 6. Following the approval of CANFLEX-NU fuel design and fabrication method in Korea as well as the successful demonstration irradiation of CANFLEX-NU fuel in PLGS, a 3-year industrialization program for the use of CANFLEX-NU fuel in a CANDU-6 Wolsong reactor has been jointly conducted by the Korea Electric Power Research Institute (KEPRI) and KAERI since 2000 November. This KEPRI and KAERI joint R & D program will be conducted by 2003 November. A demonstration irradiation of 24 CANFLEX-NU fuel bundles in Wolsong Unit 1 is expectantly started in the late part of 2001, which is detailed in Reference [4]. The decision on full-core conversion of CANFLEX-NU fuel in Wolsong Unit 1 will be processed in this program.

3.2.2 CANFLEX-SEU/RU and Other Advanced Fuels

KAERI and AECL agreed a joint CANFLEX-SEU fuel development program in 1996 September in order to prepare for the introduction of advanced fuel cycles such as SEU including RU, as an economical alternative to natural uranium and also a fuel for existing or future CANDU reactors. The prime objective of this joint program is the small-scale demonstration irradiation in a CANDU power reactor of 20 to 100 bundles of CANFLEX-0.9 % Equivalent SEU, followed by selective post irradiation examination of selected

2 CANFLEX((CANDU Flexible Fuelling) is a registered trademark of Atomic Energy of Canada Limited(AECL) and Korea Atomic Energy Research Institute(KAERI).

irradiated bundles. This is a necessary prerequisite to a full-scale conversion to CANFLEX-SEU. The program includes the necessary analysis and out-reactor tests. Also, in parallel with the agreement on AECL/KAERI joint CANFLEX-SEU fuel development program, a cooperative program was agreed between KAERI and British Nuclear Fuels Plc(BNFL) in 1996 November, as a similar cooperative agreement between AECL and BNFL, to complete the development and proof testing of recovered uranium fuel for CANDU reactors. The three Parties, KAERI, AECL and BNFL have implemented the three agreements to create one joint cooperative program.

0.9% or 1.2% SEU fuel would increase fuel burnup and hence reduce the quantity of spent fuel produced by a factor of 2 or 3 compared with NU fuel [5]. The SEU fuel would reduce uranium requirements per unit energy by about 24% and so improve uranium utilization, and would also reduce CANDU fuel cycle costs by 20 to 30% compared with NU fuel. RU offers similar characteristics and benefits as 0.9% SEU. The total amount of RU produced from reprocessing operations in Europe and Japan is around 25,000 tons with additional quantities from reprocessing in the former Soviet Union [6]. It is anticipated that RU can be obtained at very attractive price, because some utilities pay for the storage of the RU. Security of supply is not an issue, as SEU of equivalent enrichment can be substituted. The technical feasibility of using RU as a fuel cycle option for CANDU reactors in Korea has been studied to show the overall evaluation and identification of the potential benefits, risks, and costs associated with the use of the fuel to a CANDU-6 utility [7]. This feasibility study indicated that the use of RU in CANDU reactors has beneficial environmental and economical impacts on overall fuel cycles. Anticipating the advantages of the use of 0.9% SEU or RU of the fuel cycle option for CANDU reactors in Korea, the CANFLEX-0.9% SEU/RU fuel development program is scoped into three Phases as follows.

In Phase 1 from 1997 July to 2003 March, the overall evaluation and identification of the potential benefits, risks, costs associated with the use of 0.9% SEU or RU to CANDU-6 utility, and the overall possibility to satisfy the licensing issues described in Korea Safety Review Guideline[1] have been shown to provide a rationale for the justification of the R & D efforts on it for the advanced fuel cycle of CANDU reactors in Korea.

In Phase 2 from 2003 April to 2006 March, the detailed fuel design, reactor physics, thermalhydraulics, and safety analyses, proof testing, and code validations will be performed to lead the small-scale demonstration irradiation in a commercial power reactor. Topical Reports on the fuel design and fabrication method will be licensed as a part of the Korean Licensing process. But this task will not be fully completed in Phase 2.

In Phase 3 from 2006 Arpil to 2010 March, the remaining workscope will be completed. If the results obtained from Phases 1 and 2 show sufficient merit of the use of RU of the advanced fuel cycle option for CANDU reactors in Korea, then a business case including a small-scale demonstration of CANFLEX-RU fuel in a Wolsong CANDU-6 reactor will be started in Phase 3 for which the business workscope would be drafted. Activities [1] would include the preparation of all safety and licensing documentation for irradiation of 20 to 100 bundles in a CANDU-6 reactor, including interaction with the Korean licensing authorities, and fabrication of those bundles in KNFC.

In Phase 3, it is expected that a CANFLEX advanced fuel equal to and/or higher than 1.2% equivalent SEU fuel cycle will be briefly assessed and reviewed to reduce the annual production rate of spent fuel volume from CANDU reactors in Korea as much as that from PWRs in Korea. This assessment will include the overall evaluation and identification of the potential benefits, risks, and costs associated with the use of 1.2% ~ 1.5% SEU to CANDU-6 utility, and the overall possibility to satisfy the licensing issues described in Korea Safety Review Guideline [1]. Also, it will review the option of extending the U-235 indefinitely through the use of fuel cycles based on the thorium in Korea. If the assessment indicates CANFLEX-1.2% ~ 1.5% SEU fuel to be feasibly justified to continue the R & D, the SEU fuel will be developed for the next around 10 years from 2011. The R & D efforts of CANFLEX-1.2% ~ 1.5% SEU fuel will be more clearly justified, if CANDU NG (Next Generation [8] is introduced in Korea just after the last nuclear power plant of KNGR (Korean Next Generation Reactor) #4 in the long-term construction plan of Korean nuclear power plants.

3.3 DUPIC Fuel Cycle

Considering that PWR spent fuel contains enough fissile materials to be burned in CANDU reactors, DUPIC [9] involves converting the PWR spent fuel into CANDU fuel by a thermal-mechanical dry process without any wet chemical processing. DUPIC fuel cycle technology is currently under development by KAERI and AECL in cooperation with the US Department of State and the International Atomic Energy Agency (IAEA). Including the additional energy extracted from the fuel in a CANDU reactor, the potential benefits of the DUPIC fuel cycle in comparison with conventional wet reprocessing and with respect to uranium utilization and spent fuel arising are:

- proliferation resistance due to the non-separation of uranium, plutonium and fission products during the fabrication process,
- a smaller amount of radioactive waste from processing, due to the nature of dry processing,
- savings of uranium resources due to the efficient uranium utilization - the DUPIC fuel cycle could reduce the natural uranium requirements by about 25% compared with the direct disposal fuel cycle, and

Table 1. Current Status of CANDU Power Plants in Korea

Reactor Name	Reactor Type	Capacity (MWe)	Reactor's Manufacturer	T/G Manufacturer	Commercial Operation
Wolsong #1	CANDU-PHWR	679	AECL	NEI/PARSONS	April, 1983
Wolsong #2	CANDU-PHWR	700	AECL	KHIC/GE	June, 1997
Wolsong #3	CANDU-PHWR	700	AECL	KHIC/GE	July, 1998
Wolsong #4	CANDU-PHWR	700	AECL	KHIC/GE	Sept., 1999

- a significant reduction in spent fuel arising - a three-fold reduction in the quantity of spent fuel arising per unit electricity generation, compared with direct disposal fuel cycle.

The DUPIC fuel cycle is being developed in a phased approach. Phase I was a feasibility study, which was conducted between 1991 and 1993, to conceptually evaluate several possible DUPIC fuel fabrication processes. Among several fabrication options, the OREOX (Oxidation/Reduction of Oxide fuel) process was selected as the optimum DUPIC fuel fabrication method for further study [10], and its safeguardability was judged to be achievable.

Phase II, which is currently under way from 1994 to 2002, is focused on demonstrating that DUPIC fuel can be fabricated using the OREOX process on laboratory scale, and on assessing the fuel performance by irradiating the fuel in research reactors. Both KAERI and AECL are developing the fuel fabrication technology and also assessing the reactor physics and the fuel element performance. The DUPIC fuel performance will be experimentally verified by conducting the following activities:

- fabrication of several DUPIC pellets and elements from spent PWR fuel in KAERI
- evaluation on the performance of DUPIC fuel by the irradiation tests at HANARO research reactor in KAERI
- development of safeguards equipment and technology for the fabrication of several DUPIC pellets and elements
- evaluation on the compatibility of the DUPIC fuel with existing CANDU reactor.

KAERI is developing the safeguard methods through international collaboration with Los Alamos National Laboratories (LANL) in USA and with the IAEA. In 1999, KAERI completed preparations for hot cell equipment, refurbishment of a hot cell for the fuel fabrication, and the verification of safeguards equipment. Using about 1 kg of spent PWR fuel, a characterization study on DUPIC powder and pellets has successfully been performed in a hot cell of PIEF (Post Irradiation Examination Facility) in KAERI. Subsequently, KAERI has fabricated three DUPIC fuel mini-elements with 50 pellets at the remote fuel fabrication laboratory in IMEF (Irradiation Materials Examination Facility). For a in-core fuel performance evaluation of the DUPIC fuel elements, the KAERI-made DUPIC elements have been irradiated in the HANARO research reactor for about 2 months since 2000 May. These mini-elements had been burned out up to 43 MWh/kgHe by irradiating with an average linear power of about 50 kW/m. Some data obtained from the post-irradiation examinations of the irradiated DUPIC fuel at PIEF and IMEF in KAERI indicated that the microstructure of the DUPIC pellets is quite similar to that of a CANDU-6 fuel pellets irradiated with a linear power of 73 kW/m[11]. In the Spring of 2001, KAERI also fabricated another three DUPIC fuel mini-elements which have been irradiated in the HANARO reactor since 2001 May. These fuel elements with an estimated maximum-linear power of 49.0 kW/m will be irradiated up to 290 MWh/kgHE.

The scope of DUPIC fuel cycle R & D for the next five years from 2002 April will be planned in the late part of 2001 by KISTEP. KAERI's DUPIC fuel cycle R & D team issues Korean PWR spent fuel management, national energy security through reuse of spent fuel, non-proliferation of nuclear fuel cycles, and self-reliance in fuel technology to continue the laboratory-scale R & D of the fuel cycle in KAERI:

- remote fabrication of prototypical DUPIC elements and bundles from spent PWR fuel
- DUPIC fuel performance evaluation by the irradiation tests in HANARO research reactor
- development of computer programs for the evaluation of DUPIC fuel performance
- development of safeguards equipment and technology for remote fabrication of prototypical DUPIC elements and bundles
- evaluation on DUPIC fuel licensing for the use in existing CANDU reactors.

KAERI's DUPIC fuel cycle R & D team also claims the following activities to be continued for the mid- and long-term as the periods from 2006 to 2015:

- remote fabrication of prototypical DUPIC elements and bundles from spent PWR fuel
- small-scale demonstration irradiation of DUPIC fuel bundles in a CANDU-6 reactor
- development of safeguards equipment and technology for the mass production of DUPIC fuel
- design and construction of a pilot plant for the DUPIC fuel manufacturing

- construction of DUPIC fuel handling facility at a CANDU-6 reactor site
- licensing of DUPIC fuel for the use in a existing CANDU-6 reactor
- development of a dry process technology for the mass treatment of PWR spent fuel

4. Concluding Remarks

The current status and future prospect of CANDU fuel R & D in Korea is always subjected to the consideration of domestic and international environments concerning nuclear safety, nuclear waste, non-proliferation and economy in favor of the arguments from public acceptance, international environments, and utilities. The R & D of CANDU fuel and fuel cycles such as the 37-element bundle, CANFLEX fuel, and DUPIC fuel cycle for the four Wolsong CANDU-6 power reactors in commercial operation and expectantly future CANDU reactors in Korea have been actively and successfully conducted so far since 1980. Considering that, at the end of 2000, the procurement of additional CANDU units in Shin Wolsong site was decided not to proceed, the current and future CANDU fuel R & D in Korea would be oriented to the safety and economy of fuel and reactor operations rather than the national strategy of nuclear fuel cycle and reactor programs in Korea. Therefore, the current CANDU advanced fuel R & D programs such as CANFLEX-NU fuel industrialization, CANFLEX-0.9%SEU/RU fuel R & D, and DUPIC fuel cycle development in a laboratory-scale will be continued for the time being. But the R & D of CANDU innovative fuels such as CANFLEX-1.2% ~ 1.5% SEU fuel, thorium oxide fuel and DUPIC fuel would have some difficulties to continue in the mid- and long-term if they would not have the justifications in the points of the non-proliferation, economic and safety views of fuel, fuel cycle and reactor. The R & D efforts of the CANDU innovative fuel would be more clearly justified if CANDU NG as an example would be introduced in Korea just after KNGR #4 which will be constructed for the period of 2007 to 2014 as shown in the long-term construction plan of Korean nuclear power plants.

Acknowledgement

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Advanced Pressure Tube Sampling Tools

by K.C. Wittich and J.M. King[1]

***Ed. Note:** Although the following paper was first presented at the CNS CANDU Maintenance Conference in November 2000 it is still current and relevant.*

Abstract

Deuterium concentration is an important parameter that must be assessed to evaluate the fitness for service of CANDU pressure tubes. In-reactor pressure tube sampling allows accurate deuterium concentration assessment to be made without the expenses associated with fuel channel removal. This technology, which AECL has developed over the past fifteen years, has become the standard method for deuterium concentration assessment. AECL is developing a multi-head tool that would reduce in-reactor handling overhead by allowing one tool to sequentially sample at all four axial pressure tube locations before removal from the reactor. Four sets of independent cutting heads, like those on the existing sampling tools, facilitate this incorporating proven technology demonstrated in over 1400 in-reactor samples taken to date. The multi-head tool is delivered by AECL's Advanced Delivery Machine or other similar delivery machines. Further, AECL has developed an automated sample handling system that receives and processes the tool once out of the reactor. This system retrieves samples from the tool, dries, weighs and places them in labelled vials which are then directed into shielded shipping flasks. The multi-head wet sampling tool and the automated sample handling system are based on proven technology and offer continued savings and dose reduction to utilities in a competitive electricity market.

PT Sampling Overview

Deuterium concentration is an important parameter that must be assessed to evaluate the fitness for service of CANDU pressure tubes. Accurately estimating the remaining life of these tubes and ensuring their integrity are major long-term concerns to utility owners. Assessing deuterium content, at one time, meant periodic removal of a pressure tube. This was very costly because of the length of the shutdown required, and yielded information on one reactor lattice location only. A better approach was needed.

In recognition of this need, a method of obtaining a small sample of material from the inside of the pressure tube was developed by AECL Chalk River Laboratories (CRL) and first used at the Nuclear Power Demonstration (NPD) plant in Rolphton, Ontario, in 1987. Soon, a standard method was developed for obtaining a sample of material for deuterium content analysis, after first removing the hydride-rich oxide layer on the inside surface of the pressure tube. The cut made by the leading cutter is nominally 3.8 cm long x 1.3 cm wide x 0.008 cm deep, (1.5 in. x 0.5 in. x 0.003 in.), while that made by the second cutter is 3 cm long x 1 cm wide x 0.001 cm deep (1.2 in. x 0.38 in. x 0.004 in.). The cut profile is chosen to maintain fuel channel (FC) integrity, with smooth changes in geometry in all axes and careful control on total depth.

The sample obtained is in the form of a single curl, or "chip", and weighs about 120 mg (Figure 1). Deuterium content is determined at CRL using Hot Vacuum Extraction Mass Spectrometry (HVEMS). Total isotopic hydrogen content is estimated by determining the hydride solvus temperature using Differential Scanning Calorimetry (DSC), and along with baseline hydrogen content of tube off-cuts, provides a check for the HVEMS results. Testing of post-irradiated pressure tubes has shown good agreement of deuterium content measurements from samples and through-wall punch pellets taken from removed pressure tubes. Sampling is performed at four standard axial locations-2, 4, 5 and 5.6 meters from the inlet end-which allow adequate modelling of the deuterium concentration profile.

Damp Sampling

The method of removing the material samples was based on "damp"2 sampling tools by 1989. These tools comprise a cylindrical tool head, slightly smaller than the pressure tube inside diameter. The tool head contains two cutter assemblies mounted in tandem in a common carriage. The carriage is driven over a cam that causes the two cutters to rise in turn and contact the pressure tube. The first cutter removes the oxide layer and then the second cutter removes the sample of pressure tube material for analysis.

Use of damp tools requires prior isolating of the fuel channel, typically by feeder freezing. Actuation is by hydraulic or pneumatics, and can operate with residual water present in the pressure tube. Heavy water droplets and vapour are isolated from the cut area by a purge gas system to prevent deuterium pick-up by the sample during initial oxidization of the freshly cut material.

Loading of damp tools into the reactor is performed manually from a platform adjacent to the face. Once actuated, a step that requires about 30 seconds, the

1 Both authors are with Atomic Energy of Canada Limited, Chalk River Laboratories

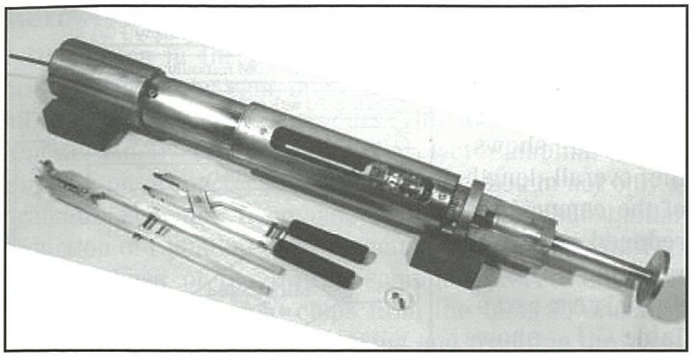

Figure 1: CANDU 6/Pickering Wet Sampling Tool with Hand Tools and Chips (see circular dish).

tool is recovered from the reactor, and the oxide and sample chips are removed. Handling of the chips includes placing them in small plastic vials, capping the vials and then placing them in a shipping flask. Auxiliary equipment supplied by AECL facilitate this transfer, paying heed to the radiation fields of the chips and reduced operator dexterity due to personal protective gear.

Damp sampling requires substantial effort for a modest production rate. Feeder freezing alone for one channel typically requires at least one shift of a four-person crew (40 person-hours). This is followed by removal of the closure plug, shield plug and fuel by the fuelling machine. Then positioning the tool in the channel using push rods, actuating the tool, recovering it and retrieving the chips requires about 1 hour total (or about 20, 5, 15 and 20 minutes respectively) using a crew of about three. Given the general fields and contamination in the work area, dose accumulation can be a concern.

Wet Sampling

Wet pressure tube sampling increases production rate and decreases accumulated dose by avoiding feeder freezing and, in fact, any work on the reactor face. This is accomplished by fuelling machine (FM) delivery into flooded FCs at maintenance flow conditions. The tools are picked up by one FM from a fuel handling (FH) port (e.g., ancillary port in CANDU 6 plants, or the transfer mechanism "T-port" at Pickering Nuclear Generating Station (NGS)), delivered to the desired channel and axial location, actuated by advancing a plunger integral to the tool by the opposing FM, and then recovered by the delivering FM. Once deposited into the FH port, the tools are manually withdrawn, the chips removed and the tool reset, before being loaded into the port for another delivery by the FM. The tool plunger is advanced via a string of fuel bundles or custom spacers.

The wet sampling tool (Figure 1) consists of a carriage, cam and cartridge assemblies, similar to the damp tools. The carriage is moved by the FM via a plunger and shaft arrangement. The FMs at CANDU 6 plants and at Pickering NGS are not capable of rotary control, and so the tool must provide this. Typically, samples are taken at the top of the pressure tube (i.e., the 12 o'clock position) when first sampled then at the 11 or 1 o'clock position. The CANDU 6/Pickering wet sampling tool uses a counter-balance arrangement to tilt the carriage-containing segment of the tool to the desired clock position. This segment is mounted on rotary bearings at either end. When the plunger is pushed by the FM, the initial travel of the shaft extends pads that lift the tool segment clear of the bearing supports to hold the tool in the correct radial orientation. A smaller counter-balance arrangement mounted on an independent radial bearing records the radial position of the cut; it is free to move until a pin locks it at the start of plunger travel.

Further plunger movement displaces light water from an onboard reservoir via a piston. The displaced light water flows through a conduit system to the cutter region. This provides flushing to clear heavy water and eliminate unwanted deuterium pick-up by the sample, like the purge gas system of the damp tools. By using internal valves that open as the cutters lift, less than 400 ml of light water is introduced per sample, an amount acceptable to reactor operators.

The wet sampling tools must be compatible with fuel handling equipment. Their length is that of two fuel bundles (fuel bundles are typically handled in pairs), their outboard end is that of the FH ram grapple adaptor to facilitate FM delivery, and their plunger plate is compatible with fuel bundle end geometry. Wet tools for Bruce NGS take advantage of the rotary positioning capability of the FMs there and interface with the FM via a dedicated spacer.

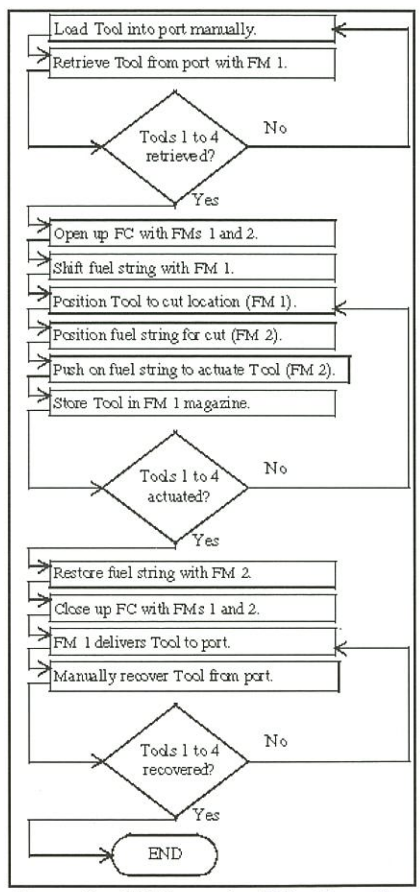

Figure 2: FH Steps for Wet Sampling of One FC.

Wet sampling tools are tested and qualified prior to each campaign in a test facility at CRL that simulates the maintenance flow conditions expected. Heavy water is circulated at up to 465 kPa and 70 litre/min during the cutting process. Samples taken are routinely analyzed on site for deuterium content to ensure the flushing system is eliminating deuterium pick-up.

2 "Damp" – The pressure tubes are defuelled and drained, but may contain some residual heavy water.

Tool actuation and transferred forces, and actuation speed are monitored. Chip weights, and oxide and sample cut depths are also measured to ensure repeatability.

Typical wet sampling campaigns use four tools and production rates are as high as 5 channels per day (24 hour shift coverage) depending on FH practices. Tool reliability is very high. Ten to twenty channel campaigns typically do not require tool change-out. However, a spare tool is qualified to remain in abeyance.

Prior to a wet sampling campaign, FM software must be prepared and tested, and FM operators must be trained. At the beginning of the campaign, FM load and speed settings must be adjusted from that of normal operations and then tested. Electrical jumpers must be installed for control room monitoring of ram force. Commissioning runs, either in the reactor (without cutters) or in a FH test port, are then performed.

FH effort during a wet sampling campaign is summarized in Figure 2. Because each tool samples at only one of the four axial locations, substantial effort is required to shuffle fuel/spacers and deliver the tools. This overhead can limit production rate despite the fact that tool actuation requires only 10 seconds.

Multi-Head Tool

AECL is developing a multi-head tool that would reduce this effort by allowing one tool to sequentially sample at all four axial pressure tube locations before removal from the reactor. After the first actuation, the tool would be positioned for subsequent ones rather than be removed. Four sets of independent cutting heads, like those on the existing damp or wet tools, facilitate this. In this way, the approach incorporates proven technology demonstrated in over 1400 in-reactor samples taken to date.

The multi-head tool is delivered by AECL's Advanced Delivery Machine (ADM) or other similar delivery machines. ADM-delivery essentially eliminates any fuelling machine modifications (hardware and software) allowing much simpler preparations to be made off-line. This eliminates calibration of FM loads and speeds specific to sampling, as well as any specific FH staff training. The overall burden on FH staff is greatly reduced, freeing up this critical plant resource. Figure 3 shows FH and ADM steps required with the multi-head tool. Production rate is expected to exceed 6 channels per day.

An added benefit is that actuation forces are transmitted directly through the delivery machine ram and not through fuel or spacers. This eliminates concerns regarding loading of fuel. Further, spacers are not required, saving considerable effort in handling, inspecting and maintaining the spacers. The ADM provides clock position control, eliminating the need for this provision in the tool.

Chip recovery and tool resetting is simplified as well since only one tool is used during the campaign. Compared to wet sampling, only one-quarter of the entries are required by personnel for chip recovery and tool resetting. As Figure 3 shows, the overall length of the campaign is reduced, further reducing staff requirements. Table 1 shows expected accumulated dose compared to that of typical damp and wet campaigns.

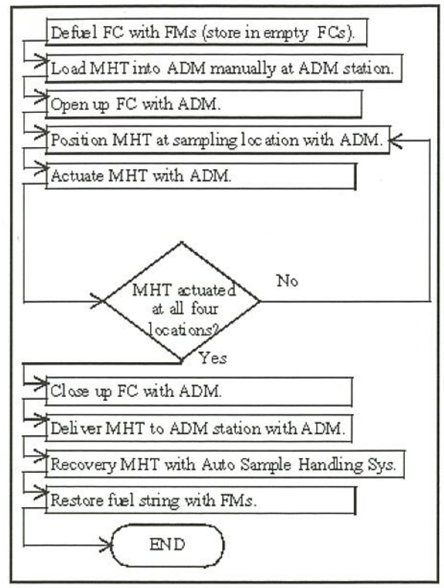

Figure 2: FH Steps for Wet Sampling of One FC.

Tool General Arrangement

The tool is compromised of a carriage, cam and cartridge assemblies, like its predecessors. The carriage in this case, contains four sets of independently actuated cartridges. To accommodate channel sag, a flexible joint resides between the tool segment housing the carriage and that housing the actuator and ADM coupling. Overall carriage housing length is kept to an acceptable amount by a novel approach whereby the carriage moves forward and then reverse one carriage module length for each cut, and the cam travels to the next carriage module on the reverse stroke. Figure 4 shows the overall tool arrangement.

The cam or "ramp" mechanism must lock in place to resist the forces of the followers traversing it, then release and travel with the carriage in the reverse direction, and finally lock in place for repeating the cycle. Outside of the reactor, the ramp mechanism must be brought forward by a similar sequence. Testing at CRL has shown this mechanism to be reliable and robust.

Actuation for carriage motion is provided by an electric motor/ball screw arrangement or by a hydraulic cylinder. This motion is simplified since the carriage always travels its full stroke. Both ramp and carriage position are monitored. Motor power signal provides a measure of actuation force. The connection for these power and signal lines is via a connecting module at the end of the tool. This connects to the ADM Advanced Fuel Channel Inspection System (AFCIS) umbilical, which connects to the appropriate power supply and signal conditioners outside the reactor.

In addition to these lines, light water flushing water is supplied to the tool via the umbilical. The water is directed to the appropriate cutting head by valves similar to those of the wet tools. This minimizes the light water introduced into the primary heat transport (PHT) system, keeping the total to that of a typical wet sampling campaign.

Automated Sample Handling System

Discussion in the preceding sections have highlighted how pressure tube sampling technology has advanced significantly in the past few years with the introduction of remotely delivered and actuated wet sampling tools. Elimination of reactor face work has resulted in not only a dramatic schedule decrease, but also in a substantial reduction of radiation dose accumulated by operators. The second phase of the overall sampling process involves transferring the sample chips from the tools to shielded shipping flasks, and then checking and resetting the tools for further in-reactor use. A large majority of the remaining dose is accumulated during this sample retrieval and tool handling. During a typical sampling campaign of 10 channels using CANDU 6 style wet tools, the total absorbed dose is in the order of 1.5 Rem. While the in-reactor tools have changed, much of the out-reactor sampling equipment is still similar to when sampling was first introduced. With this in mind, AECL has developed a system to automate sample retrieval and tool resetting. It is expected that the use of this system will reduce the radiation exposure to one-third of current levels.

There are other important benefits to the implementation of such a system beyond dose reduction. These include:

- Improved In-Field Monitoring: The automated system is capable of visually inspecting and weighing the pressure tube chips and recording the data for QA purposes. This provides better capability to ensure quality in-reactor samples are taken. Analysis results are affected by both oxide and sample chip weight. Weighing the chips on-site allows the sampling support specialists to more closely track tool performance and enables quicker response if tool adjustments are required, ensuring high quality analysis results. An added benefit of pressure tube chip weighing is that it uniquely identifies the chips at the earliest stage of processing.
- Reduced Staffing: Staffing for the current wet sampling campaigns typically involve four operators to perform sample retrieval, tool preparations and flask loading. This is in addition to Sampling Tool Technical Specialists and any QA and radiation protection personnel. This staffing level is required for each shift, usually two or three depending upon station practice. These personnel must undergo training with the sampling auxiliary equipment prior to the in-reactor campaign and are then dedicated to the project for its duration. The automated system reduces staffing requirements since all operations are performed by the Sampling Tool Technical Specialist via a remote control panel. Conventional safety hazards due to crowding of the work area are also eliminated. Only one operator is required to perform flask change-outs, freeing up scarce resources during an outage.

Two design configurations have been produced for use with either the wet axial or multi-head sampling tools. The main components of each configuration are the same with different arrangements to meet installation requirements. The design for use with wet-style tools at CANDU 6 stations has the handling system installed at the ancillary port. The configuration for the multi-head tool has the handling system mounted directly onto the ADM frame. This approach allows remote sample retrieval directly on the reactor face to minimize tool and platform movements and save time. The modular design of the system will allow it to be easily adapted for use at other reactor types or with other delivery systems.

The operational steps the system can perform include:

- receiving and positioning of the tool head (in conjunction with the ADM for the multi-head tool),
- opening of the chip retaining clips,
- visual inspection of pressure tube chips and cutters,
- retrieval of the pressure tube chips from the sampling tool head,
- individual weighing of the pressure tube chips,
- packaging in labeled vials and flasking of the chips,
- verification of the sampled clock position (wet axial tool only),
- preparation of the tool for further sampling by returning the carriage to home and recharging the light water reservoir (wet axial tool only),
- re-inspection of cutters, general tool condition, and
- returning the tool to the tool delivery system.

All operations are performed remotely via a touch-screen panel. The computer control system has been set up with an automated module for performing various sequences. The program contains several hold-points for operator verification at critical steps. Both the equipment hardware and control software have been designed to allow for easy manual intervention for any equipment malfunction or non-standard situation.

Summary

Advances in both sampling tool and sample handling equipment offer reductions in dose, cost and schedule. The designs draw upon proven technology to ensure process reliability. The multi-head sampling tool is scheduled for demonstration 2000 December. The Automated Sample Handling System currently exists in a working prototype.

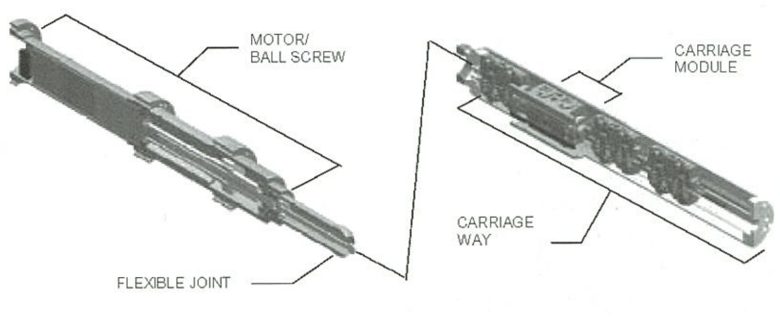

Figure 4: Multi-Head Sampling Tool

Figure 4: Multi-Head Sampling Tool

Plant Control System Upgrades in the Context of Industry Trends Towards Plant Life-Extension

by J. de Grosbois, R. Basso, and A. Hepburn[1] and V. Kumar[2]

***Ed. Note:** This is the first of an intended series of papers on CANDU plant control system upgrade issues.)*

Abstract

Domestic CANDU nuclear plants were brought online between 1972 and 1986. Over the next decade, most of these stations will be nearing the end of their designed operating life. Effort has traditionally been placed on ensuring that the existing installed plant control system equipment could operate reliably until the end of this design life. Until recently, little attention has been given to plant control system upgrades or replacements to meet the expected requirement for 30+ years of additional plant operation following potential plant refurbishments. Industry developments are changing this thinking. The combination of expected increases in electricity demand (and prices), and the many recent successful turnaround stories of U.S. nuclear power plants has resulted in new interest in plant life improvement and plant life extension programs. Plant control system upgrade decisions are now being driven by the need to replace or upgrade these systems to support plant life extension.

This article is the first of several that investigate aspects of plant control system upgrades or replacement, specifically in the context of the CANDU station digital control computers (DCCs). It sets the context for the discussion in the subsequent articles by providing a brief review of industry trends favouring plant refurbishment, by outlining the basic issues of aging and obsolescence of control system equipment, by establishing the need for upgrades and replacements, and by introducing some of the basic challenges to be addressed by the industry as it moves forward.

1 Recent Trends in the Industry

A recent Uranium Information Centre (UIC) Nuclear Issues Briefing Paper, *"Plans for New Reactors Worldwide"*, [1] presents some interesting statistics on the global nuclear power industry. As of 2001, there were 440 nuclear power reactors operating in 31 countries, with a combined capacity of 353 GWe. In 1999 these plants provided 2400 billion kWh, or over 16% of the world's electricity. Some countries, notably Japan, China and the Republic of Korea, are expected to continue their nuclear power construction programs. The briefing paper points out, however, that the rate of growth of installed nuclear generating capacity over the next ten years is expected to be low, for the following reasons:

- nuclear power capacity worldwide is increasing steadily, but not dramatically, with over 30 reactors under construction in 11 countries,
- significant further capacity is being created by plant upgrading, and
- plant life extension programs are decreasing the need for new capacity.

The Nuclear Issues Briefing Paper [1] reports that although most nuclear power plants originally had a nominal design lifetime of up to 40 years, engineering assessments of many plants in the 1990's established that many could operate longer. In the U.S., for example, most reactors now have confirmed life spans of at least 40 years, and in Japan predictions are for 40-70 years. In the U.S., the first set of reactors built have been granted license renewals that extend their operating lives to 60 years, and operators of some 80 more plants are expected to apply for similar extensions. The same paper [1] states that some countries have increased nuclear capacity because of uprating3 existing plants, and cites examples of power reactors in the U.S., Belgium, Sweden and Germany that have had their generating capacity increased. A key factor in achieving these upratings is improved instrumentation and plant process control.

2 External Factors Affecting Life-Extension Economics

Electricity supply in the U.S. is reaching record lows, and the cost of electricity is rising. The recent power shortages in California are clear evidence of a building problem in the U.S. Sudden fluctuations in the price of natural gas and oil have also been experienced over the past year, partly due to increased demands for power generation. Two key factors, when coupled with the effects of supply shortages and longer-term predictions of energy price increases, have resulted in much more favourable economics of nuclear plant life extension. First, the Kyoto Protocol calls for reductions in greenhouse gas emissions. Second, the de-regulation of electricity generation is expected to have an impact.

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2.1 Kyoto Protocol and Environmental Pressures

Based on a detailed study of the Kyoto Protocol, a U.S. Department of Energy study predicts that a significant increase in electricity rates may occur commencing around 2005, and further steady increases thereafter are predicted [2]. The DOE models predict that nuclear power capacity will increase, driven by carbon reduction targets, by between 8 and 20 percent by 2010, relative to the reference case without Kyoto. Extending the lifetimes of existing nuclear plants is projected to become more economical with higher carbon-based energy prices. In the more stringent carbon reduction cases of the DOE's model predictions, most existing nuclear plants are assumed feasible to be life-extended through 2020, in contrast to the gradual retirement of approximately half of the nuclear plants projected in the reference case. All of these factors increase the likelihood of positive refurbishment (plant life-extension) decisions for many of North America's aging nuclear plants, including our domestic CANDU units.

An environmental report just released by the North American Free Trade Agreement (NAFTA) and endorsed by the governments of Canada, Mexico, and the U.S. provides strong support for the Kyoto Protocol initiatives. It provides evidence that rising levels of greenhouse gases are expected to result in more storms, droughts, heat waves, floods and rising sea levels. The report also concludes that efforts to curb greenhouse emissions and other forms of air pollution are hampered by government energy subsidies that encourage high consumption, and that low energy costs that do not reflect the real environmental costs of developing, distributing and using these resources have a detrimental effect on the North American ecosystem.

2.2 The Impact of Deregulation

A paper from the 23rd Annual Symposium of the Uranium Institute, "Electricity Market Competition and Nuclear Power" [3], describes how governments are promoting competitive electricity markets. In particular, there is a move away from administrative price setting by government institutions and towards market price setting through the introduction of competition (note that Ontario, Canada's largest electricity market, is scheduled to open to competition on May 01, 2002). The report contends that the single most important influence of competition on electricity supply systems will be a greater emphasis on cost efficiency by utilities, and concludes that nuclear plants will compete not only based on their typical "historical" costs, but also through lower unit costs resulting from performance improvements and increased plant output. The authors document a worldwide trend towards improved nuclear plant technical performance since the late 1980s, and contend that competition, or the expectation of competition, has played a key role, particularly in the United States. Finally, the report cites many indicators of plant performance and safety that are likely to further improve under competition including:

- decreased corporate and plant-level overhead,
- decreased duration for plant refueling,
- increased time between refueling,
- higher energy utilization of nuclear fuel,
- higher plant utilization rate (capacity factor),
- reduced staffing,
- fewer unplanned plant shutdowns, and
- lower collective radiation exposure of workers.

All of these factors influence the expected economics of plant life extension. It can be argued that any financial analysis investigating the economics of plant refurbishment should take into account the payback from expected improvements in these key performance indicators. In subsequent articles, we will discuss how improved instrumentation and control, in particular improvements in plant control systems, can play a key role in achieving these cost efficiencies.

The competitive advantage of owning existing nuclear plants with low marginal costs, combined with the difficulty in locating and building new plants of any type, is likely to lead many utilities to invest in refurbishment and extend the lives of their nuclear plants. This may explain the recent investment by British Nuclear in the Bruce Generating Station (now Bruce Power) and their intent to re-license units 3 & 4. With continued investments and refurbishment, it is expected that many current nuclear plants should be able to operate a total of 60 years, or longer. As long as the expected value from continued operation exceeds the cost of capital refurbishments needed to operate safely, individual owners will seek to continue operating their plants.

3 Nuclear Plant Aging

World-wide experience with aging of nuclear plant components, systems and structures has shown that if unmitigated, aging effects will reduce the safety margins provided in the design and thus increase risk to public health and safety, and may impact on power production capabilities.

3 "Uprating" refers to increasing the limit on reactor power approved by the regulator under a plant's operating license. Uprating is achieved through design changes, refurbishment, or more in depth safety analysis.

Studies of nuclear power plant aging, in general, are aimed at identifying problems that may result from plant aging and the actions or initiatives that are available to manage aging degradation of plant components. The aging degradation is usually taken into account by establishing a so-called "qualified life", the maximum period that a component may be kept in normal service with adequate assurance that it will perform as required. Routine maintenance, testing and calibration activities are part of normal service conditions and they, as well as the operational stresses, should be taken into account when establishing the qualified life. The qualified life may be dependent on the implementation of scheduled maintenance activities such as parts replacement, cleaning, or lubrication, but these activities may also have an adverse effect if handled improperly.

In the specific case of the station's digital control computers (DCCs), although aging is a serious concern, it is somewhat mitigated by the fact that these systems are for the most part repairable systems. Many of the components can be either stocked as replacement spares or repaired in-house. Most CANDU plants have formal system surveillance and maintenance programs in place to counter DCC aging effects. Several aging mechanisms play a role in overall DCC system health and reliability. For example:

- cable degradation is a known problem that has been quite pervasive and is costly to repair;
- failure of electro-mechanical components (particularly peripheral devices) is a known problem;
- failures of electrolytic capacitors (dry-out), transistors, integrated circuits, edge-connectors, ribbon-cables, video display units, and core memory have all been documented as recurring problems;
- time-dependant failure mechanisms such as effects related to temperature, humidity, dust, vibration, flexing, chemical deterioration, and power cycling are known problems; and
- availability of replacement components is, in itself, a function that decreases with time (i.e. the age of the system).

Instrumentation and control systems play a key role in plant safety and reliability and are subject to both physical and non-physical aging. Physical aging results in the deterioration of physical and performance characteristics of systems, structures and components. Non-physical aging results from obsolescence (i.e., being out of date in comparison with current safety concepts, standards, and technology). As time progresses, the confidence in the reliable maintainability of the existing DCCs will diminish. Diligent monitoring and maintenance management of the aging equipment is therefore important.

4 The Digital Control Computer (DCC) Experience

CANDU nuclear power plants were the first to move to computer-based control and shutdown systems in the early 1970's. At the time, the primary reason for adopting digital control was that there really was no other practical method of controlling the large CANDU core. The digital electronics used in computer-based control also offered more accurate and reliable performance free of the drift that afflicted analog electronics and, as a result, maintained calibration better. Computer-based control offered improved system performance in terms of accuracy, testability, configurability, and computational ability.

The DCCs provided higher data handling and storage capacities, so operating conditions could be more fully measured and displayed. They were easier to use than analog controllers and were more flexible in application. In general, computer-based systems improved plant capabilities (e.g., fault tolerance, self-testing, signal validation, process system diagnostics) and formed the basis for many past improvements in plant and system reliability.

CANDU nuclear power plants rely on DCCs for both monitoring and control. An extensive service history has shown these systems have reliably performed their intended monitoring and control functions. While the existing design presents some constraints on the implementation of design changes, the primary concern with extending the life of existing DCC systems is due to obsolescence and the effects of aging (e.g., mechanical failures, environmental degradation) and the continued ability to reliably maintain these systems.

Vendors are gradually discontinuing support and stocking of needed spare parts, and long-term inventories for critical spare parts held in-house at the stations are diminishing. Although form-fit-function replacement component modules are available in some cases, they are typically redesigned using modern electronics. Such replacements must be certified as "equivalent" through a comprehensive and sometimes costly equivalency process. Finally, knowledgeable maintenance staff are being lost through retirement and attrition, and the skills necessary to maintain the hardware and software of these old systems are becoming progressively less available. For these reasons, the issue of DCC upgrades or replacement (to meet expected plant life extension requirements) has become an increased priority for the industry in the past year.

5 Introducing New Control System Technology

The successful introduction of commercial off-the-shelf

(COTS) industrial process control equipment into Canadian nuclear power plants to replace the aging DCCs has yet to be accomplished and faces several challenges:

- uncertainty inherent in the introduction of new technology (i.e., performance, reliability, cost, maintainability) and its ability to meet demanding requirements,
- the need to shift from the existing technology base while leveraging existing design basis experience (i.e., build and improve on reference designs),
- technical problems identified from industry applications of software-controlled systems technology in nuclear power plants (i.e., software quality and qualification, software validation, software maintenance),
- a sometimes difficult and time-consuming licensing approach, and
- the high cost, in lost production, of any outages required to install and commission new equipment.

At the present time, there is no widely accepted systematic industry-wide methodology for the upgrade of I&C systems, particularly more complex software-controlled systems such as a modern plant control system. Some progress is being made with the recent release of international standards such as IEC 61508: "Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems" [4]. This umbrella standard focuses on life-cycle safety and will be discussed in the follow-up articles. The IEC standard is intended to be tailored to each industry or national system of standards and several compliant IEC sub-standards are in development. Effort is now underway to better align CANDU(r) industry standards and guidelines with the IEC standards. These developments will hopefully enable design engineers to obtain the safety and reliability benefits available from modern products and technology using a consistent approach while avoiding unexpected and sometimes overly conservative licensing requirements.

6 Summary and Conclusions

The economic feasibility of major plant component replacements (including DCC replacements) and license renewals extending the lifetimes of existing CANDU(r) plants is becoming more attractive to our domestic utilities. This situation will be enhanced by deregulation of electricity markets, pressure from environmental concerns and committments, and the difficulties involved in public acceptance for constructing new replacement plant capacity. It is reasonable to conclude the refurbishment of stations like Point Lepreau Generating Station, Hydro Quebec's Gentilly 2 station, and Bruce Power's Bruce A units 3 & 4 are likely to proceed, and that for all of these stations, replacement of the aging and obsolescent plant control computers will be a likely immediate requirement.

Subsequent papers in this short series will further explore the issues of control computer replacement and will discuss: industry experience and directions for nuclear power plant control system upgrades; how control system upgrades support better plant economics; the financial justification of control systems upgrades; the technical and licensing issues of control system replacement; and possible economic opportunities that improved plant-wide automation can provide in the CANDU(r) plant refurbishment context.

References

[1] Nuclear Issues Briefing Paper 19: "Plans for New Reactors Worldwide", Uranium Information Centre Ltd., Melbourne Australia, January 2001.

[2] Energy Information Administration Report: "Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity", U.S. Department of Energy, 1998.

[3] Varley, C. and Paffenbarger, J., "Electricity Market Competition and Nuclear Power", the Twenty-Third Annual International Symposium of the Uranium Institute, 1998.

[4] IEC 61508, "Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems", International Electrotechnical Commission, 1998.

GENERAL news

Happenings at The CNSC

There has been considerable activity at the Canadian Nuclear Safety Commission over the past couple of months.

Major CNSC reorganization

On January 10, 2002, Ms. Linda Keen, President and Chief Executive Officer of the Canadian Nuclear Safety Commission (CNSC), announced a major restructuring of the regulatory staff of the Commission.

A new **Operations Branch** has been created which will encompass the regulatory responsibilities previously handled by the Directorates of Reactor Regulation, Fuel Cycle and Materials Regulation, and Environmental and Human Performance Assessment. **Mr. Ken Pereira** has been appointed as the Vice-President, Operations Branch.

The restructuring complements a number of changes made at the CNSC in the spring of 2001, which resulted in the creation of the Offices of Regulatory Affairs and International Affairs, and in the restructuring of Corporate Services and the Commission's Secretariat. The CNSC stated that those changes were implemented in order to improve the management of corporate functions supporting the CNSC's regulatory activities, to more clearly support the CNSC's safeguards-related activities, and to improve the support to the Commission while emphasizing its decision-making authority.

The new Operations Branch has been established to enable the CNSC:

- to realign its regulatory operations in order to meet its strategic objectives of improving the effectiveness and efficiency of the regulatory regime,
- to increase the CNSC's openness and transparency for all stakeholders, and,
- to maintain the competence of the CNSC's workforce by ensuring that CNSC attracts and retains excellent staff.

The new Operations Branch is divided into five directorates each headed by a Director General:

Directorate of Power Reactor Regulation
J. Blyth, Director General

Directorate of Nuclear Cycle and Facilities Regulation,
C. Maloney, Director General

Directorate of Nuclear Substance Regulation,
T. Viglasky, Director General

Directorate of Assessment and Analysis,
I. Grant, Director General

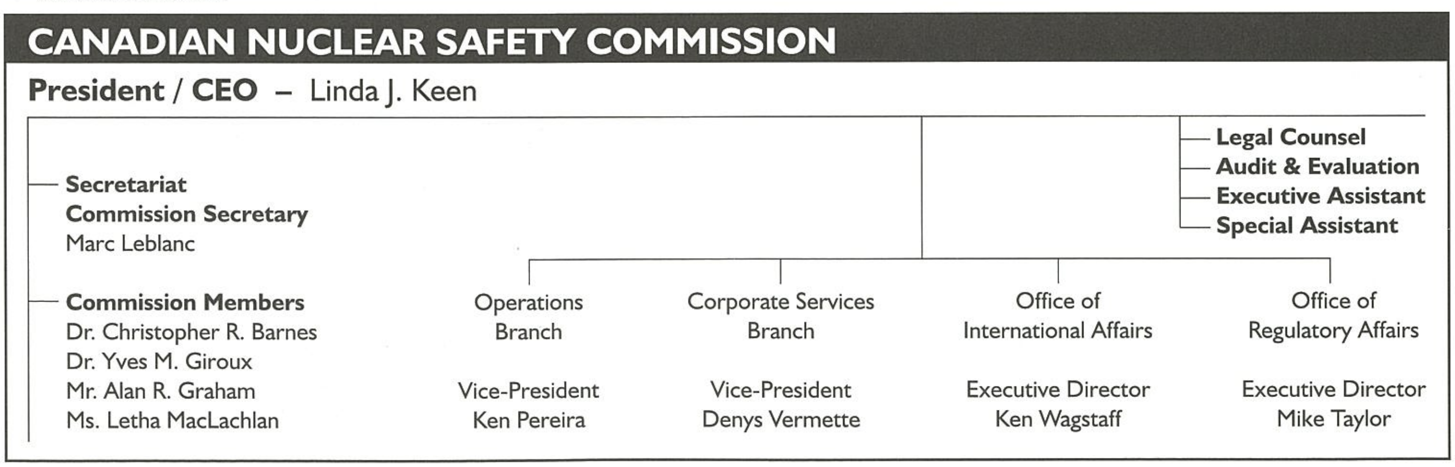
Directorate of Operational Strategies,
I. Grant, Acting Director General
(until an external staffing action is completed).

The first four directorates will have similar responsibilities to the existing ones. The Directorate of Operational Strategies will be responsible for the development of regulatory processes, programs and documents to provide a basis for consistent and effective regulatory practices.

A "top-level" organization chart is shown in the accompanying figure.

The new organization and the appointments take effect immediately, and the Directors General are responsible as of January 10, 2002 for all activities related to the regulation of their area of responsibility, including licensing, compliance, enforcement, and the development of regulations and setting standards.

Further information on the CNSC's restructuring is available on the CNSC Web site at < www.nuclearsafety.gc.ca >.



CNSC decisions

Following its hearings and meetings in October and November, the Canadian Nuclear Safety Commission issued its decisions on some licensing matters.

On November 5 the CNSC announced its decision to amend the Operating Licence for the Pickering A nuclear generating station to permit the restarting of its four units. The amendment requires Ontario Power Generation to complete a number of improvements and upgrades that had been identified in the application. Specific approval from CNSC staff will be required before each reactor is restarted and before specified power increases. OPG is also required to report back to the Commission every six months on the progress of the restart program.

Also in November the CNSC approved Cameco Corporation becoming the licensee for the uranium mine site preparation licence for the Cigar Lake project. When operating Cigar Lake will be the largest uranium mine after McArthur River. It is owned 50% by Cameco, 37% by COGEMA, and the rest by minor shareholders. Cameco has stated that it expects to apply for a mine construction licence in early 2002.

Senior CNSC staff retire

Three long-term and senior members of the CNSC staff have retired recently.

In November 2001, **Murray Duncan,** retired after 35 years with the former Atomic Energy Control Board and the CNSC. In recent years Murray was Director General of the Directorate of Fuel Cycle and Materials Regulation, stepping down about a year ago in anticipation of retirement and serving in a special capacity on the re-organization of the Commission staff. Before joining the AECB Murray had been with the Civilian Atomic Power Department of Canadian General Electric.

Jim Harvie, former Director General of the Directorate of Reactor Regulation, surprised many by announcing that he would retire on January 4, 2002. Jim was also a long-term member of the AECB / CNSC staff. Over the years he had been a project officer at Bruce, director of one of the power reactor divisions before becoming Director General in 1998.

Ron Thomas, another AECB / CNSC veteran retired on January 3, 2002, after 31 years service. Over the years Ron had been manager, then director of several divisions, including Quality Assurance, Operator Certification and Materials Regulation In his years in quality assurance Ron was very involved in the development of the CSA and IAEA.QA standards.

ITER negotiations begin

The first formal negotiations for the ITER project began in meetings held in Toronto, November 8 and 9, 2001. Delegations from Canada, the European Union, Japan, and Russia met in the first of a series of negotiations that is expected to lead, by the end of 2002, to an agreement on the implementation of the project. Peter Barnard, chairman and CEO of Iter Canada, chaired the negotiation meeting. Following meetings will be held in Tokyo on January 22 and 23 and, tentatively in Moscow in March and France (Cadarache) in May. Cadarache is possible as the EU proposed site.

Preparatory meetings had been held in June in Moscow and in July in Vienna. It was at the former meeting that Canada's ambassador to Russia, Rod Irwin, presented Canada's formal proposal to host the ITER project.

Prior to the negotiation meeting five workshops were held over November 5 and 6 to provide delegates from the other participating parties the various aspects of the public / private partnership underlying Canada's bid. The workshops addressed financing, environmental assessment, Canadian project experience, site specific information, and, the living and social environment for foreign scientists.

At the close of the two day formal meeting a joint news release was issued, as follows:

Delegations from Canada, the European Union, Japan and the Russian Federation met in Toronto this week to begin formal negotiations on the joint implementation of the ITER project. ITER is the world-leading international collaborative scientific and technological project with the goal of taking the next major step in the development of fusion energy as a safe, clean and sustainable energy source for our planet.

The Toronto negotiations were the first in a series that is expected to lead, by the end of 2002, to an agreement on the joint implementation of ITER.

This agreement will govern, under international law, the construction, operation and decommissioning of ITER. Matters covered in the discussions also included the site-selection criteria and process, the cost sharing and procurement allocation schemes.

This first round of negotiations followed preparation meetings in Vienna in July, and in Moscow in June, where Canada presented its bid to host the ITER project. Other site offers are under consideration by the European Union and Japan. Earlier this week there were a series of discussions by experts supporting the negotiations, including international workshops on aspects of the Canadian site offer to host ITER.

The participants in the negotiations took important first steps on a variety of issues, and plan to hold the second round of negotiations in Japan in January of 2002.

W. B. Lewis lecture

The W. B. Lewis lecture for 2001 was held in Ottawa on October 17, with Dr. Robin Jeffrey, chairman of British Energy and of Bruce Power as the guest lecturer.

Dr. Jeffrey titled his talk "Replacing Nuclear with Nuclear - a UK Perspective". The substance of the lecture was drawn from the submission by British Energy to the UK government's policy review the previous month. The key points of the British Energy argument were: (1) nuclear is the only large scale source of carbon-free electrical generation (other than hydroelectric); (2) nuclear provides energy security without the price volatility of gas. Therefore the UK should continue generating 25% of its electricity by nuclear, which means that ten new nuclear plants of about 1,000 MW need to be built between 2010 and 2025 to replace the existing ageing ones. Jeffrey said that the CANDU NG design appeared to be a likely candidate for new nuclear plants in the UK.

In the very active question period the topics changed to public acceptability, privatization and safety, the last in the context of the events of September 11.

The W. B. Lewis lectures were initiated by Atomic Energy of Canada Limited in 1988 to honour the memory of Dr. W. B. Lewis who led the scientific work of AECL for three decades and is considered the "father" of the CANDU design. The 2001 lecture was cosponsored by the Program of Research in Innovation, Management and Economy of the University of Ottawa, the Carleton Research Unit on Innovation, Science and Environment, the Canadian Academy of Engineering and the Canadian Nuclear Society.

OPG cutting 2,000 positions 1160 from nuclear

On January 16, 2002, Ontario Power Generation (OPG) announced a restructuring plan that will lead to a company-wide staff reduction of approximately 17 per cent, representing about 2,000 positions. The company expects the reductions to be achieved equally over each of the next two years. In addition, a number of staff currently located at Head Office will be redeployed closer to OPG's generating stations.

The nuclear department will cut 340 positions in 2002 and 820 further in 2003. Another 260 will move into positions currently held by contractors. Some nuclear support staff will be moved from 700 University Avenue to a site between the Pickering and Darlington stations. The Inspection Services and the Nuclear Safety Analysis divisions will become "service organizations based on commercial models".

The downsizing is a direct consequence of the Ontario government's decision to open the electricity market to competition. OPG has been ordered to decontrol some of its facilities so as to reduce its share of electricity generation to 35%. Last year, the company leased its Bruce Nuclear facilities to Bruce Power. Currently OPG is seeking to decontrol its Lakeview, Lennox, Thunder Bay and Atikokan fossil-fuelled stations, along with four Mississagi River hydroelectric stations.

Also, OPG expects to complete, over the next two years, a number of major improvement initiatives that required considerable resources, including the Pickering A restart, nuclear performance improvement projects (including the Integrated Improvement Plan) and various upgrades at fossil and hydroelectric stations.

The company has stated that, to the extent possible, much of the targeted downsizing will be achieved on a voluntary basis. Implementation plans that maximize voluntary reductions will be developed in consultation with the Power Workers' Union and the Society of Energy Professionals.

As well as the relocation of nuclear related Head Office personnel closer to the Pickering and Darlington stations, Head Office personnel that support OPG's hydroelectric and fossil stations will be moved to either the Sir Adam Beck facilities near Niagara Falls or to the Nanticoke Generating Station, located in Haldimand County.

The cost of the restructuring plan, including relocation costs, is estimated to be approximately $400 million. However, company officials state this will make it more competitive in the coming open electricity market.

Canadian Nuclear Society
Société Nucléaire Canadienne
Canadian Nuclear Association
Association Nucléaire Canadienne

27th Annual Student Conference

Holiday Inn on King Toronto, Ontario, Canada
2-5 June 2002

Call for papers

The 27th Annual CNS-CNA Student Conference will be once again part of the 23rd Annual CNS Conference. There will also be a Best Paper competition with awards at each schooling level.

Deadlines

- Deadline for abstracts: 1 February 2002
- Notification of acceptance: 18 February 2002
- Firm deadline for full papers: 5 April 2002

The abstracts and the presentations can be in either French or English. The abstract length should be of one page. Please indicate the level of the paper (undergraduate, Master's or Ph.D.) and the name(s) of the supervisor(s). The presentations should last around 20 minutes and are followed by a 5 minute question period.

Conference Topics

Every subject concerning nuclear technology will be considered.

Best Paper Competition

The presentations will be evaluated on the basis of both technical and communicative merit by a bilingual jury committee composed of industrials and academics.

Additional Information

Overhead projectors will be provided. Electronic projection will also be available upon prior request. All presenters will have their registration fees and accommodation provided by the Conference.

Preferably, all papers and abstracts should be sent via e-mail to this address:
student-cns2002@polymtl.ca
Hard copies can also be sent to:

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2-5 Juin 2002

Appel de textes

La 27ième Conférence annuelle étudiante SNC/ANC fera encore une fois partie de la 23ième Conférence annuelle de la SNC. Il y aura aussi compétition pour le meilleur texte, à tous les niveaux universitaires.

Dates limites

- date limite pour les résumés: 1er février 2002
- Lettre d'acceptation: 18 février 2002
- Date limite pour les textes complets: 5 avril 2002

Les résumés, textes complets et les présentations peuvent être en français ou en anglais. Les résumés devraient être d'une page. SVP indiquer le niveau universitaire du (1er cycle, maîtrise ou doctorat), et les noms des directeurs de recherche. Les présentations dureront environ 20 minutes et se termineront par une période de question de 5 minutes.

Sujets pour la conférence

Tous les sujets reliés à la technologie nucléaire seront acceptables.

Compétition du meilleur texte

Les présentations seront évaluées sur le mérite technique et sur la qualité de la communication orale, par un jury dont les membres seront bilingues et qui proviennent des milieux industriels et académiques.

Informations supplémentaires

Des projecteurs à acétates seront disponibles. La projection électronique sera aussi disponible sur requête antérieure. Les frais d'enregistrement à la conférence annuelle, de même que les frais de séjour seront couverts par la SNC/CNA.

De préférences, tous les résumés et textes devront être envoyés par courriel à l'adresse suivante:
student-cns2002@polymtl.ca
avec le texte écrit sur une seule colonne.
Les copies sur papier et tout autre correspondance pourront être envoyées à:
27ième Conférence annuelle étudiante SNC-CNA
a/s Jean Koclas
Institut de génie nucléaire
Ecole Polytechnique de Montréal
CP 6079, Succ. Centre-ville
Montréal,
QC
H3C 3A7

CNS news

From the President

The year 2001 started on high note for the nuclear industry with a nuclear renaissance gaining momentum. Reactor performance figures were up all over the world and more nuclear electricity was produced in 2000 than ever before. In Canada substantial progress was made toward restarting the laid up reactors at Pickering and Bruce and plans were under consideration for extending the lifetimes of other reactors. A new nuclear utility, Bruce Power, had been born and competition in electricity production was initiated. An excellent safety record had been re-established and the memory of Three Mile Island had largely faded in the US. Chernobyl was still with us but there was a renewed optimism that it too would soon become a warning rather than an obstacle to further nuclear development. The California power shortage added growing urgency to secure additional nuclear capacity - already driven by the threat of climate change, increased air pollution from fossil fuels, and continuing political instability in the Middle East.

Then came September 11th and everything changed for the worst. The horrifying images of the aircraft smashing into the World Trade Center Towers were soon transposed to aircraft smashing into all types of installations critical to the functioning of our society including nuclear power stations. A new and mounting criticism was leveled at nuclear power namely that power reactors were particularly vulnerable to terrorist attack because, according to the critics, the consequences of an aircraft hit on a reactor would be catastrophic. In France antiaircraft defenses were installed near reactors seemingly acknowledging the reality of the threat. In Canada and the US, the industry reaction to this criticism was strangely muted even though reactor containment designs had apparently taken into account (accidental) impacts of passenger aircraft and there had even been a test in the US involving a fighter aircraft deliberately impacting a containment-like structure. An unequivocal and authoritative response is needed to dispel this new accusation so we can go forward with the nuclear renaissance.

As we have seen the world can unalterably change in a single morning. In the face of rapid change education and information are constants that give can provide direction to orient governments and the public. A primary objective of the CNS continues to be effective education and communication on nuclear issues. In 2001, our activities in these fields were:

- Teachers Courses on Nuclear Energy
- AECL's Science for Educators Seminar
- Journalism Workshops on Scientific Reporting
- Deep River Science Academy
- Science Fairs and other special events

Our 2001 Officer's Seminar was on the theme of Communications with media relations professionals from OPG, AECL and the CNA attending. New ideas coming out of the Seminar included an interactive web site, a business card with web site locations, and the concept for of a CNS Newsletter since named "C-News" . It will be published 3 times a year starting in January 2002. It will contain mainly brief news items and notices of upcoming conferences and courses including the CNS program. The basic audience for the Newsletter is not only CNS members but also the large constituency of non-members who attend our meetings and conferences, and in other ways support our activities. It is intended to be complementary to the existing and excellent CNS Bulletin which will continue in its present form.

Throughout the year the CNS has continued to provide courses and stage conferences that enhance the dissemination of information on nuclear topics. All the CNS Conferences were successful this year including.

- Annual Conference (June 10- 13, 2001, Toronto)
- International Conference on CANDU Fuel (September 24-27, 2001, Kingston)
- Climate Change 2: Canadian Technology Development (October 3-5, 2001, Toronto).

Planning for the 2002 Annual Conference (June 2-5, 2002, Holiday Inn, Toronto) is in full swing and bookings have been made for the 2003 Annual Conference (June 8-11, 2003, Marriott Eaton Centre, Toronto). Also arrangements are now advanced for the 4th CNS International Steam Generator Conference (May 5-8, 2002, Toronto) and a Nuclear Simulation Symposium is planned for Ottawa in September 2002.

The CNS has become one of the member societies of the Engineering Institute of Canada (EIC) and for first time CNS Courses are eligible for credits under the EIC professional development recognition system. Courses held in

2001 were the following.

- CANDU Chemistry Course (February 19-20, 2001, Cambridge)
- CANDU Reactor Safety (April 25-27, 2001, Mississauga)
- CANDU Reactor Safety (June 20-22, 2001, Bruce)
- CANDU Fuel Technology (November 7-8, 2001, Mississauga)

Courses planned for 2002 include further ones on the above topics in addition to a Quality Assurance course. In addition, the local CNS Branches held numerous local seminars on topics of interest to their members.

The CNS is fundamentally a volunteer organization that depends on the efforts of its individual members. I would like to personally thank all those members who have worked so hard over the past year to make it so successful. Finally, on behalf of the CNS Council, I would also like to thank our sister organization the CNA, the companies in the nuclear industry, and all of the other organizations and individuals that have supported CNS activities in 2001. We look forward to your continued support and encouragement in the coming year.

David Jackson
President, Canadian Nuclear Society

BRANCH ACTIVITIES

Bruce

Eric L. Williams

The Bruce Branch hosted two presentations in 2001. Mr. Duncan Hawthorne, Bruce Power, addressed the Branch on the challenges ahead for the Bruce during the Bruce A Restart in January. Dr. Jerry Cuttler gave his presentation on "Why Are We Afraid Of Nuclear Radiation" on September 11 .

The Bruce Branch is planning at least three presentations in 2002.

Mr. Ken Talbot, Bruce Power, will be sharing his experiences with the International Nuclear Community with us on 12 March 2002.

Dr. Robin Jeffery, British Energy, plans to present his paper "Replacing Nuclear with Nuclear (in the United Kingdom)" early in 2002.

Chalk River

Michael Stephens

The active Chalk River Branch held meetings in November and December and have several planned for early 2002.

Nov. 8 - Phillipe Duport (Director, International Centre for Low-Dose Radiation Research, Institute of the Environment, University of Ottawa) spoke on "Radiation and Cancer at Low Doses Put into Perspective".

Dec. 13 - Albert Lee (Director of Nuclear Studies, Office of the AECL Chief Engineer) spoke on "Maple Reactors - From Concept to Product".

Seminars are planned for late January, mid March, and May (two, including one linked to the unveiling of the NPD plaque).

Reports on Branch seminars are publicized in the North Renfrew Times (the weekly newspaper for the Chalk River/Deep River area) and through the Branch webpage on the CNS Internet site.

The Branch is in the process of purchasing a radiation monitor for Fellowes High School in Pembroke.

The Branch Annual General Meeting was held November 8,2001. The Branch Executive for 2002-2002 comprises:

Chair - Michael Stephens
Vice-Chair - vacant
Secretary - Fenella Lane
Treasurer - Bryan White
Program Director - Jeremy Whitlock
Member-at-Large - Morgan Brown
Past Chair - Alan Lane

Manitoba

Jason Martino

Morgan Brown resigned from the post after many years of dedicated service and hard work due to a job relocation to Chalk River. Jason Martino has taken over the running of the branch with support from Underground Research Laboratory (URL) staff.

In the past year the Manitoba Branch had supported the Whiteshell Campus of the Deep River Science Academy (DRSA). The Branch recently received the DRSA annual report outlining the many interesting projects conducted by the academy students and recognizing the sponsorship of the CNS Manitoba Branch.

Ottawa

Bob Dixon

The Ottawa Branch held one meeting in the fall of 2001. On October 25 Dr. David Sinclair, professor of physics at Carleton University and deputy director of the Sudbury Neutrino Observatory (SNO) described that project and presented some of the first scientific results.

On January 17, Dr. Jerry Cuttler (former CNS president) is scheduled to talk on "Low-Level Radiation: What is there to fear?"

The Branch will again be sponsoring a prize at the Ottawa Regional Science Fair which will be held in March 2002.

Toronto

Adam McLean

The CNS Toronto Branch is working to have a great lineup of events for 2002.

January 23rd, 12-1PM, brings Ontario Power Generation fire protection specialist Malcolm Rawlingson to the OPG Mini-Auditorium to talk on the subject of "Protecting Nuclear Facilities From Fire", sure to be an interesting seminar.

In February, a to-be-announced executive from Bruce Power will come to talk about the progress made thus far at the Bruce Nuclear Generating Station. Details will be posted on the Toronto Branch web site.

March 5th Peter Boczar from Atomic Energy of Canada Limited will be here to speak on the new CANDU NG reactor design.

March 2nd-10th is Canadian National Engineering Week!

For more information on Engineering Week, see their national web page at: www.new-sng.com.

The 2002 Toronto Area Science and Technology Fair will be held April 20th at University College of the University of Toronto and the CNS Toronto Branch will again be a sponsor. In addition to donating to their general fund, this year two awards will be given out for nuclear-related and other high-technology subjects, encouraging students to enter those fields in university.

The Toronto Branch web page has again undergone extensive additions! New material has been added to the Low Dose Radiation, As Education in Nuclear, and A Career in Nuclear topical pages. The Nuclear Career page now contains links to employment pages of 30 companies in every nuclear field! In addition, an extensive update to the Nuclear Fusion page has been made with emphasis on Canadian activities in fusion research and development and the future of Iter Canada. Check it all out at: www.cns-snc.ca/branches/Toronto/toronto.html

In the Toronto Branch executive, the recent addition of Ms. Margaret MacDonald has come to an early end with her move to Mississauga. Although an unfortunate loss for us, she has been very well received by the Sheridan Park branch and will bring a great deal of enthusiasm there. Thanks goes out to Margaret for helping us out in the program and being a great friend.

New Members

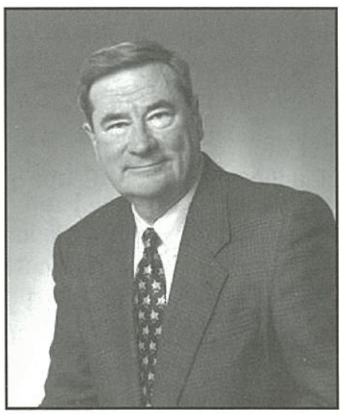
We would like to welcome the following new members, who have joined the CNS since our last report.

Nous aimerions accueillir chaudement les nouveaux membres suivants, qui ont fait adhèsion à la SNC aprés notre dernier rapport.

Gisèle Aucoin	AECL
Serguei Podobed	Lexington Capital Group LLC
Robert Kapteyn	Independent Market Operator
Charlene Fawcett	Department of National Defence
Barbara Majchrowski	Insurers' Advisory Organization Inc.
Brian McGee	Ontario Power Generation
Nima Safaian	McMaster University
Ashraf Sadek	AECL
Sumita Makol	University of Toronto
Frank (Fengmei) Song	University of Toronto
Thien Thanh Le	University of Toronto
Mohammad Babar	University of Ottawa
Elton Chan	University of Toronto
Peter M.-Y. Chung	University of Toronto
Majid Fatemi	University of Toronto
Kristi Clark	McMaster University
Vicky Wong	Ryerson Polytechnic University
Kim Tsoi	University of Toronto
Charles Packer	Cherrystone Management Inc.
Heather M. Douglas	
Catherine Gucciardi	University of Toronto
Tanya Huong Tran	University of Waterloo
Murray G. Love	IESVIC, University of Victoria
Jack Howett	
Ron C. Field	CANATOM NPM Inc.
Ali Dolatabadi	University of Toronto
David Gilbert	McMaster University
Reza Ghafouri Azar	University of Toronto
Dave T.F. Kuo	University of Toronto
Brian Shanks	New Brunswick Power
Ray Brougham	University of Victoria
Rao V. Annamraju	AECL
Rao F.H. Khan	Medical Physics & Applied Radiation Sciences
Victor Caxaj	McMaster Univeristy
Maninder Jandu	McMaster Unversity
Stèphanie Trottier	Universitè d'Ottawa
David Claus	University of Victoria
Hilary Johnson	Bruce Power
Greg J. Terry	University of Victoria
Mike Walker	Royal Military College
Marian Soare	S.C. Nuclear NDT Research & Services
Mirela Milanovic	University of Victoria
Jeff D. Kennedy	University of Victoria
Stephen McAuley	
John C. Krane	Bruce Power
Kee Kwong Fung	Ontario Power Generation
Muzibur Khan	University of New Brunswick
Mahmood Shad	AECL
John Baron	Ontario Power Generation
Ashraf El Sayed Mohamed	
Xiaoyu (Jack) Zhou	AECL
Monica El-Behery	University of Toronto
Clarissa Wai Ying Leung	Queen's University
Andrew C. Wallace	Bruce Power - NSAS
Alan Nicholls	Glen Rother School
Pierre Wolfshagen	AECL
Kevin Y.K. Ko	University of Toronto
Karl Babineau	University of New Brunswick
Benoit Villien	
Charles (Guobing) Jiang	
Ariandokht Espahbod	University of Toronto
Michael D. Street	Framatome ANP
Naoya Iwashita	Hitachi Canada Ltd
Sami A. Douara	Stone & Webster
Khaled Chaabouni	HEC Business School
Tom Stevens	Ontario Power Generation
Noel F. Harrison	McMaster University
Mingjian Zhang	New Brunswick Power
George Sutton	New Brunswick Power
Jim O'Donnell	New Brunswick Power
John R. Ferris	New Brunswick Power
Kris McIntyre	New Brunswick Power
Evan G. Young	New Brunswick Power
Frank Steward	CNER
Kathleen Heppell-Masys	Department of National Defence
Ken J. Maillet	New Brunswick Power
Raman K. Verma	University of New Brunswick
David S. Chu	Ontario Power Generation
Clayton G. McLean	Ryerson University
Jenieveve Fredette	University of Guelph
Dan Quach	McMaster University

Patrick Hawley	Canadian Nuclear Safety Commission	Anis Ahmed Siddiqi	Candesco Research Corp.	Liang Yu (Fred) Huang	AECL
Valeh Aleyaseen	McGill University	Rohit Raina	AECL	Abebe Tilahun	University of Ottawa
Peter Schwanke	AECL	Fernando Iglesias	Bruce Power	Hui (Helen) Zhao	AECL
Jason Cheng	OPG	Malcolm Rawlingson	Ontario Power Generation	Nancy Fish	Ontario Power Generation
Ruben Y. Oris Valiente	AECL	Edward J. Leader	CNSC	Ki-Seob Sim	AECL
Angela Kosmatos	Ontario Power Generation	Yaman M. Hakmi	University of Ottawa	Liliana Popescu	Ontario Power Generation
Daniel F. Duncan	Duncan Associates Corp.	ValÈrie Lyne Lèveillè	Universitè McGill	Matthew t Turk	Royal Military College
Kathleen Duguay	New Brunswick Power	Minerva Yaniz-Gonzalez	AECL	Scott Miller	McMaster University
Angela D'Antonio	New Brunswick Power	Avery Prandtl Yuen	McMaster University	J. Krasnodebski	
Sue K. Moore	New Brunswick Power	Holly Bruce Hamilton	AECL	Neil MacLeod	Babcock & Wilcox
Margaret MacDonald	Dimensions	Richard Verrall	AECL	Ehud Ne'eman	
Tony (Taofeng) Liang	AECL	Mikhail S. Ioffe	Cameco Corporation	Oleh Yur. Tushkov	Rivne Nuclear Power Plant
Igor V. Chichkov	URS Corporation	Engin Ozberk	Cameco Corporation	Alex I. Belov	AECL
Mark Huddart	AECL	Jennifer Jamieson	McGill University	Rao Guduri	AECL
C. Fraser Forrest	Stern Laboratories Inc.	Didier Laux	Universite Montpellier II (LAIN)	Jimin Peng	AECL
Rachna Clavero	Candesco Research Corp.	Guoping Zhang	AECL	Jameel Hashmi	AECL
Michael Snow	Memorial University	John G. Roberts	Bruce Power	Blair Bromley	Brookhaven National Laboratory

Meet the President



Dr. David P. Jackson, the 2001 - 2002 president of the Canadian Nuclear Society, brings a wealth of experience and background to the position, in research, management, academia, business, communications and international affairs.

After obtaining a Ph.D. from the University of Toronto in 1968 David joined Atomic Energy of Canada Limited at Chalk River where he conducted research in particle solid interactions phenomena including plasma-wall interactions. In 1975-76, he spent a year's sabbatical at the Max Planck Institute for Plasma Physics, Germany largest fusion laboratory. Returning to Chalk River he initiated the fusion breeder blanket program at Chalk River Laboratories for the Canadian Fusion Fuels Technology Project (CFFTP) and became Manager, Fusion in 1985.

From 1987-1997 he was Director of Canada's national fusion program and was the federal official responsible for CFFTP and the Centre canadien de fusion magnètique at Varennes, Quebec. In this role, he represented Canada on a number of senior international committees involving fusion and chaired the International Fusion Research Council of the International Atomic Energy Agency from1993 to 1998. With support from Natural Resources Canada, he continues to represent Canada on the IAEA's Fusion Power Coordinating Committee and on the Executive Committee of that Agency's Implementing Agreement on the Environmental, Safety and Economic Aspect of Fusion Reactors.

He began a long association with McMaster University in 1979. Since then he has at various times been involved in McMaster's Institute for Energy Studies, the Institute for Materials Research and the theme school on Science, Technology and Public Policy. He is currently Adjunct Professor of Engineering Physics.

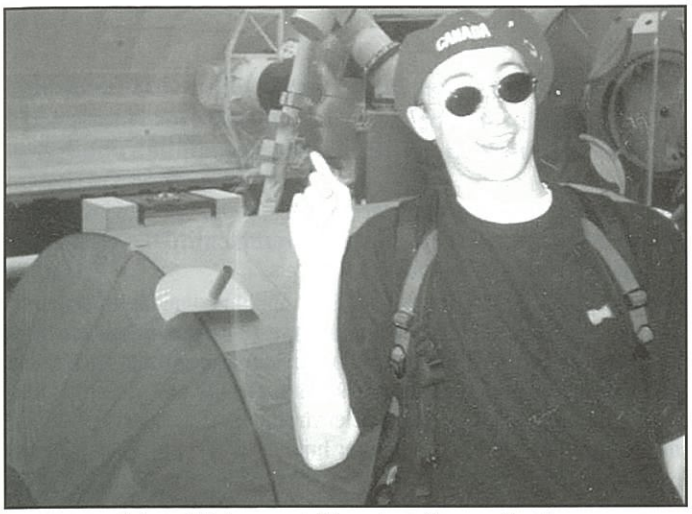
David is also involved with the new Universities Network of Excellence in Nuclear Engineering. Initiated by Ontario Power Generation Inc. UNENE is a consortium of utilities, industry, other major nuclear organizations and universities, which recently established five new Chairs of nuclear engineering at Ontario universities.

A few years ago David formed a consulting company, David P. Jackson and Associates Ltd., which designed, coordinated and wrote the successful proposal to the Canadian Foundation for Innovation to establish an Institute for Applied Radiation Sciences based on the McMaster Nuclear Reactor. Recently, the company partnered with PricewaterhouseCoopers LLP to do a major study of the Iter project for Natural Resources Canada.

Over his research career David has written some 80 journal publications, conference papers and reports. Last year he co-authored, with Hans Tammemagi, "Unlocking the Atom: the Canadian book on nuclear technology", soon to be published by McMaster University Press. He hopes that the book, written for the layperson, will not only enhance public understanding of nuclear subjects but also inspire more students to enter the nuclear field.

David has been active with the CNS for a number of years, initially with various committees such as: Education and Communications; Fusion; Branch; and Universities. In recent years he served, sequentially, as 2nd and 1st vice president, prior to being elected president at the Annual General Meeting in June 2001. He also serves as the CNS representative to the federal Partnership Group on Science and Engineering.

McLean in Texas



Adam McLean at Houston Space Centre.

Last spring Adam McLean the energetic (and young) chairman of the CNS Toronto Branch attended an international conference for students of nuclear science and technology held at Texas A & M University near Houston, Texas. Over 300 students from more than a dozen countries participated - Adam was the only Canadian. Following are some excerpts from a short note he sent to the CNS Bulletin some time ago but which was overlooked at the time of the last issue.

I was the only Canadian attending and proudly showed off my Roots Canada hat (same design as the Athletes wore at the last winter Olympics) every chance that I got. My trip and stay was kindly sponsored by Ontario Power Generation - as always, I greatly appreciate their support. My paper was the summary of my Master's work up to that point and an extension of my undergraduate paper presented at the 2000 CNS student conference, entitled "Modeling Transport of Methane and Its Derivatives in the Tokamak Edge-Effect Simulation Code DIVIMP". It was presented along with 30 other papers in the "Next Generation Technologies" track chaired by Dr. James Lake, then president of the ANS. For it, I won a first runner up award and a certificate for 'an outstanding presentation'. Also on the trip was a tour of the research reactor and the pulsed-fusion facility at TAMU, as well as a trip to the Houston Space Centre.

Attending this conference was a wonderful opportunity - to meet people in the industry, to learn about just how similar 'nuclear' is, not just in North America, but around the world, and also, to remind everyone that nuclear is alive and well in Canada! I encourage all students to take part locally - at the CNS student conference held every year - and to think globally. Understand the depth of the nuclear industry in other countries, but appreciate just how well our CANDU system stacks up against the competition.

The CNS at the Canada Wide Science Fair 2002!

www.usask.ca/cwsf

The Canadian Nuclear Society has for many years been involved in local school science fairs across the country, primarily through the involvement of Branches.

In 2002 the Society will be a sponsor for the Canada Wide Science Fair to be held on May 11th-19th in Saskatoon, Saskatchewan. This fair brings together winners of the many regional fairs across the country and will be a showcase for the scientific innovation and creativity of more than 400 of Canada's best and brightest youth. An additional 500 adult delegates, judges, VIPs and international students from around the world are expected.

The University of Saskatchewan in Saskatoon is the site of the 2002 fair to highlight construction of the Canadian Light Source (CLS) synchrotron being built there. As Canada's biggest science project in more than 30 years, this world class, football field sized "field of beams" will bring powerful ultraviolet, X-ray, and infra-red beams for use in pharmaceutical, biotechnology, electronic, advanced materials, and computing research. *For more information, see their web site at: www.cls.usask.ca.*

As a sponsor of the Canada Wide Science Fair, the CNS will send two representatives to attend the Awards Ceremony, viewing session and other delegates activities. Mr. Walter Keyes and Dr. Tony Harras, both of the Saskatchewan Branch, have accepted those positions. The CNS will also have an advertisement in the Fair handbook, and our logo on the CWSF web page and prominently posted in the science fair exhibit hall.

CNS members are most welcome to both view the projects and encouraged to volunteer to judge the event. The full schedule of events and volunteer signup can be found on the CWSF web site, or by emailing them at cwsf@usask.ca.

For more details and information, please see: www.usask.ca/cwsf or contact Adam McLean, CNS Education Committee member, at adam.mclean@utoronto.ca or 416-535-0616.

BOOK REVIEW

The Skeptical Environmentalist, Measuring the Real State of the World

By Bj¯rn Lomborg
Cambridge University Press
Original (Danish) 1998, Translated (English) 2001
ISBN 0 521 01068 3

Reviewed by Dan Meneley

The impression of Björn Lomborg as a careful and professional statistician comes to mind very early in this book. He obviously has reviewed a huge number of publications with a critical eye so as to move our understanding of the state of the world toward the truth. This book should become required reading for anyone preparing data for presentations leading to factual conclusions.

The main thesis of the book is that the world is not, in fact, going to the dogs but continues to improve steadily and, in some cases dramatically when compared with "the good old days". The "Litany" describing steady world decline and impending doom espoused by many environmentalists is found to be fallacious. This may not be a surprising result to professionals working in the field of nuclear energy but is a bit surprising when it comes from a former member of Greenpeace who includes himself firmly (page 32, under the heading 'Reality and Morality') into the environmental movement. It is refreshing to read of a member of this general grouping demanding that environmental discussions should be based on true facts. Also, Mr. Lomborg gives sound evidence that many in the movement exhibit a familiar human behaviour that he identifies as "environmental self-interest" when presenting their arguments. It is comforting to find that these folks are human after all.

Finally, Mr. Lomborg shows evidence of his own humanity, in his treatment of nuclear fission as a future energy source. In Part 6 of the book, under the heading 'The Real State of the World' he begins with the statement "Throughout this book I have tried to present all the facts, to give us a rounded feel of the real state of the world." And yet nuclear fission energy is discussed in only five paragraphs on one page, with text containing only five reference notes out of a total of 2930 in the whole book. This compared with about six whole pages devoted to renewable energy, with text containing about 65 reference notes.

Mr. Lomborg makes a hopeful statement in the conclusion of Chapter 11 on energy supply: "Second, we know that the available solar energy far exceeds our energy needs and it will probably be available at competitive prices within 50 years." He then fails to mention nuclear fission energy in his final paragraph of this Chapter, a paragraph dealing with energy options available in the long run. This indeed gives the reviewer a "rounded feel" for Mr. Lomborg's opinion of nuclear fission energy.

Despite this understandable flaw, this book offers a much-improved basis for rational discussion about future of our existence on the planet. It is recommended as a reference text for professionals working on all the various aspects of the nuclear energy enterprise.

Publications available

Reliability Programs for Nuclear Power Plants

This is a new regulatory document issued by the Canadian Nuclear Safety Commission as Regulatory Standard S-98.

It describes the reliability program the CNSC may require in connection with t alicence to construct or operate a nuclear power plant. It is available in English or French in electronic form on the CNSC website < www.nuclearsafety.gc.ca > or in hard copy from the CNSC.

Publications available

Trends in the Nuclear Fuel Cycle:

Economic, Environmental and Social Aspects
OECD Paris 2002 ISBN 92-64-19664-1 157 pages
US$33

This report gives an overview of potential and promising nuclear system developments aimed at meeting sustainability goals and responding to public concerns. As well as advanced water cooled reactors and high-temperature gas-cooled reactors the report considers possible future concepts suchas thorium-fuel cycle and molten salt reactors.

It is available from the OECD. Online ordering at their website www.oecd.org/publications

Publications available

Musings on the Nature of Things

by W. G. Morison

Former Ontario Hydro vice-president Bill Morison has written a 160 page text questioning some of the basic concepts of electromagnetism and proposing a "Universal Flux Theory" as a basis for unification of gravitational, magnetic, and electromagnetic forces.. To obtain a copy go to his website < www3.sympatico.ca.wmorison >

CANDU Owners Group

The members of the CANDU Owners Group Inc. would like to solicit expressions of interest from suitably qualified candidates for the position of President of the CANDU Owners Group Inc.

A brief description of the Position and Qualifications follows.

Application should be made in writing prior to January 31, 2002, addressed to:

John D. Sommerville
CANDU Owners Group Inc.
480 University Avenue
Suite 200
Toronto, Ontario
M5G 1V2

The POSITION

The CANDU Owners Group Inc. was formed in mid 1984 by the Canadian CANDU nuclear utilities and Atomic Energy of Canada Ltd. In 1999 the group was transformed into a separate incorporated not-for-profit entity, the CANDU Owners Group Inc., which has as members both on shore and off shore utilities owning & operating CANDU stations as well as AECL.

The broad mandate of COG Inc. is to provide a framework that will promote closer co-operation among the utilities owning and operating CANDU stations in matters relating to plant operation and maintenance and to foster co-operative development programs leading to improved plant performance. In particular, COG manages the industry joint R&D Program and the industry OPEX (Operational Experience) feedback Program.

COG Inc. is managed by a Board of Directors comprised of senior representatives of the Canadian member organizations. The member organizations are Ontario Power Generation, Atomic Energy of Canada Ltd., Hydro Quebec, New Brunswick Power Corporation and Bruce Power.

The President of COG reports to the Board of Directors and is responsible for the day to day administration and direction of the group as well as providing a long term vision for organizational initiatives consistent with COG's overall mandate.

The staff of COG comprises in the vicinity of 30 permanent positions and includes secondments from member organizations, contract staff and regular employees. Temporary staff positions may fluctuate significantly depending on the extent of project/program management being under-taken by the group.

The overall annual program budget is in the region of \$40M with a general operating budget of around \$5M.

The CANDIDATE

The candidate for President of the CANDU Owners Group Inc. will have had extensive exposure to the management, operation and maintenance aspects of CANDU nuclear facilities. Such exposure would ideally include some degree of familiarity with areas such as:

- Nuclear regulatory affairs
- Public and media relations
- Research and development issues
- Safety and licensing
- International co-operation in nuclear related issues

Above all, the candidate will have the business skills necessary to ensure that the CANDU Owners Group Inc. is operated according to sound business practices.

The ideal candidate must be able to develop and promote a vision for the CANDU Owners Group which will meet the changing and often disparate requirements of the members while enhancing the overall safety and economics of CANDU stations.

QUALIFICATIONS

The candidate will have a degree in science or engineering and ideally possess an advanced degree in business administration or have sufficient alternate business related experience at a senior management level.

Preference will be given to candidates who are not employees of any of the member organizations of the CANDU Owners Group, although such candidates will be considered assuming acceptable secondment terms can be negotiated.

REMUNERATION

The appointment will be a contract position with the CANDU Owners Group Inc. for a period of two years, renewable at the discretion of the Board of Directors. Salary and expenses will be negotiable.

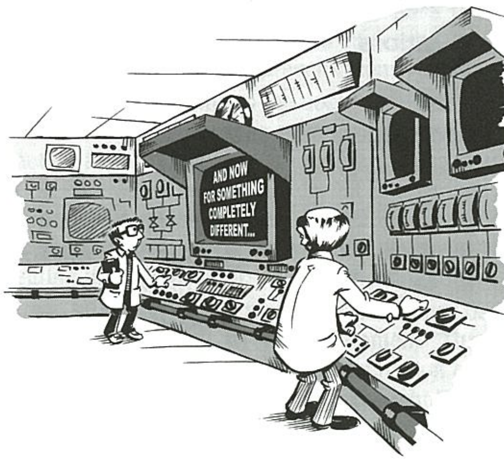
2002: Not Just Another Palindrome

by Jeremy Whitlock

As fate would have it, 2001 will probably not be remembered as the year of Clarke and Kubrick's Space Odyssey, nor for the 50th anniversary of first electricity from nuclear fission (EBR-1, Idaho, December 20, 1951).

Our minds occupied by a greater drama (Act II now underway, wherein we second-guess everything we do, say, and thought we understood), let us find comfort in the familiar: 2002, in the nick of time, comes rife with nuclear nostalgia.

To get the ball rolling on this banner year for topical anniversaries, the following compendium is offered (mostly factual):



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1.8 billion years ago - Natural reactor at Oklo goes critical for the first time (April 1, 2:18 am). Event witnessed only by anti-nuclear activists dressed as barrels of atomic waste.

500,000 years ago - Intelligent life evolves on Earth.

150 years ago - Henri Bequerel is born (December 15, 1852). Discoverer of radioactivity.

120 years ago - Hans Geiger is born (September 20, 1882). Without him Bequerel's discovery wouldn't have clicked.

100 years ago - Rutherford and Soddy observe and characterize nuclear decay (April 1902). Not to be confused with nuclear laboratory decay, observed and characterized eight decades later.

70 years ago - Chadwick discovers the neutron (February 17, 1932). Researchers begin systematically activating elements in search of interesting stuff - pinch themselves seven years later for not starting at the other end of the periodic table.

60 years ago - C.D. Howe launches Canada's nuclear programme with the stroke of a pen and now-legendary "OK, let's go", creating the NRC's Montreal Lab at McGill University (August 17, 1942).

60 years ago - Americans do it first (CP1, Chicago, December 2, 1942).

55 years ago - NRX research reactor goes critical for the first time (July 22, 1947, 6:13 am). Physicists too shy for photograph - take picture of blackboard.

50 years ago - AECL created (April 1, 1952), declares that the future is bright, and what could possibly go wrong now?

50 years ago - NRX accident, worst-to-date on record (December 12, 1952, 3:07 pm). Jimmy Carter makes famous visit as part of American naval assistance in clean-up. American navy embarrassed to learn that Chalk River is not a seaport.

50 years ago - U.S. explodes first H-bomb ("Mike", 10.4 MT, Enewetak Atoll, October 31, 1952).

45 years ago - World's first civilian nuclear power plant reaches full power for the first time (Shippingport, Pennsylvania, December 23, 1957)

45 years ago - Decision to halt work on Canada's first nuclear power plant, NPD, and switch to radical "NPD-2" design: horizontal pressure tubes, on-line refuelling, natural uranium fuel bundles. CANDU is born. (March 27, 1957)

45 years ago - NRU research reactor goes critical for first time (November 3, 1957, 6:10 am). Physicists agree to photograph, if they can leave their sandals on.

45 years ago - Windscale fire (U.K., October 10, 1957). "Wigner energy" earns prominent spot in future nuclear engineering textbooks.

40 years ago - First electricity from nuclear fission in Canada (NPD, Rolphton, Ont., June 4, 1962). Not the first time in the world, but certainly the niftiest. (First criticality: April 11; First full power: June 28)

35 years ago - First electricity from a full-scale CANDU plant (Douglas Point, June 7, 1967).

30 years ago - NRU calandria replacement: Canada makes core refurbishment look easy (shut down June 5, 1972; returned to service August 2, 1974). Old calandria cleaned up and turned into ashtray.

30 years ago - Gentilly-1 reaches full power for first time (May 13, 1972).

25 years ago - Gentilly-1 shut down for last time (June 1, 1977).

25 years ago - President Carter deems civilian plutonium too dangerous, bans reprocessing in the U.S. (April 7, 1977). No problem with military plutonium.

20 years ago - Point Lepreau reaches full power for the first time (December 18, 1982).

20 years ago - Wolsong-1 goes critical for first time (November 21, 1982). The Wolsong Dynasty begins.

20 years ago - World's first commercial nuclear plant, Shippingport, shuts down for last time (October 1, 1982). Eventually becomes world's first completely decommissioned nuclear power plant.

15 years ago - NPD shut down for last time (May 5, 1987). End of an era.

15 years ago - Wilfrid Bennett Lewis, "Father of CANDU", passes away (January 10, 1987). End of an era.

15 years ago - George Craig Laurence, Canada's first nuclear pioneer, passes away (November 6, 1987). End of an era.

5 years ago - Canada's first reactor, ZEEP, torn down to make way for new Maple isotope reactors (September 1997). End of an era.

So here's to 2002, and the start of new eras - of Maples, Pickering restarts, new-generation CANDUs, open electricity markets, Pt. Lepreau refurbishment, neutron holography, and maybe, if we're really lucky, a wee bit of fusion.

CALENDAR

2002

February 3 - 6 — **PIME 2002**
Prague,Dzech Republic
See Website:
www.ens-pime.org

February 18,19 — **CNA Nuclear Industry Winter Seminar**
Ottawa, Ontario
Contact: Lise Marshall
CNA Office
Tel: 613-237-4262
e-mail: marshalll@cna.ca

March 13 - 15 — **Globe 2002**
Vancouver, B.C.
See Website:
www.globe2002.com
e-mail: info@globe.apfnet.org

March 10 - 14 — **4th International Conference on Isotopes**
Cape Town, South Africa
Contact: 4ICI Conference Secretariat
Claremont, South Africa
Tel. +27-21-762-8600
e-mail: 4ici@globalconf.co.za
Web: www.globalconf.co.za

March 25 - 27 — **Food Irradiation 2002**
Dallas, Texas
See Website:
www.intertechusa.com/food
e-mail: bwilkie@intertechusa.com

April 14 - 18 — **ICONE-10 10th International Conference on Nuclear Engineering**
Arlington, Virginia
Contact: Dr. Jovica Riznic
CNSC
e-mail: riznicj@cnsc-ccsn.gc.ca
web: www.asme.org/icone10

April 16 - 20 — **International Youth Nuclear Congress**
Taejon, Korea
Contact: Han Seong Son
KAERI
e-mail: hsson@nanum.kaeri.re.kr
web: www.iync.org

May 5 - 8 — **4th CNS International Steam Generator Conference**
Toronto, Ontario
Contact: Robert Tapping
Tel: 613-584-8811 ext 3219
e-mail: tappingr@aecl.ca

May 14 - 16 — **Nuclear Technology 2002**
Stuttgart, Germany
e-mail: jk@inforum-gmbh.de

June 17 - 21 — **ANS Annual Meeting**
Hollywood, Florida
Contact: ANS
LaGrange Park, Illinois
Tel. 708-352-6611
e-mail: meetings@ans.org

June 2 - 5 — **23rd CNS Annual Conference**
Toronto, Ontario
Contact: CNS office
Toronto, Ontario
Tel. 416-977-7620
e-mail: cns-snc@on.aibn.com

July ?? — **Symposium on the Isolation of Radioactive Waste**
Toronto, Ontario
Contact: Judy Tamm
AECL - SP
Tel. 905-823-9060 ext. 4197
e-mail: tammj@aecl.ca

Aug. 4 - 8 — **Spectrum 2002**
Reno, Nevada
See Website:
www.ans.org/spectrum

Aug. 11 - 16 — **INAC 2002 International Nuclear Atlantic Conference and Exhibition**
Rio de Janiero, Brazil
e-mail: tdn@ten.com.br

Oct. 6 - 10 — **ANS International Topical Meeting on Probabilistic Safety Assessment**
Detroit, Michigan
See Website:
www.ners.engin.umich.edu/PSAConf

Oct. 7 - 9 — **ENC 2002 International Nuclear Congress and Exhibition**
Lille, France
See Website:
www.enc2002.org
e-mail: enc2002@to.aey.ch

Oct. 7 - 10

PHYSOR-2002: International Conference on the New Frontiers of Nuclear Technology - Reactor Physics, Safety and High-Performance Computing
Seoul, Korea
Contact: Prof. Nam Zin Cho
KAIST
Taejon, Korea
Tel. +82-42-869-3819
e-mail: tpc@physor2002.kaist.ac.kr

Oct. 21 - 25

PBNC 2002 - 13th Pacific Basin Nuclear Conference
Shenzhen, China
Contact: PBNC 2002 Secretariat
Fax: +86-10-6852-7188
e-mail: cns@cnnc.com.cn

?? (Fall)

Corrosion of Nuclear Reactor Core Components
Toronto, Ontario
Contact: CNS Office
Tel. 416-979-7620
e-mail: cns-snc@on.aibn.com

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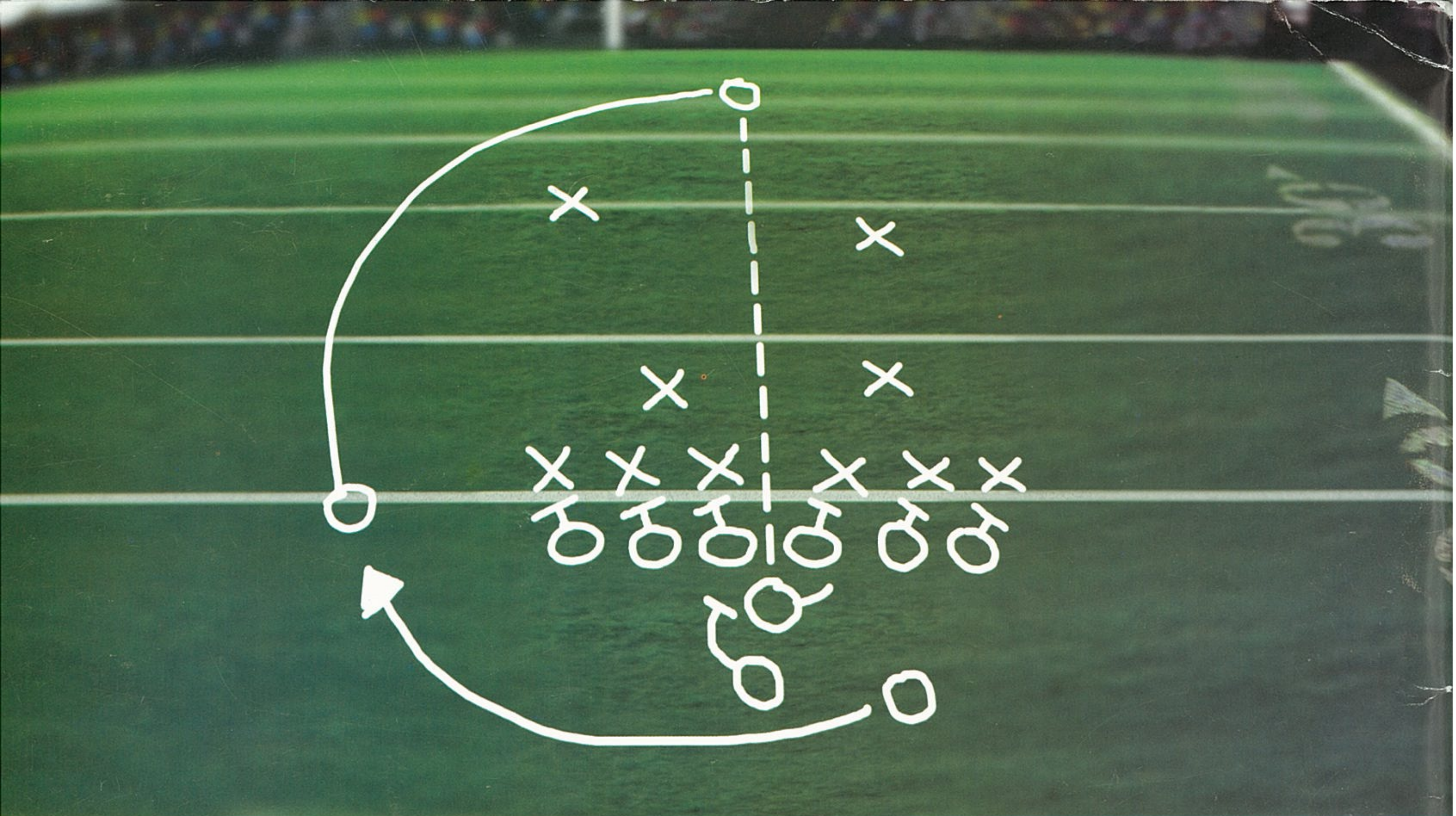

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