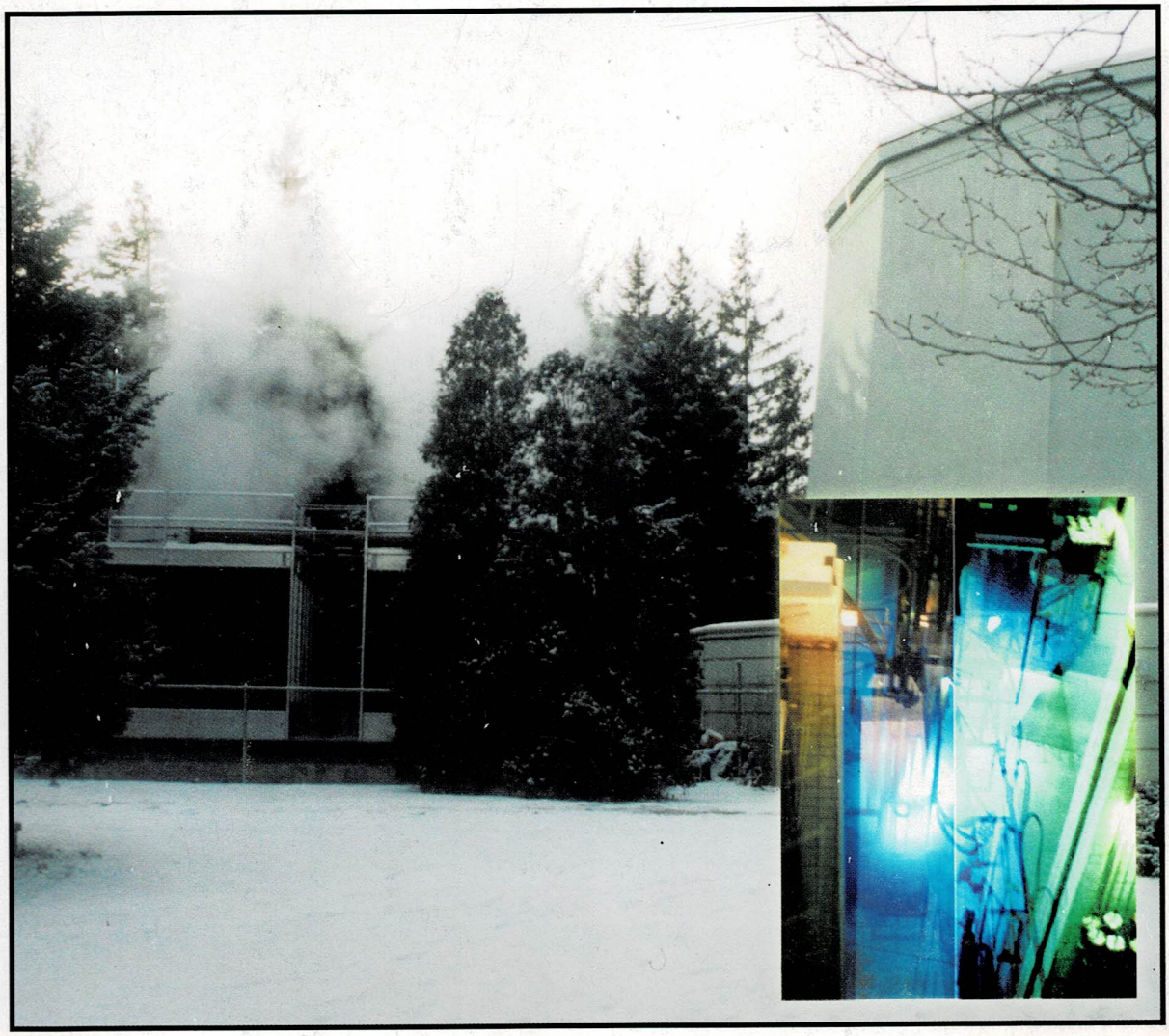
CANADIAN NUCLEAR SOCIETY

bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

January 2000 Janvier

Vol. 20, No. 4



- McMaster Reactor – new life at 40
- Reducing cost of CANDU
- Surveying at Chernobyl
- Climate Change & Energy Options – symposium report and summaries
- Airlie and COP5
- Harold Smith

Contents

Cover Illustration

The illustration on the cover shows a recent photograph of the McMaster Nuclear Reactor containment building with a view of the core, and its Cerenkov glow, superimposed.

CANADIAN NUCLEAR SOCIETY

bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

ISSN 0714-7074

The *Bulletin of the Canadian Nuclear Society* is published four times a year by:

The Canadian Nuclear Society
144 Front Street West, Suite 475,
Toronto, Ontario, Canada, M5J 2L7.
Telephone (416) 977-7620
Fax (416) 979-8356

Le Bulletin SNC *est l'organe d'information de la Société Nucléaire Canadienne.*

CNS provides Canadians interested in nuclear energy with a forum for technical discussion. For membership information, contact the CNS office, a member of the Council, or local branch executive.
Membership fee is $60.00 annually, $35.00 to retirees, $20.00 to students.

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

Editor / Rédacteur
Fred Boyd
Tel./Fax (613) 592-2256
e-mail: fboyd96@aol.com

Associate Editor / Rédacteur associé
Ric Fluke
Tel. (416) 592-4110
Fax (416) 592-4930

Printed by The Vincent Press Ltd., Peterborough, ON

EDITORIAL

The Positive and The Sad

A number of events or happenings associated with our nuclear program have occurred over the past couple of months that evoke reflection. The AECB approved continued operation of several facilities but also announced another cancer study around nuclear facilities. Given the minuscule doses even theoretically received from the very small releases from the various plants there appears to be little justification for such a study. The AECB claims there is "widespread public concern". It is highly likely that these new studies will increase public concerns not allay them, as suggested by AECB staff.

The MOX affair ended up almost comical but, unfortunately, the issue has not gone away and will undoubtedly resurface with a vengeance when Russian MOX is brought in. Ironically, although this program is being pursued in the interest of international disarmament, the public relations burden has fallen on AECL instead of the Department of Foreign Affairs and International Trade. Like many in the industry we feel that DFAIT should either strongly and publicly support the program or forget it.

The changes at OPG are intriguing. Whether or not they lead to improvements in the rate of recovery of its nuclear plants or in the morale of OPG staff (an underlying and serious problem) remains to be seen.

However, the two things that stuck us most in putting this issue of the *CNS Bulletin* together were: (1) the amazingly successful Symposium on *Climate Change and Energy Options,* and, (2), sadly, the number of obituaries we report.

The Climate Change symposium achieved what had been considered almost unthinkable. It brought together, in one room, at one table, senior representatives of almost all of the energy forms that we have in this country. And, they talked to each other, they recognized the need for all energy sources and forms, they observed that there is potential synergy, and, they agreed to continue to talk together. A significant achievement.

The other factor, the large number of obituaries in this issue, brings starkly into focus that we in the nuclear program are an ageing population. We have commented before on this problem but more in abstract. These many deaths of nuclear pioneers highlight the situation. Yet, little is being done. The major organizations in the country that are involved in nuclear activities appear unwilling to provide any meaningful help for initiatives to encourage young people to consider a career in nuclear science or technology. This, in our view, is very short sighted. Assuming the nuclear program does not die an unnatural death (through political or other means) it may well die a natural death lacking any rejuvenation. We urge any readers in a position to influence decisions to consider assisting university programs, courses for science teachers, science fairs, special programs such as the Deep River Science Academy, or whatever activities might bring young people into the program and ensure its continuation.

IN THIS ISSUE

The bulk of this issue is drawn from the excellent ***Climate Change and Energy Options Symposium*** held in November 1999, with an **Overview,** extensive **Session summaries,** and two reprinted papers, one on **Using the Clean Development Mechanism** and the other on **Reducing the Cost of CANDU.** The last fits into the "climate change" debate because, in our market driven world, the cost of nuclear must be decreased if it is to contribute, as it should and can, to the curtailment of greenhouse gas emissions.

A **"Letter"** from John Beare, formerly of the AECB, offers some stinging comments on the federal government's radioactive waste policies.

Our "cover story", **Life begins (again) at 40 for McMaster reactor,** is a happy account of a resurrection brought about by some dedicated people who had a vision. We are pleased to add this note on the McMaster Nuclear Reactor to our series on organizations associated with the Canadian nuclear program.

There are three, first hand, accounts of important gatherings of the past few months. **COP5 - a personal view** provides not only information on this fifth "conference of parties" under the UN Framework Convention on Climate Change but also some insight into the enthusiastic efforts of the younger members of our nuclear community to ensure nuclear is within the "climate change" agenda. **Bridging radiation policy and science,** is a report by Norm Gentner on a closed meeting held to try to resolve the controversy between the observed minuscule effects of low doses of ionizing radiation and the view of ICRP and national regulatory agencies. Finally, **Chernobyl 4 - post accident radiation monitoring in the exclusion zone** provides information on radiation surveillance techniques as well as some personal observations of Chernobyl.

A short paper, originally prepared for a Chinese audience, is reprinted to give an overview of the **Qinshan III CANDU nuclear power plant.**

There is the usual modest section on **General News** with items you may not have picked up elsewhere, and, sadly, several **Obituaries,** including a relatively long note on **Harold Smith,** the engineer that led Ontario Hydro into the nuclear power game.

The section on **CNS News** is longer than usual, reflecting the active nature of your Society.

Finally, there are some reviews of books and reports and the second of Jeremy Whitlock's **Endpoint** dissertations, accompanied by a cartoon by his cousin Lorne Whitlock.

As always we thank our contributors and invite your comments.

LETTER TO THE EDITOR

Waste policy"hypocritical"

Ed. Note: *John Beare, the author of the following letter, was a former director-general at the Atomic Energy Control Board. Over the years his responsibilities included the licensing of radioactive waste facilities. John is now living outside of Ottawa and has his own consulting company. His letter has been edited slightly to meet the space available.*

When I read the article [Nuclear Fuel Waste Policy in Canada] in Vol. 20, No 3 of the Bulletin, I laughed; then I cried. I do not slight the authors of the article. They were simply reporting on the federal government's policy. My emotional reaction was triggered by the federal policy statement, itself.

My assessment of the federal government's policy regarding radioactive waste disposal can be summed up by the words: "pompous, pretentious, hypocritical, redundant, ambiguous and unnecessary" — no more than what we in the Atomic Energy Control Board (when I worked there) called "pious platitudes".

To avoid readers having to dig out their copies of the aforementioned CNS Bulletin I list below the major elements of the policy statement contained in the paper:

1) *The federal government will ensure that radioactive waste disposal is carried out in a safe, environmentally sound, comprehensive, cost-effective and integrated manner;*
2) *The federal government has the responsibility to develop policy, regulate, and to oversee waste producers and owners for ensuring that they comply with legal requirements and meet their funding and operational responsibilities;*
3) *The waste producers and owners are responsible for the funding, organization, management and operation of disposal and for other facilities for their wastes.*

The Policy Framework for Radioactive Wastes covers "... all forms of radioactive waste including nuclear fuel waste, low-level radioactive waste and uranium mine and mill waste."

My first, and least, problem with the policy statement regards its coverage. I am sure that the policy statement does not cover relatively "short-lived" radioactive wastes which are stored for a relatively short period until they decay and become innocuous and then may be discharged to the environment (often a sewer). I also assume that the policy statement does not refer to small sources of long-lived radioactive material, such as in smoke detectors, which may be disposed of without any control whatsoever. Disposal of such sources has been going on for decades and needs no policy statement.

I assume that the policy statement is really directed at large quantities of long-lived radioactive materials. For the purpose of my letter it is not important to define "large" and "long-lived".

I agree, unreservedly, with policy item (3), above. This is the basic tenet for controlling nuclear wastes in Canada.

With respect to policy item (2) above, it seems there is some confusion. Existing legal requirements apply before policy. It is, therefore redundant to state, as a matter of policy, that *"waste producers and owners comply with legal requirements and meet their funding and operational responsibilities"*. What is meant by, "funding and operational responsibilities" that is not included in "legal requirements" is not clear.

What is really ambiguous about (2) is the statement that the federal government *" ... has the responsibility to develop policy ... and to oversee waste producers ...".* Nothing in the current Atomic Energy Control Act (AEC Act) or the soon-to-be-proclaimed Nuclear Safety and Control Act (NSC Act) relates to "policy" development or an "oversee" function. The question arises whether the federal government is contemplating new legislative initiatives to "occupy" these roles.

The major issue is whether the federal government has any legitimacy in policy issues relating to disposal of significant quantities of long-lived radioactive waste. While it might appear nice if the federal government were to assume a leadership role in the disposal of long-lived radioactive wastes, we should review the federal government's performance regarding the substantial volume of long-lived, low level wastes in and around Port Hope. Here is a brief review.

In 1980, after much dithering on its own part, the AECB ordered Eldorado Mining and Refining [the owner of the uranium refinery], then a Crown Corporation, to find a way of disposing of uranium refinery wastes which had accumulated over the decades and had been placed in trenches relatively close to the shores of Lake Ontario. A few hundred thousand cubic metres of material were involved.

By 1986 Eldorado started public consultations on various alternative methods and sites. Because of the resulting public controversy the federal government stepped in and took over the responsibility for finding a site. A siting task force was formed, under the auspices of the Minister of Energy Mines and Resources, which used an approach based on obtaining cooperation from communities in exchange for social and economic benefits which could be negotiated. Ten years later the number of interested communities and candidate sites had diminished to one, a site on AECL property which is part of Deep River. In return Deep River wanted federal government guarantees on jobs at the Chalk River Laboratories. This the federal government refused so even that opportunity was lost.

Far from being part of the solution, the federal government became part of the problem.

Unlike the current AEC Act the NSC Act is binding on both the

federal and provincial Crown. The AEC Act, NSC Act and the Environmental Assessment Act collectively already provide for protection of health, safety, security and the environment and public consultations. Adequate and secure long-term funding for waste disposal is implicit in protecting health, safety, security and the environment, and is specifically addressed in the NSC Act.

If we remove from the federal policy statement all those elements already covered by statute law we are left with:

1) *The federal government will ensure that radioactive waste disposal is carried out in a ... comprehensive, cost-effective and integrated manner*

Well, "comprehensive, cost-effective and integrated" may make good sense to the owners of irradiated nuclear fuel, but frankly, whether [or not] those owners want to collaborate with each other is none of the federal government's business. The policy statement — what's left of it — implies that the federal government will play some sort of high level role in the management (overseeing?) of waste disposal. I doubt the owners of the wastes would agree.

The statement definitely makes no sense when applied to uranium mine tailings. It is certainly hypocritical when one recalls that much of the historical uranium mine waste, as well as the uranium refinery wastes that require remedial action belong to the federal government, and nothing, or next to nothing, is being done about those wastes. Also, does the federal government intend to take over from the Province of Ontario responsibility for the Madawaska uranium mine wastes? These wastes were "de-licensed" by the AECB about ten years ago and responsibility for managing the wastes was dumped onto Ontario's lap.

My conclusion is that the federal government no longer has any policy role in the disposal of radioactive wastes. It has, so-to-speak, written itself out of the equation.

And now for a "modest proposal", with apologies to Jonathan Swift.

When the NSC Act goes into effect, the CNSC should place a legal obligation on the licensees who are owners of irradiated nuclear fuel to develop and implement a program for the disposal of nuclear fuel wastes. The CNSC could do this through a condition of licence in those facilities that produce the irradiated fuel or it could make a regulation. The establishment of such a legal requirement is needed to show the public that the CNSC is serious about its mission: to ensure that the use of nuclear energy in Canada does not pose undue risk to health, safety, security and the environment. This mission applies to future generations as well as to the current one.

Part of the regulation or licence condition should be that continued production of irradiated nuclear fuel, that is, continued operation of a reactor, should be conditional on progress, satisfactory to the CNSC, in the development and implementation of the disposal program.

In truth, there is nothing to stop the AECB from making such a regulation now. However, trying to develop such a regulation now could seriously affect the already delayed completion of the NSC Regulations and coming into force of the NSC Act.

A key part of this proposal for a regulation or licence condition is that it refers to a program. A program would be expected to contain elements such as: R&D; site selection; public consultation; funding; construction and operation of the facility; compliance with international safeguards; closure; and, post-closure monitoring. Since development of later phases of a program would depend on the results from earlier phases the program would have to evolve over time.

Since the rate of progress in implementing a program will depend on some factors outside the control of the licensee (for example, review under the Environmental Assessment Act, the course of public consultations) the CNSC should take these factors into account when deciding whether the licensee is making satisfactory progress.

The meaning of "disposal" would not be limited to physical disposal as currently defined by the AECB. Disposal by transfer to another party willing to accept it would be included. In principle, disposal could include transferring the irradiated fuel to a foreign party for reprocessing. If the irradiated fuel is disposed of by transfer to another party in Canada, such as a consortium established by the utilities or by government, that party would, of course, have to have its own disposal program.

The regulation would not specify the means of physical disposal. A licensee would be free to choose a method other than [the] geological concept [developed by Atomic Energy of Canada Limited].

If a licensee were to dispose of its irradiated fuel by transferring it to another party, the producer (the licensee with the reactor) would still be held responsible for ensuring that the other party makes satisfactory progress. A key aspect of this proposed regulation or condition of licence is the linkage between continued production of irradiated fuel and satisfactory progress in developing and implementing a program.

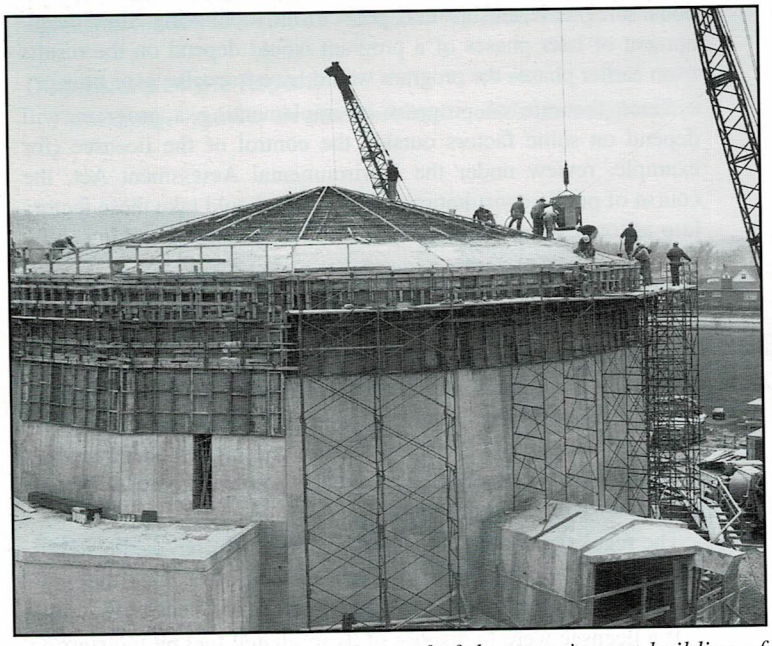
The establishment of the proposed legal obligation would put the responsibility for disposal where it belongs, on the producer of the irradiated fuel. Also, a legal requirement would prevent licensees from having a change of heart by lowering their priority for implementing their disposal programs. As a side benefit, the public might begin to see that authorities are taking effective action to deal with the issue of disposal of nuclear fuel wastes. It might help to squelch one of those "memes" to which Jeremy Whitlock refers in *"When Memes Collide"*.

John W. Beare
Woodlawn, Ontario
email: jwb@igs.net

~ Correction ~

Printed along with the paper *Nuclear Fuel Waste Policy in Canada* in the last issue of the *CNS Bulletin,* Vol. 20, No. 3, there was an illustration of the Underground Research Laboratory near AECL's Whiteshell Laboratory in Manitoba. This was NOT part of the paper and was totally inappropriate. Our apologies to the authors of the above paper.

Life begins (again) at 40 for McMaster Nuclear Reactor
– MNR has new mandate as part of new Institute



Workmen are shown finishing the roof of the containment building of the McMaster Nuclear Reactor in this photograph taken in May 1958. Photo courtesy of McMaster University

Ed. Note: This report in our continuing series on organizations in the Canadian nuclear scene came about serendipitously. In December 1999, Jeremy Whitlock, an active member of the Council of the Canadian Nuclear Society and an alumnus of McMaster University, commented on the new cooling towers at the McMaster reactor and suggested a photograph in the Bulletin. On finally following up this lead we were pleasantly surprised to learn of some very recent developments involving the reactor, which are the subject of the following article. We wish to thank Elise Herzig and Frank Saunders for the time they spent with us and for the very helpful material they provided (from which we have borrowed extensively).

Does life begin again at 40, as the saying goes? It would seem so for the McMaster Nuclear Reactor. Just past its 40th birthday, MNR, the first university reactor in the British Commonwealth when it started up in 1959, is entering a new and exciting life as an integral facility of the new Institute of Applied Radiation Sciences at McMaster University in Hamilton, Ontario.

The creation of the new Institute was officially ratified by McMaster's Senate in early January 2000. It will comprise a diverse range of faculty disciplines together with industrial and international collaborators, making use of MNR and associated facilities such as accelerators and radiation laboratories. An initial focus of the Institute will be upgrading and extending the existing facilities, acquiring new specialized equipment and upgrading MNR. Reactor projects will include a new reactor control system and a new beryllium reflector which will almost double the thermal flux of the reactor.

All of this has been made possible by a grant of $3.2 million from the new federal Canadian Foundation for Innovation and matching grants from the Province of Ontario. In addition there have been substantial industrial contributions and strong commitment from the University.

Formation of the Institute

The story of renewal began in mid 1996. After some uncertain years and termination of the annual grants from the Natural Sciences and Engineering Research Council of Canada (NSERC) the University had, in 1995 decided to shut down the reactor. This sparked an outcry from reactor users who did not want to see the demise of the facility. Over a nine month period, the University was in discussions with various outside groups who expressed an interest in taking over the management of the reactor. From these discussions, the University developed a business plan to expand the commercial operations of the reactor to meet the financial and academic objectives of the University and outside users' needs. Based on this business plan, in June 1996 the governing bodies of the University reversed the earlier decision to decommission the reactor.

An essential element in the business plan was increased production of Iodine 125 which has begun widespread use in the form of seed implants for the treatment of prostrate cancer. Elize Herzig, who had been involved in the business planning process joined the University as director, commercial operations of MNR, to help in the implementation of the turnaround strategy. Frank Saunders, director of nuclear operations and facilities, is in charge of operations of MNR and its

refurbishment..Prior to joining McMaster Frank had many years of experience in nuclear plant operation with the former Ontario Hydro Nuclear. Frank played a key role in the development of the business plan.

Recognizing that security of supply of the I 125 was essential to obtain and maintain market share, MNR negotiated a licence agreement with Studsvik Nuclear in Sweden involving the technology transfer of McMaster's patented I 125 manufacturing process. Now, as the second largest global supplier of I 125 in the world, MNR can offer two dedicated facilities for its production, thereby positioning MNR to become the world leader in I 125 production. This combined effort will come fully into effect in the spring of 2000.

The new Institute is headed by Dr. David Chettle, who is also director of McMaster's medical physics program. He is an expert in the study of trace toxic elements in the human body, such as cadmium and lead, that have been linked to health problems. The Institute will have a modest staff plus cooperative arrangements with researchers in many disciplines throughout the University.

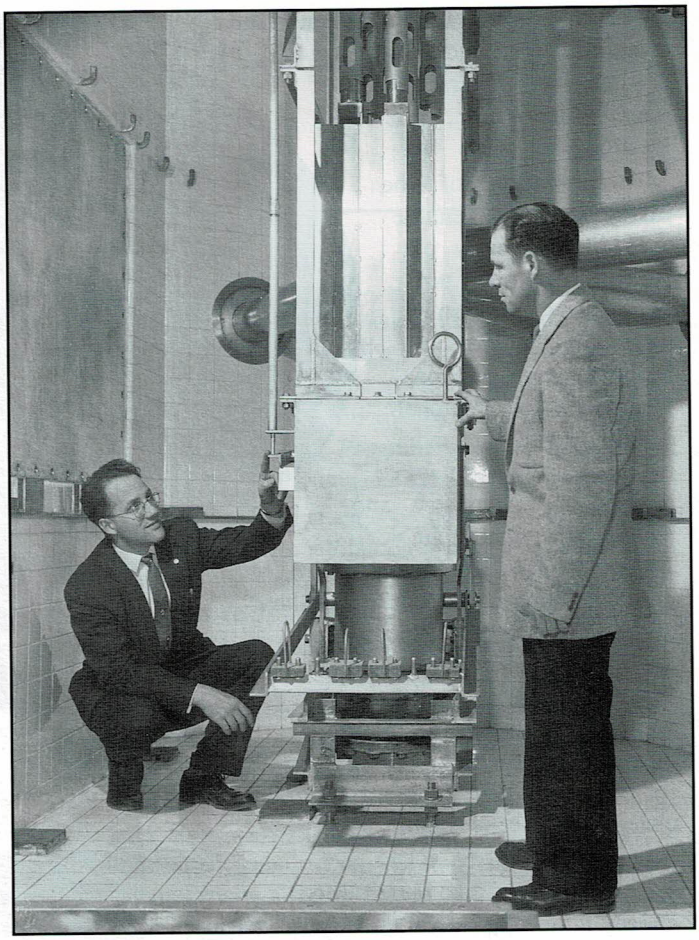
History

The MNR began operating in 1959. At that time it was the first university research reactor in the British Commonwealth. It is a pool type reactor with a core of plate type fuel employing aluminum clad enriched uranium, designed to operate at powers up to 5 megawatts thermal. The heat generated is dissipated through two new cooling towers.

The startup of MNR on April 4, 1959 was the culmination of several years of planning and negotiating and 10 years of construction. In the early 1950s McMaster University, through the leadership of Dr. Harry Thode, then director of research for the University, established the first university radioisotope laboratory in Canada. Thode had been associated with the Montreal Laboratory and early Chalk River Laboratory during World War II and immediately afterwards, primarily in research on fission products. In an unusual arrangement for the time, he conducted most of his research at McMaster which then had the only mass spectrometer in the country. His work included an accurate measurement of the yield of Xenon 135, a very important isotope for the operation of nuclear reactors because of its large neutron capture cross section.

In the mid 1950s Thode pushed for a research reactor at McMaster to be the central component of a nuclear science centre. His efforts were rewarded with grants totaling $2 million, half from the National Research Council (NRC) and half from local industries. The reactor type chosen was a 5 megawatt (thermal) pool type designed by the firm AMF in the USA. Among those very much involved with the building and early operation of the reactor were: Dr. Bill Fleming, professor of nuclear engineering; Dr. Dick Tomlinson, professor of nuclear chemistry (and still a professor emeritus at McMaster) and John McDougall, the first chief supervisor of the reactor. (Thode was vice-president of McMaster when the reactor began operation in 1959 and subsequently became president.)

A program is underway to gradually replace the high enriched



Bill Fleming (L) and John McDougall are shown examining the core structure of the McMaster Nuclear Reactor in early 1959 before the reactor started.
Photograph courtesy of McMaster University.

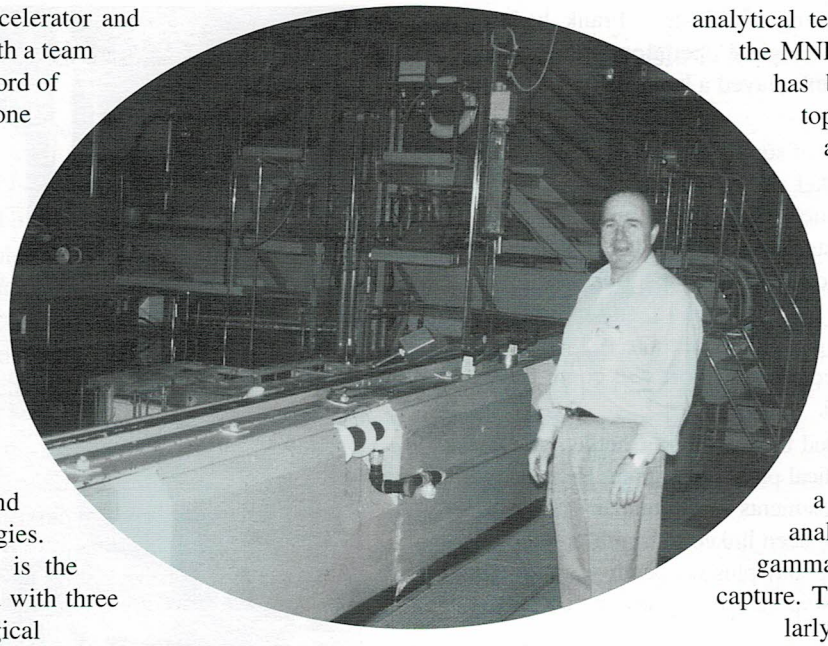
fuel (> 90% U 235) to low enriched (< 20%) to comply with international agreements. This has required considerable reactor physics and engineering analyses which have been led by Dr. Bill Garland, professor of nuclear engineering (and member of the CNS Council). These support analyses, which includes the revision of the safety report and other operating and regulatory requirements, has provided an excellent education and research environment for students, professors and industrial partners. Industry standard computer codes are being used in an educational setting and students conduct their experiments in an operating facility. The nuclear engineering program offered by the Department of Engineering Physics relies on the reactor in its research and laboratory components. Recently, the program has been extended with its offering of the Nuclear Technology Diploma.

MNR and the new Institute

The mandate of the new Institute of Applied Radiation Sciences is to promote the use of radiation to address scientific, industrial and medical concerns. McMaster will be the only place in Canada with highly specialized radiation research facil-

ities such as the reactor, accelerator and cyclotron, in conjunction with a team of scientists with a track record of scientific innovation, all in one location.

The creation of the Institute will enable McMaster to carry out sixteen research programs, new and established, in the areas of health sciences, environmental and occupational health, geophysics, radiation metrology, neutron physics and chemistry, and nuclear analytical technologies. As an example, McMaster is the only institution in the world with three of the leading geochronological methods for paleolithic archeology and dating of fault zones, namely: mass-spectrometric uranium series dating; electron spin resonance dating; thermally-stimulated and optically-stimulated luminescence dating.

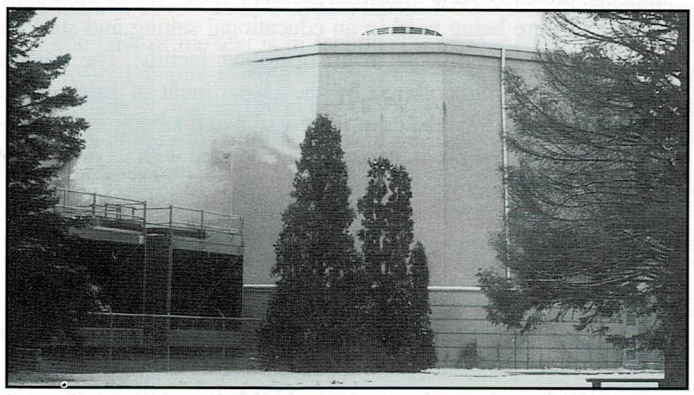


Frank Saunders, director of the McMaster Nuclear Reactor, is shown beside the reactor pool structure.

The MNR will be a key part of the business plan for the Institute and in this regard MNR's management team has already turned the reactor into a viable business entity. Building on that successful track record the Institute will be able to "jump start" into future opportunities.

MNR has provided analyses for industrial applications throughout its life and this capability will be expanded with the new Institute. An important technique that makes use of MNR is neutron radiography which allows for non-destructive testing of materials and mechanical components. As distinct from gamma or X-ray radiography, neutron radiography can distinguish between materials of similar density. It has been used extensively for testing of turbine blades, various aircraft components, explosive charges, and detecting the presence of lubrication films inside gear boxes and bearings.

Neutron activation analysis (NAA) is another widely used analytical technique that makes use of the MNR. The greatest use of NAA has been with short-lived isotopes. The relatively high flux available in MNR permits quick analysis for many elements, such as aluminum, calcium, chlorine, iodine, potassium, manganese, sodium, titanium and vanadium. The process is semi-automated and computer controlled, with the analysis data delivered directly to a PC based system. Some analyses make use of prompt gammas emitted during neutron capture. This phenomenon is particularly useful for the analysis of boron, cadmium, and the rare earths.



A recent view of the MNR containment building and new cooling towers (at left).

As befits a university, the principal objectives of the Institute are: to attract and retain outstanding scientists, young as well as established; to perform world-class research; to deliver excellent educational programs; and, to serve the research and training needs of industry. There will be extensive overlap between the research agenda of the Institute and existing academic programs at both undergraduate and graduate levels which is anticipated to provide synergy between research and teaching. Faculty involved in the Institute will be, for the most part, engaged in teaching in the medical physics and radiation science programs. Additional faculty for the Institute are anticipated and there is the possibility of an endowed chair. Expanded training of medical physicists will help overcome the shortage in that profession in Canada. The MSc program in health and radiation physics is the only specific health physics graduate program in Canada. The sister program of medical physics offers training at both the MSc and PhD levels. Graduate diploma programs have recently been established.

To quote the expert review committee for the Canadian Foundation for Innovation in its report recommending the funding of McMaster's Institute of Applied Radiation Sciences:

> *The Institute will facilitate access in a central location to a unique combination of personnel, tools and techniques, where new technologies can be developed in partnerships between researchers, practitioners and industry. This will be an outstanding installation.*

Postscript

For anyone interested in the continued viability of a broad Canadian nuclear program, it is encouraging to see this renewed life for the McMaster Nuclear Reactor as part of McMaster University's broadly based new Institute of Applied Radiation Sciences.

Climate Change and Energy Options
– a beginning of dialogue

by Fred Boyd

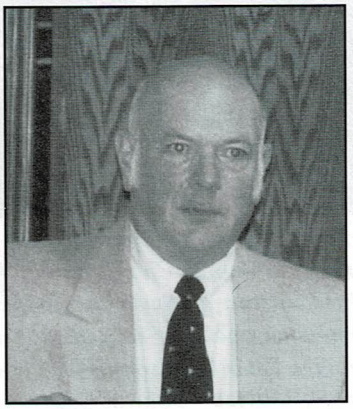
Preamble: In November 1999, the Canadian Nuclear Society presented a remarkable symposium on the subject of Climate Change and Energy Options. Remarkable because the organizers, through great effort and persuasion, assembled advocates of almost all of the various energy forms being used or promoted in this country at one meeting. More remarkable, there evolved positive communication and mutual understanding, in place of previous sniping, and agreement to continue the dialogue.

The CNS sponsored Symposium on Climate Change and Energy Options was held in Ottawa November 17 to 19, 1999. The objective of the Symposium was to provide information on various energy systems that will assist in meeting commitments to the Kyoto protocol. (Readers will recall that at the meeting held in Kyoto, Japan in December 1998 on the issue of climate change, nations committed to reduce their emissions of "greenhouse gases" (GHG) that are considered to be contributing to global warming. Canada's commitment was to reduce its emissions of GHG by 6 percent relative to 1990 levels by the period 2008 to 2012.)

The Symposium, which brought together at one forum representatives of almost all of the various existing or proposed energy systems, was organized into four sessions:

- Climate change and energy demand / supply
- Energy without greenhouse gas emissions: the potential
- Development of energy options
- Environmental and economic aspects of energy technologies.

Ralph Goodale, Minister of Natural Resources opened the symposium with a speech which outlined the problem and described a number of the federal government's initiatives, such as the $150 million Climate Change Action Fund. The lion's share of that fund, he said, is going toward developing and deploying "climate friendly" technologies. He noted that overall the federal government is investing about $260 million annually into energy research and development and specifically mentioned three programs administered by his department: the Renewable Energy Deployment Initiative, the Renewable Energy Technologies Program and the Program of Energy Research and Development.



David Sanborn

Duane Pendergast

David Torgerson

On the question of nuclear power Goodale noted the contribution nuclear power had made to the Canadian economy in the past. For the future he commented that "Canada's nuclear industry will need to show it has the smarts to compete". "Government and industry need to demonstrate to Canadians that nuclear power is safe", he added. "Canadians need convincing", he said, " that the [nuclear] technology is sound, the track record is strong and clean, the regulatory system is impeccable, and the industry is responsible and transparent. Without that conviction, meeting a global challenge like climate change will be a whole lot tougher."

Each of the four sessions was chaired by someone knowledgeable in the subject matter and contained a number of papers by experts from various energy fields. (A detailed summary follows this overview.)

Following opening remarks by Symposium chairman, **Duane Pendergast,** the first paper was by **Ian McGregor,** deputy head of the federal Climate Change Secretariat, who summarized the work of that group and the many "tables" that brought together people from various areas of industry, government and academia. He was followed by two speakers representing the oil industry, **Jack Zagar,** a consultant from Colorado, and **Robert Lyman,** senior director Oil Division, Natural Resources Canada.

The second session opened with a broad look at energy supply in the coming century by **Romney Duffey,** principal scientist with AECL. He was followed by speakers from Transalta Corporation in Alberta, from the Canadian Wind Energy Association and the Canadian Hydropower Association and two consultants in "sustainable" energy.

The third session continued this diversity with speakers from: the Canadian Petroleum Products Institute, Stuart Energy Systems Inc. (a firm

looking at various alternative energy systems), the Coal Association of Canada, and AECL (The paper by **David Torgerson** of AECL on *Reducing the Cost of CANDU* is reprinted elsewhere in this issue.).

The last session (on environmental and economic aspects) began with a paper by **Helen Howes,** the recently appointed director of environmental affairs at Ontario Power Generation. She commented that OPG remained committed to the target set by Ontario Hydro to stabilize their greenhouse gas emissions at 1990 levels by the year 2000. She noted that Ontario Hydro's GHG emissions declined from 36 million tonnes CO2 in 1984 to 15.5 million tonnes in 1995 due largely to the startup of Darlington NGS. However, by the fall of 1999 OPG fossil generation had increased to 40 TWH, producing 36 million tonnes of CO2 annually. "If Canada did not have nuclear generation there is no way our country would achieve the carbon dioxide reduction target set in Kyoto", she stated.

National Resources Minister Ralph Goodale, (L), the opening speaker at the "Climate Change and Energy Options Symposium" held in Ottawa, November 17-19, 2000, poses with symposium committee member Kris Mohan (C) and NRCan deputy minister, Dr. Peter Harrison (R).
Photo courtesy of Colivrette/Ottawa

Other speakers in the closing session included **Chris Green,** head of the department of economics at McGill University and **Tom Tisue** of the International Atomic Energy Agency. (Tisue's paper is reprinted elsewhere in this issue of the *CNS Bulletin*). The Symposium closed with an extended discussion period in which several people thanked the organizers and urged the continuation of the dialogue that had been begun in this meeting.

At the opening reception on the evening of November 17, **Bob MacDonald,** host of CBC radio's science show, "Quirks and Quarks", gave an entertaining and informative insight into the challenge of communicating science.

The special speaker at the Symposium dinner on the evening of the first full day was **Doug McRoberts** from British Energy who gave an amusing but insightful account of BE's experience with deregulated (commercially) nuclear power in the UK. Good communications (with all stake holders) is definitely needed, he stated, but to be commercially successful it is essential to maintain a very high level of safety, to be open, to pursue professional integrity, and, to make a profit.

Speaking at the luncheon on the second day, **David Sanborn Scott,** director, energy systems, of the Institute for Integrated Energy Systems at the University of Victoria, emphasized the potential synergy between the various energy forms and systems. This view was picked up in the closing discussions with many delegates suggesting continuing the communication that had been opened with this Symposium.

After the close of Session 4, **Dan Meneley,** recently returned to AECL Sheridan Park after three years in China, presented a masterful "reflection" on the symposium, with the aid of overheads he had prepared on the spot with his trusty laptop.

It was "like drinking water from a fire hose - much information, hard to get a balanced view", he observed. Canada is a favoured nature, he commented, but our well-being depends much on others, therefore we should give priority to international matters.

Turning to the various sessions he commented that, "meeting the Kyoto protocol is only the start of the adaption required for our grandchildren - they will face a much larger problem." "We have successfully avoided discussing the central problem - too many humans", he added.

On "GHG-free" energy, he observed that a [technical] capability exists to meet the challenge by using nuclear, but, as he noted earlier, people are afraid of technology. After noting that sequestration of CO2 appears feasible and that there are potential contributions from biomass, solar, wind, and hydropower, he suggested that all options can make a contribution. There is not much time for reflection on energy options, he commented, action is needed. "Where is the "market" mechanism now that we need it.", he asked. Nuclear power saves CO2 but we have lost the public's trust. New non-carbon sources of energy must be developed, he said.

In closing Meneley stated that it had been a very productive meeting. "Let us get on with some work" he urged, and closed by asking, "How can we stay in touch?"

The Symposium was organized by an energetic, determined and hard working committee chaired by Duane Pendergast, of AECL Sheridan Park. Other members included Corneliu Manu, Kris Mohan, Rayman Sollychin, Ben Rouben, Anca McGee, and Gillian Hurley. Sylvie Caron of the CNA/CNS office handled registration and Karthik Ramaswamy, Renée Trottier and Jeremey Whitlock developed the special Web site (which can be accessed through the CNS site) for the Symposium. The organizing committee was supported by a technical advisory committee with international membership.

Co-sponsors of the Symposium were: 3-L Filters, AECL, BC Instruments, Canatom, COGEMA, Canadian Petroleum Products Institute, Dresser Industries, ES Fox, Grinnell, Natural Resources Canada, Nu-Tech, OCI, Ontario Power Generation, Sulzer Pumps, Tirino Northern, Velan Valves.

Proceedings of the symposium, containing most of the papers, are available from the CNS office.

Postscript: It is understood that serious discussions are proceeding towards a further gathering similar to this ground-breaking one. We hope to be able to report on the progress towards such a needed on-going forum in the next issue of the CNS Bulletin.

Symposium on
Climate Change and Energy Options

Summaries of the sessions

Ed. Note: *The organizers of the CNS sponsored Symposium on Climate Change and Energy Options, held in Ottawa, November 17 - 19, 1999, assigned several people to be "rapporteurs" of each of the four sessions of the Symposium. Following are the "official" summaries as compiled by Ray Sollychin, technical program chairperson for the Symposium.*

Session I, "Climate Change And Energy Demand/Supply"

Prepared by Betty Rozendaal (AECL) and Nigel Fitzpatrick (Azure Dynamics Inc)
Edited by Ray Sollychin

This session was chaired by **Gerry Manwell** of Suncor. It discussed the Kyoto Protocol and the process initiated by Canada's Climate Change Secretariat, and the implications of Canada's commitment to the Kyoto Protocol. It also discussed the gradually depleting fossil fuel supplies. In his opening remarks, Manwell reinforced the need for more diverse sources of energy and that the variety of energy sources will be like a growing layer cake building on the existing layers of energy sources rather than the elimination of layers such as oil and nuclear energy. The area of growth for the future will be in the development of new technologies that reduce the cost of operations and add value such as sequestration by CO_2 re-injection, cogeneration, hybrid vehicles and other new products.

The first presentation was by **Ian McGregor** of Climate Change Secretariat. He provided an update on Canada's National Climate Change Process. As part of this process, the Climate Change Action Fund has been operating for three years. It focuses on 4 areas: building of national process; technology early action measures, public education, science, and impact assessment and adaptation. Sixteen sector issue tables were established in mid - 1998. They have completed foundation reports which have been submitted to the government. Twenty-two of the reports from the issue tables will be available to the public.

McGregor felt that the key issue in reaching the Kyoto targets is in the need for behavioral change, technology development and adaptation. A number of provinces are looking at implementation of climate change initiatives. The next steps in the National Climate Change Process will be focused on the completion of the following: technological analysis/economic modeling; integration of the issue tables papers; and policy analysis. A strategy will be developed and recommendations made to Ministers. The strategies will be implemented into a 3-year rolling plan.

A draft national implementation strategy is expected to be completed by March 1, 2000 and will take approximately 6 months to refine. A Joint Energy and Environment Minister's meeting to be held in March 2000 will be followed up another one in the fall when decisions will be made on international negotiations.

Jack Zagar presented a rather discouraging prediction of oil supply made by Colin Campbell and himself. This prediction has been discussed in many world's forum including International Energy Agency. Basically, they predicted the exit of conventional oil as a major player on the world's energy stage, although it has been instrumental in the growth of the world's economy in the 20th century. Conventional oil production outside the Middle East is declining, and that in the Middle East will soon reach the mid-point of historical production curve and begin its irreversible decline.

The stage is now set for another energy crisis starting with higher prices from Middle East control and followed by the onset of real oil supply shortage around 2010. Any reduction in demand for oil, such as that contributed by energy conservation, can only shift the timing but not alter this fundamental trend. Zagar acknowledged that their prediction might not be perfect but believed it was better to base climate change and energy options strategy on sound-working hypothesis based on available knowledge, than to rely on blind faith alone.

Contrary to Zagar's presentation, **Robert Lyman,** of Natural Resources Canada, provided a more optimistic analysis of the future of oil supply. He made compared the views of pessimists and optimists on the future of conventional oil resources. Focusing on the impact of new technologies on oil production, Lyman believed that oil prices would not exceed US $ 28 per barrel by 2020. This price would not reduce demand in any way.

Lyman felt that climate change policy in the transportation area, for example, should therefore focus on vehicle efficiency and alternative fuel vehicles. If this is successful in restraining oil demand, it will, paradoxically, restrain the pressure on the price of oil and lengthen the life of existing reserves.

The ensuing discussion was mostly for clarification. For example, there were questions related to the effect of other energy sources such as oil shale and natural gas on the price and hence future availability of conventional oil. It was thought that these

would have little bearing on the supply of the conventional oil.

A question was raised on the acceptance of the argument that GHG emissions clearly contributes to the current change in climate. It was stated that the Canadian federal government has determined that there is sufficient evidence to support this relationship and has decided to move forward.

Several questions and discussions related to the issue of government policies, especially the use of tax as an instrument to direct the GHG emissions reduction program. Some participants felt strongly that the program should be driven by market force alone and that anything that does not follow the dynamics of the market can not be sustained. However, one opinion was that it was important to develop appropriate tax structure on the demand side and to promote vehicle efficiency. Taxes are one of the government's important economics instruments. Good policy would maintain a strategic but practical balance among various instruments.

Generally, it was believed that the Kyoto Protocol was just the start. Achieving the GHG emissions reduction target required by the Kyoto Protocol will only delay the doubling of the emissions by 10 years. To stabilize the emissions, a reduction target of 50% is needed.

Gerry Manwell closed Session I by stating the materials presented in the session had provided a brief account of the current reality of energy resource unavailability. This background information would be useful to the rest of presentations and discussions in this symposium. The reality would drive our economic inducements. However, the future is alive with possibilities.

Session II, "Energy Without GHG Emissions: The Potential"

Prepared by Dave Jackson (McMaster University) and Jerry Hopwood (AECL)
Edited by Ray Sollychin

Session II was chaired by **Sandy Stuart,** Chairman of Stuart Energy Systems. The session consisted of talks covering the possibilities for GHG reduction in several energy generation technologies.

The first speaker was **Romney Duffey** of AECL. His message was that the current and projected magnitude of the world's total GHG production present such a large challenge that all the energy supply technologies available, including nuclear, will have to be used to meet it. A vision of energy supplies in the 21st century is presented, in which hydrogen is one of the essential energy currencies, and is generated from the various energy sources available. He noted that although Canada has a small fraction of the world's population, our national response does matter.

Specifically, Duffey pointed out that nuclear, renewable and hydrogen energy sources together are uniquely synergetic, reducing cost, extending energy resources, providing additional electricity generation capacity, and reducing transportation emissions. These benefits provide an economic advantage and export potential, increase the lifetime of oil and gas resources, and encourage technical innovations.

Malcolm McDonald of Transalta spoke of the potential for reducing GHG emissions from fossil fuels. He believes this is important as continued use of fossil fuel over the next 20 to 30 years with significantly reduced emissions will considerably ease the transition to the eventual sustainable world. In the long-term, all energy options that are available must be explored to find an optimum solution. Fossil energy can play a role by providing critical time required for other new energy options to develop.

Several fossil fuel technology options with reduced emissions were described by McDonald. They are: increasing efficiency and hence, lowering the need for (fossil) energy; shifting to fossil fuels with lesser GHG impact, for example from coal to natural gas; and, the capture and permanent storage (sequestration) of carbon dioxide. One possibility for sequestration is high pressure injection of carbon dioxide back into wells that have been exhausted of natural gas.Some geological sequestration pilot projects are now in operation, e.g. in the Norwegian North Sea gas field.

Holly Mitchell discussed BIOCAP, a community of university and government researchers with private sector partners whose purpose is to explore the technical and policy aspects of biosphere carbon sequestration and biomass energy. Mitchell stated that the amount of carbon added to the atmosphere as a result of deforestation and agricultural practice in Canada in this century is probably similar to that released due to the use of fossil fuel in the same period. BIOCAP believes that if the biosphere can be managed better to return even a fraction of atmospheric carbon to biological sinks, a significant contribution can be made to reducing the of GHG emissions. A wide range of relatively low cost options are considered, initially focusing on forest management, biomass crops and soil management. BIOCAP is just starting and has applied for funding under the federal Networks of Centres of Excellence program.{1}

Andrew Pape of Sustainergy Consulting reviewed the solar outlook for Canada. Several currently cost-effective solar energy applications were reviewed. These included passive solar building design, solar water heating, solar photovoltaics for remote power, and solar assisted space heating and cooling in industrial building. Pape believes using these applications, solar energy could contribute between 6% and 14% of the total emission reduction required by Canada under the Kyoto Protocol.

In Pape's view solar energy is still suffering from a bad reputation resulting from the hasty and ill- considered entry of many solar companies into the energy market during the 1970's oil shock. While solar technologies have found certain niches (for example passive solar techniques for space heating, swimming pool heaters and photo-voltaic electricity for remote locations), he said that a "level playing field" was needed for the successful marketing of solar products. He noted that more solar R&D funding was required; in Canada he quoted $ 8M per year for solar R&D versus $ 100 M for nuclear.

In contrast to the solar situation, **Jim Salmon** of the Canadian Wind Energy Association presented a very upbeat picture of

world progress in the installation of wind generation facilities. As of October 1999 there were 11,800 MW of wind energy installed in the world of which 2,950 MW were installed in 1998. This is an impressive growth rate, which makes wind by far the world's fastest growing renewable energy technology. However, in Canada there are only a few wind power facilities and the installed capacity to date is just 124 MW (mainly in two wind farms at Cowley Ridge, Al., and Le Nordais, PQ.)

Salmon described future development of wind power generation. A few countries such as Germany, USA and Denmark are supporting wind power development via significant R and D and production subsidies. He predicted a rapid decline in the cost of power generated from wind.

Hydroelectric power has long been a main stay of Canadian electricity generation. **Pierre Fortin,** Canadian Hydropower Association, outlined the short-term prospects for additional hydroelectricity, which are estimated to be 76 TWh, if the Kyoto agreements were implemented. This would result in GHG reductions equivalent to the emissions of all the 14 million private cars in Canada.

The barriers to increased hydro power are primarily environmental and regulatory uncertainties and the opposition of aboriginal communities to further development in their hunting territories. The Canadian Hydropower Association sees these barriers as challenges and is committed to working with government and all stakeholders in developing a healthy policy framework, in which hydropower is an integral part of Canadian Climate Change Strategy.

Murray Stewart of the Canadian Nuclear Association presented nuclear energy as one essential component of Canada's solution to meeting its GHG emission reduction target required by the Kyoto Protocol on Climate Change. This is because the impact of nuclear energy on emissions reduction is powerful, and yet it is sustainable and economical; and that Canada possesses unique strength and capabilities for applying nuclear technologies to the global effort in reducing GHG emissions. Canada is the world's leading uranium supplier, operates some 20 CANDU reactors, is a leader in radioactive waste management, and the world's leading medical and industrial isotope producer.

Stewart also discussed the recent trend in the North America power industry toward deregulation, streamlining of nuclear regulation, and consolidation of utilities ownership. Under this new environment, nuclear power plants are expected to reduce cost, extend plant life, and become more economical. He advocated that in Canada, refurbishing existing nuclear stations is the best energy investment one can make both in terms of lowest cost and in reducing GHG emissions. He stressed that successful recovery of Ontario Power Generation's laid up units is essential not only for the continued credibility of the CANDU system but also from a climate change perspective.

Some interesting questions were raised in the discussion following the presentations. Some years ago several hundred people living around an African lake were suffocated by an unexpected but huge carbon dioxide bubble emitted from the lake. In reply to a question on this in terms of the safety of carbon dioxide sequestration, Malcolm McDonald said that gas bearing formations had been stable for millions of years since the gas hadn't leaked out. Therefore, once the carbon dioxide was injected into them it was likely to remain there for the same reason. This argument, of course, is essentially the same one used to support the geological disposal of used nuclear fuel.

Interestingly, environmental concerns and public acceptance were not confined only to nuclear power but were mentioned as problems by several of the speakers. For example, large amounts of methane are generated by the decay of submerged vegetation in the reservoirs created behind hydroelectric dams. Since a given quantity of methane is estimated to be some twenty times more effective (harmful) as a GHG compared to the same quantity of carbon dioxide, hydroelectric power has to be carefully examined over its full life cycle. Wind power is frequently criticized for its aesthetics - environmentalists often oppose wind installations because they are "ugly". More mundane but pertinent questions included the extent to which a reliable grid can accommodate varying sources of power such as wind and solar generators.

Another issue was how renewable energy supplies would be affected by climate change. In the case of wind power, wind speeds might not change on average but the distribution of speeds might tend to be higher because of more frequent storms. Would weather changes cause a tendency to lower reservoirs at hydroelectric dams (as has recently been the case in eastern Canada) or to increase cloud cover and hence a decrease in the useable solar flux at ground level?. What would be the effect of the new weather on biomass crops? Although these may well turn out to be second order effects, the energy production of these technologies is directly coupled to the climate.

This session was of particular interest to the nuclear specialists present since they are rarely exposed, at least in a systematic way, to the work being done in other energy technologies. The conclusions were that several energy supply technologies have the potential for substantial GHG reduction and that, perhaps, nuclear power has many more non-technical problems in common with other energy technologies than one might otherwise expect.

{1} It is worth noting that Mitchell expressed GHG emissions in terms of their carbon content. This is the standard practice of scientists involved in accounting of carbon cycled by biological processes. Other speakers expressed GHG emissions with respect to carbon dioxide equivalents in accordance with fossil fuel combustion practice.

Session III, "Development of Energy Options"

Prepared by Ed Price (AECL) and Douglas Lighfoot (Retired, McGill University)
Edited by Ray Sollychin

In this session, chaired by **Erdal Yildirim** of the Alberta Chamber of Resources, eight papers examined particular technologies of energy production and the features that characterize their use and development, from the point of view of green house gas emissions.

Jack Belletrutti, of the Canadian Petroleum Products Institute, discussed the potential contribution of alternative transportation fuels (ATFs) to emissions reductions in transportation . His main message was to let market force determine the most appropriate energy sources. Focusing on gasoline as an example, Belletrutti pointed out that in spite of higher gasoline prices from taxation policies, the favourable factors [of gasoline] to consumers have allowed it to retain market share. A comparison of five alternatives proposed to replace gasoline as a transportation fuel, i.e., liquified petroleum gas (LPG); compressed natural gas (CNG); 15% methanol with gasoline; 15% ethanol with gasoline; and, fuel cells; shows that only natural gas has sufficient supplies to be a realistic alternative. Gasoline has been the preferred transportation fuel over alternatives such as LNG and CNG because of its driveability, performance, range, reliability, availability, distribution, safety and minimal effect on vehicle cost. Energy density is the biggest factor that favours gasoline. When all factors are considered, natural gas displaces more carbon when used to displace coal or heavy fuel oils than when used as a transportation fuel.

Applying the same principle to fuel cells the supply of hydrogen as a compressed gas makes it a low energy density fuel, which limits usage. However, extracting hydrogen from a liquid fuel with an on-board reformer is promising and is a predicted solution for fuel cell powered cars. In this way the range of such vehicles can be improved. Reformers can use methanol and gasoline but the gasoline system produces twice as much hydrogen as a methanol system. These examples emphasize the important point that we must select the application for each fuel that provides the most benefit, especially in reduction of CO_2 emissions and not try to use fuels where they are inappropriate.

Nigel Fitzpatrick, of Azure Dynamics Inc., looked at how the use of electrochemical products produced from electricity derived from nuclear and renewable sources, can make an indirect contribution to green house gas reduction both in the transportation field and in the products that can be traded internationally. Light weight products such as aluminum have a benefit in transportation of increased efficiency. Transportation in Canada is estimated to have emitted 123 million tonnes of GHG to the atmosphere in 1995. Hydrogen will eventually be used as a fuel to reduce these emissions, but is not yet cost effective. Evaluating energy sources in terms of effectiveness showed that only diesel had an advantage over gasoline and the highest cost fuel was hydrogen extracted from natural gas for fuelling a fuel cell.

The use of a hybrid system in vehicles has the potential to reduce fuel consumption by 30 to 50% and can save an additional 10% by regenerative braking. Examples of hybrid systems are a fuel cell and batteries, and a gasoline engine and batteries. Use of various types of batteries in 'near term' electric vehicles were discussed and the advantages and disadvantages of each compared to the nickel-metal hydride battery which presently has the best capacity, but the lithium ion battery shows great potential in cost effectiveness.

Andrei Tchouvelev, Stuart Energy Systems, described the various electrolyser systems available from Stuart Systems which produce pure hydrogen from alkaline water. The company philosophy is based on the belief that the direct use of hydrogen for transportation and stationary applications is more efficient than making hydrogen by reforming methanol or gasoline. Widely distributed electrical grids allow the manufacture of hydrogen virtually anywhere to meet any sized fuel demand. The typical product of Stuart Energy Systems for either transportation or stationary application is a complete hydrogen delivery package consisting of a low temperature electrolyser integrated with mechanical gas compression; gas purification and dispenser process, automation and remote monitoring and control. Storage of hydrogen allows for off-peak and intermittent operation. The applications include fleet fuel appliances (FFA's) for buses, cars and trucks and personal fuel appliances servicing 1 to 3 cars. Other stationary applications include industrial hydrogen generation systems which produce hydrogen that can be sent to storage at ~ 200psig. The "fuel appliance" approach is believed to be an effective counter to the lack of infrastructure to support the hydrogen industry compared to the gasoline and natural gas industries.

Stuart Energy Systems predicts a hydrogen fuel economy for vehicles in the near future. Hydrogen as a transportation fuel is expected to pick up by 2004 and to reach significant numbers by 2010. Tchouvelev sees a future where more electricity will be generated by nuclear, and renewable sources of energy for production of hydrogen may become attractive.

Alistair Miller, AECL, compared various types of transportation in their potential to adapt to hydrogen as a fuel. Using criteria such as, number of operators, utilization factor, consistency of loads, dispersion of operations, volume of fuel and public anxiety, he outlined how trains are the easiest to adapt, ships are close behind with planes and trucks as much poorer candidates. He elaborated on the potential niche in rail transportation which is appropriate to the use of hydrogen, either directly to substitute for diesel, or to generate, via fuel cells, the electricity to drive freight trains. In this way rail can take advantage of its inherent capability to move goods with 2.5 to 4 times the fuel efficiency of trucks. Such an approach would be far cheaper than electrification of lines, and Miller shows a factor of 30 in capital investment between electrifying a line and the use of fuel cells.($4.5 billion without winterization against $150 million) The annual power costs would be twice as great for fuel cells (150Mwe) to that for electrification of a track such as Quebec City to Windsor(70Mwe).

However, the only convincing CO2 reduction strategy would be to produce hydrogen from a non- carbon source of electricity such as from a nuclear plant. The basic economics of converting the Windsor to Quebec City line to use fuel cell powered locomotives indicates a far superior economic case for fuel cells over electrification of the track.

Using the prediction that oil production from conventional sources will drop from 26 billion barrels a year now, to 6 billion barrels per year by 2050, **John Donneley,** of Marengo Energy Research Ltd., and **Duane Pendergast,** of AECL, showed how some of the difference could be made up by producing up to 20 billion barrels of oil per annum from tar sands. Currently the energy used to produce oil from tar sands (using open cast mining for sand extraction) is from natural gas and causes an emission of 0.12 tons of CO_2 per barrel of oil produced (about

2 billion tonnes of CO_2 annually for 20 billion barrels of oil.). In their paper, they point out that the development of the steam assisted gravity drainage process (SAGD) to extract oil from underground formations, makes available a process compatible with steam conditions produced by a CANDU reactor. Without an alternative energy source to natural gas or oil to achieve extraction, limits on CO_2 emissions could constrain the growth in oil sands production.

A single CANDU 9 reactor (935 MWe) could supply both the steam for heating the formation and the electricity to produce hydrogen that can be used to upgrade the extracted bitumen It is estimated that 340 billion barrels of oil can be extracted by the SAGD method. Such a facility has the possible synergy of producing heavy water from the hydrogen produced by electrolysis.

Alan Johnston, from the Coal Association of Canada, described an interesting approach of how coal deposits can potentially be used to effectively produce power or synthetic natural gas with CO_2 emissions reduced to a very small value. In a typical process, coal slurry is reacted anaerobically with CaO to produce $CaCO_3$ and hydrogen. The hydrogen can be used in a solid oxide fuel cell to produce electricity and waste heat. The waste heat is used to calcine the $CaCO_3$ back to CaO for recycling back to the anaerobic reaction vessel. Both the hydrogen produced and the CO_2 are reacted with silicate rock to produce mineral carbonate that is disposed of, and heat which can be used in a conventional power plant.

The studies are being conducted by the Coal Association of Canada with scientists from Los Alamos laboratory with the objective of having within 5 years, a pilot plant producing electricity from coal in a process that results in zero emissions of CO_2.

The overall development is in the phase of exploring the thermodynamics of several of the reactions including alternative processes. Experimental verification is needed of kinetics and other factors and whether other processes such as molten salt reactions could carbonate the silicate rock more effectively.

Ken Kozier, AECL, reviewed the potential for nuclear energy to serve as a source of process heat, either for industrial purposes or for space heating. Starting from the estimate that 67% of mankind's primary energy usage is not in the form of electricity, a large potential markets for nuclear process heat (NPH) should exist.

Kozier pointed out that heat sources for NPH tend to be small and located close to the user. This avoids transport of heat but needs high reliability and in this case of nuclear, systems to avoid radioactive contamination. The paper describes the potential for use as district heating, using the experience in Europe. Industrial heating was reviewed, pointing out the temperature needs for various industrial processes as well as sea water desalination.

Dave Torgerson of AECL outlined the strategy for developing the next generation of CANDU reactors. Nuclear energy can contribute significantly to the avoidance of greenhouse has emissions. However, the current competition in the electricity production business is combined cycle gas turbines which are favoured because of their low capital cost. For nuclear to expand in a major way, its capital costs need to be reduced and low risks with plant performance and operation need to be assured.

AECL's development of next generation CANDU is based on three main thrusts. The first is cost reductions via plant optimization and simplification. Examples of new technologies contributing in this aspect mentioned by Torgerson included the CANFLEX fuel design; optimizing the core design to maximize the power/heavy water ratio, improved fuel channels, use of light water coolant with heavy water moderator, and increase in thermodynamic efficiency through a increase in coolant temperatures.

The second main thrust is safety enhancements built on the inherent safety features of the CANDU design with a new emphasis on passive safety. Finally, the third main thrust is enhanced plant operation using "SMART CANDU" concepts or the use of advanced diagnostic tools. One specific example of this approach is the introduction of on-line monitoring of the chemistry of the systems. *(Torgerson's paper is reprinted elsewhere in this issue of the* CNS Bulletin.)

Many of the questions that followed the presentations were on, or related to, specific issues brought up, such as the challenge to launch a new generation of nuclear reactor technology, the hybrid car, alternative process to release oil from oil shales, and the interest in small reactors.

Participants were impressed with the number of energy options available to reduce GHG emission. Many were developed from innovations generated in the last few decades. There was a consensus that a future economy with reduced GHG emission in the world must be based on the use of both electricity and hydrogen currencies. Among the energy options presented that will lead toward to a hydrogen economy, the process put forward by Johnston to generates hydrogen from coal (the most 'guilty' energy source) is most dramatic. Nuclear energy can contribute to a hydrogen-based economy in a very significant way. The possibility that CANDU can be more competitive and have improved safety was assuring. Renewable energies such as wind and solar may not currently be economic in general, nor practical as large-scale base-load energy suppliers. However, they can be used as effective supplementary energy sources as part of hydrogen economy.

The use of hydrogen for domestic and industrial applications in the future rather than for transportation (except in specific niches) would allow the continued use of oil products as transportation fuel for personal vehicles, where they have a large cost and performance advantage over other fuels.

Several comments were on the best way to achieve the "hydrogen economy". One thought was to allow market forces to determine the path without any policy intervention. Another opinion called for a national policy based on both emission reduction and economic foci which need to be kept in balance in the derivation of action plans.

A related comment was that there is a need to understand the time frames of possible actions. The time frame for Kyoto Protocol is considered too short by some. There was a concern

that the Kyoto Protocol may result in a misdirection of resources. It is more important to do the right thing in a measured fashion, than to act in haste.

It was generally felt that there is cross fertilization of ideas when people from different energy technology backgrounds are brought together such as at this symposium. All of the energy technologies presented in the symposium have a potential synergy with other alternative energies. The questions were: should we coordinate this synergy, and, is there a need to setup an organization to do this ? Participants did not believe such an organization exists nationally. Some disagreed with the idea of creating a new organization and would prefer adding the synergy-coordination mandate to an existing organization such the Energy Council of Canada.

Symposium chairman, Duane Pendergast, commented that the issue of synergy and coordination between various aspects of the energy industry was a topic of considerable interest to the Technology and other Issue Tables of the Climate Change Secretariat. He suggested that participants will be impressed with the Options Reports of the Issue Tables which would be made public early in 2000.

In his closing remarks, Yildirim expressed his pleasure with the variety of the emissions-reduced energy options presented at this symposium. He felt Canada was fortunate to have the options available to us. Our challenge is to find the right resources for the right application. Some technologies are not advanced enough to be used and each region of the country needs the best mixture for its own purpose. What is good for Alberta may be not be good for Ontario. It is a multidimensional problem with a matrix of solutions.

Session IV
"Environmental And Economic Aspects Of Energy Technology"

Prepared by Alistair Miller (AECL) and Tom Foote (Environment Canada)
Edited by Ray Sollychin

Chaired by **Brian Moore,** of Natural Resources Canada, the last session of the symposium focussed on the economic and environmental performance of various energy options and implementation of policies to promote GHG emissions-free options.

Helen Howes, of Ontario Power Generation (OPG), presented a paper discussing OPG programs in responding to climate change challenge and how OPG is working with the communities around its station in managing its environmental impacts.

Howes stated that optimism about nuclear energy is increasing because of growing appreciation of nuclear's environmental and other benefits. If Canada did not have nuclear generation, greenhouse gases from electricity production would double. Nuclear power represents a major portion of OPG's generation mix and it will be the bedrock upon which a successful, competitive OPG can be built. However, without public acceptance and support, the entire nuclear investment is endangered. She presented three areas in which OPG is acting to seek continued public support: improvement of power plants' safety margins and operating performance; improvement of the environmental performance at the plants; and increased community outreach.

OPG is currently working on a new greenhouse gas strategy to guide its actions over the next five years. Real GHG emissions reductions will be made at either OPG's sites or through offsets generated at more distant locations. The new strategy, in addition to including emissions trading, will have an increased emphasis on green energy and carbon sequestration.

Bob Philips, of CAMECO, presented a review of GHG life cycle assessment. He noted that for an assessment to be meaningful, estimates of emissions from every stage of the entire cradle to grave life cycles must be taken into account. This requires an accounting of emissions from production of all materials used to build the plants, transportation of the materials to the site as well as fuels used for their construction, operation and decommissioning.

Philips' study showed a wide variation in emissions from each primary energy source used to produce electricity. No source is totally free from GHG emissions. The source with the lowest GHG emissions is hydro power which is closely followed by nuclear. The emissions from coal power plants are more than 200 times that of the hydro power. Renewable energy such as wind and solar energy produce GHG emissions that is twice to 12 times that produced from nuclear energy.

The presentation by economist Chris Green from McGill University was focussed on climate change policy. Considering the large amount of carbon-free energy required as substitutes for fossil fuel, Green asked where will they practically come from. He dismissed the hypothesis that the solution could be provided by renewable energy alone. Solar, wind and biomass energies are all dilute and require enormous land use. Their potential contribution is seemingly limited in a world in which competing demands for land for food production, living space, ecological preserve and natural resource production are increasing.

Green supported the use of hydrogen technology but wonder what is the appropriate sources of energy to produce hydrogen. He was pessimistic about the potential of nuclear fission energy as the source because of its poor public acceptance and of fusion energy because of lack of its technological progress. This led to his suggestion that climate change policy should focus on what realistically can be done and not on what should be done. What can be done is to begin the long search for and development of new carbon-free energy sources and technologies capable of eventually replacing fossil fuels as the world's main energy source. Contrary to the general view of economists, Green proposed that the climate change problem is too big and too urgent for the market solution to work.

The presentation by **Basma Shalaby,** AECL, constituted a response to the concerns related to nuclear energy raised in the previous presentation. Shalaby's presentation was focussed on

the environmental and safety performance of CANDU nuclear power plants. She stated that analyses of environmental effects of all stages of a CANDU project indicate that, at the selected sites and with suitable mitigation measures, significant adverse environmental effects are not expected. Based on measurements from CANDU 6 stations over many years of operation, the emission level has been found to be well below regulatory limits and even further below any levels of radiation known to cause harm.

The volume of radioactive waste generated at a CANDU 6 plant is extremely small in terms of the amount of energy generated. The environment continues to be effectively protected by established waste management practices. In conclusion, Shalaby noted that nuclear energy has the potential to provide an energy source with negligible GHG emissions, on the order of that from hydroelectric power and yet require 1500 times less land area. Any adverse environmental consequences of nuclear energy, in particular when produced with CANDU type reactors, are manageable. The major environmental consequence of expanded nuclear power production will be an enormous benefit to the world's environment and economy.

The last presentation of the session, and thus the symposium, was made by **Thomas Tisue** of the International Atomic Energy Agency. The focus of his paper was an interesting discussion of how the Clean Development Mechanism (CDM) can be applied to provide a win-win solution to the seeming conflict between the increased demand in energy usage in the developing countries and the requirement to reduce global GHG emissions. Tisue noted that nuclear energy is stagnant or declining in most developed countries. However, nuclear is generally well received in developing countries such as China, India, Brazil and Indonesia, as it is considered essential to meet the economic aspiration of these countries. A large-scale introduction of nuclear energy in these countries will ensure that the global GHG emission will not be significantly increased further due to the economic growth of these countries. The barrier to a rapid development of nuclear energy in developing countries, however, is the high capital cost associated with the building of nuclear power plants. Tisue suggested use of the Clean Development Mechanism (CDM), part of the Kyoto Protocol, to stimulate the introduction of nuclear energy in the developing countries.

Two typical implementation strategies were proposed. They both create a means for transferring the credit for reducing emissions from power projects in developing countries to the sponsors of those projects in developed countries. Given the extreme seriousness of the risk of rapid climate change, and the very few technically and economically feasible means of avoiding it, he argued that there should not be any constraints to the use of CDM in this regard. *(Tisue's paper is reprinted elsewhere in this issue.)*

Many questions were raised during the discussion period following the presentations as well as during the presentations. They were generally associated with several major issues. The first were about the restart of Pickering "A" nuclear power plants and OPG's definition of green energy. It was confirmed that the restart [of Pickering "A"] would help OPG meet its emission target. There was a comment that not taking this emissions reduction into account in the environmental impact assessment of the Pickering A Restart project was neither logical nor consistent with the objective of the assessment. OPG is currently having a consulting firm determine what energy sources constitute "Green Energy". In general, OPG would like to be in the position to sell green energy to customers that wish it. Ms. Howes suggested that electricity consumers will presumably be able to specify nuclear as their selected power source.

The second issue discussed related to carbon-tax. It was mentioned that this is very politically sensitive. However, this is long-term problem and requires a large-scale international co-operation. Emissions taxes or any policy instruments must encourage oil and coal companies to invest in non-carbon solutions.

On the subject of land-use, there was disagreement with the criticism that wind energy requires the use of vast land. However, all agreed that the main problem with wind energy is its intermittent availability and therefore can not be used to provide a base-load for a large proportion of grids. A suggestion was made to devote more attention to the development of ocean thermal energy which may reduce the amount of land needed for new GHG-free power generation.

Another topic of discussion was related to nuclear energy. The reasons for improved dose management in CANDU 9 were discussed as mainly related to design improvement based on experience learnt from the operation of existing CANDU plants. The future of nuclear fusion and lack of funding for its further development was also discussed.

Green commented that he believes humanity has 50 to 100 years to solve the GHG-emissions problem. Power from fusion, though problematical in his view and 40 to 50 years off into the future, and other long-term possibilities such as tapping into heat from the Earth's mantle deserve R&D attention. We should, in Green's view, forget Kyoto targets and concentrate on getting the issue right. Then we shall probably reach the right solutions.

The last major topic of discussion was the use of CDM to promote nuclear energy in developing countries while minimising global GHG emissions. Some of the questions related to details of implementation of the CDM which are yet to be developed. However, it was pointed out that a similar SO_2 credit seemed to work in US, so there is hope for a CDM initiative such as that proposed by Tisue.

Ed. Note: *Following the close of Session 4, Dan Meneley, of AECL, presented his "reflections" on the overall Symposium. The essence of his remarks is included in the overview report, "Climate Change and Energy Options – a beginning of dialogue.*

Using The Clean Development Mechanism

- for joint implementation of nuclear power in developing countries

A Win-Win Strategy for Climate-Friendly Development

by Jihui Qian and Thomas Tisue[1]

Ed. Note: *The following paper was presented at the CNS Climate Change and Energy Option symposium held in Ottawa, Ontario, November 17 to 19, 1999, by Thomas Tisue. The authors emphasize that the paper presents their personal views and does not necessarily reflect the views or policies of the International Atomic Energy Agency.*

I. The Current Situation

The United Nations Framework Convention on Climate Change (UNFCC) Secretariat makes the following points about the seriousness of global climate change and the importance of emission limitations on carbon dioxide (CO_2) and other greenhouse gases (GHG)[2]

- "Climate change is likely to have a significant impact on the global environment.[3]
- Human society will face new risks and pressures.[4]
- People and ecosystems will need to adapt to future climatic regimes.[5]
- Stabilizing atmospheric concentrations of greenhouse gases will demand a major effort."[6]

Many analysts see energy supply and demand as key factors in addressing these challenges.

The high energy use per capita that characterizes most developed countries evolved almost free of constraints external to the market-place. Now, driven by concerns about global climate change and environmental degradation, these countries are being forced to seek climate-friendly ways to preserve their enviable quality of life. Success will not come without considerable cost, but there is growing awareness that failure to act will be even more expensive. This recognition has already begun to focus increased attention and investment on conservation and efficiency measures, and on the development of renewable, non-CO_2 emitting energy sources (wind, solar electric, etc.).

At present, it is an open question whether gains in efficiency and expansion of renewable energy sources will suffice. The answer depends in part on developing better models of how the global climate will respond to various levels of GHG in the atmosphere. Another ten years or so may suffice to get the picture clear. But whatever the details, *few would argue in favor of additional large increases in GHG emissions, or of severely curtailing development plans of the less-well-off nations.* The Climate Convention attests to the worldwide recognition that action on some scale will be obligatory. As we get the problem in better focus, it is important to put all choices on the table for discussion, and to keep all options open. Solving the problem will cost money, probably a lot of it, and finding the most cost-effective approach will be important.

Nuclear energy generates very little CO_2 and is therefore inherently climate-friendly

Nuclear energy today accounts for about 7% of the world primary energy and 17% of world electricity, [already] avoiding the emissions of about 2 billion tonnes CO_2 annually."[7]

Can the CO_2 contribution to total GHG be reduced or held constant while increasing global energy supply without expanding the use of nuclear energy? Put another way, can we rely on the efficacy of piecemeal solutions outside the energy sector, combined with expansion of renewable energy sources? Given the aspirations of developing countries and their implications for global energy production, the answer is far from clear.

Present prospects for nuclear energy's contribution to CO_2 mitigation

Nuclear energy is stagnant or declining in most developed countries and is mentioned dismissively, if at all, in discussions of how to reduce global CO_2 emissions. For example, the UNFCCC Secretariat's Subsidiary Body for Scientific and Technological Advice (SBSTA) commissioned a study with the aim of meeting needs for "information on technologies and know how to mitigate anthropogenic emissions of GHG and to adapt to climate change", and in particular "to target technology transfer to those environmentally sound technologies that are most appropriate in the contexts of Non-Annex I Parties with regard to climate change concerns as well as development objectives"[8]. Based on a survey of non-Annex I countries, the report identifies energy supply and demand as priority sectors for deploying climate-relevant technology. But it mentions only carbon based fuel-switching and renewable energy sources among the "prioritized technologies for climate-relevant technology transfer"[9].

Public acceptance places constraints on nuclear

energy in many developed countries. Buttressed by the accidents at Three Mile Island and especially Chernobyl, critics cite serious concerns about safety. Moreover, long term storage of wastes from the nuclear fuel cycle remains a matter of public concern in many countries. And, despite the existence of a strong safeguards mechanism for nuclear power plants, non-proliferation is a persistent spectre in the public consciousness.

An additional constraint is that, in carbon resource-rich regions, nuclear [currently] offers no cost/price advantages over fossil fuels for the production of electricity. There are, however, advanced reactor systems becoming available that many experts think may tip the balance in favor of nuclear energy. Should emerging technology make nuclear the clear lowest-cost alternative for producing electricity in many places, the global energy scenario could be radically altered, and along with that, our thinking about how to limit GHG emissions.

In spite of all the foregoing, some developed countries [France and Japan] have reached the opposite conclusion: that, given their situations, the advantages of using nuclear energy outweigh all potential risk and cost factors. Elsewhere in the developed world, nuclear currently has very limited prospects, despite climate change concerns.[10]

Some visionaries in developed countries think that the public's negative attitude toward nuclear energy can and must change, and their voices are beginning to be heard. There is some evidence that concerns about the global climate is already driving a new trend of thought. Some industry analysts see changes on the horizon due to the impact of CO_2 reduction policies on perceptions of nuclear. One noted that these policies could "turn a lot of [current] ugly ducklings into swans" and cause investors "to reacquaint themselves with nuclear power"[11]. But public perception in many developed countries is unlikely to change soon. People will need to be shown (again) that nuclear power can be safe and cost-effective, as well as a major contributor to combating climate change.

Some developing countries present a different prospect

The involvement of developing countries may be one way to help bring about a reconsideration of the nuclear option. In developing countries, accelerated development is often the major goal. Other considerations are secondary. Shortage of capital, not hypothetical safety risks and environmental concerns, is usually the major constraint. In many places, the public and governments accept nuclear power. Compared to other alternatives, nuclear is even seen as an environment-friendly technology. In developing countries, there is recognition that nuclear power can produce electricity at a price not much higher than coal. South Korea's successful development of nuclear power is a lesson not lost on other members of the

developing world. Several large countries with emerging economies and substantial resources continue to pursue nuclear as one of their future energy sources, including China, Brazil, India, and Indonesia.

Attitudes and policies regarding nuclear energy in these emerging countries are of potentially great importance. This is because it is not at all clear whether the goal of stabilizing CO_2 emissions can be achieved without involving these major players.[12] Developing countries badly need to expand their energy supplies, and shall do so, yet they are not in a position to embrace more costly alternatives to fossil fuels, however 'noble' those alternatives may be. Understandably, these countries are not swayed by arguments suggesting they limit their CO_2 emission rates to 'survival levels' while the developed world continues to enjoy the benefits of emitting at 'luxury levels'.[13]

Decisions over how much energy to produce, and by what means, are matters that go to the heart of a nation's sovereignty and right of self determination. Such decisions are not subject to control by any existing international accord. Developing countries are free to pursue nuclear power if they so choose, just as is the case in the developed countries.

China: the key to GHG emissions controls

It is useful to elaborate this line of thought by taking China as an example. The Peoples Republic of China has been pursuing the development of nuclear power for decades as a complementary part of its energy supply mix. The Government and most of the public consider nuclear power acceptable on safety and environmental grounds, especially compared to coal. The existence of large unpopulated areas reduces concerns over waste management. As China is already a nuclear weapons state, non proliferation is not an issue to the world community. In any case, nuclear power plants (NPPs) are under full safeguards. Thus the major constraints to the utilization of nuclear power in most developed countries are not a factor in China.

What currently limits its further development is that nuclear power is not quite competitive with coal and gas in terms of construction cost and price of electricity generated. Even domestic PWR technology is not very attractive to investors at the moment. Previous government subsidies are ending; henceforth nuclear must compete in the open market. As a result, nuclear power in the PRC is likely to stagnate as it has in many developed countries.[14]

Some other developing countries may resemble China in this regard, including: Bangladesh, India, Pakistan, the Philippines, and Vietnam; Egypt, Morocco and South Africa; Chile, Mexico, Argentina, and Brazil.

In summary, no predisposition against NE exists in many developing countries, but market forces disfavor expanding its use. At the moment, nothing is driving increased use of nuclear power. Without deliberate alteration of the controlling factors, expansion in energy production in these countries will likely take place by means of carbon-based technologies, with small contributions from hydroelectric and other renewable sources. The resulting CO_2 emissions may well result in reduced options and higher costs for developed nations. China is the focus of particular concern owing to its large population and ambitious development plans. One estimate suggests that China will meet its primary energy demands in 2025 mostly with coal (68%) and oil (25%). This projection means China would be emitting 3.2 billion tonnes of CO_2 annually by that date, compared to current global emissions of 6.15 billion tonnes[15].

II. Creating New Momentum: the Clean Development Mechanism (CDM)

What is the CDM?

The CDM is a part of the Kyoto Protocol. It creates a means for transferring the credit for reducing emissions from projects in developing countries to the sponsors of those projects in Annex I (developed) states.

What is it for?

The CDM creates a unique, market-based, means by which signatories to the Kyoto Agreement can involve developing partners in achieving global reductions in greenhouse gases, while promoting those partners' sustainable development.

What are the criteria for obtaining Certified Emission Reduction (CER) credit?

Emission reductions must be realized (as opposed to conjectural or potential) and their magnitude *verifiable* (in quantitative terms).

They must also be *additional* (as opposed to reductions that would have been realized even in the absence of the CDM activity).[16]

Nuclear and the CDM: a "Win-Win" scenario for developed and developing countries, as well as the global environment

One means for achieving the CDM's goal is to enable developing countries who favor the use of nuclear power to embark on the construction of NPPs instead of comparable coal-fired plants. This approach meets the CDM's criteria in a transparent and efficient way. The CO_2 emissions avoided by using nuclear are real, quantifiable, and readily verified by keeping track of the amount of electricity produced. And, as long as NPPs, like renewable sources, cost more than carbon-fuelled technologies, their use will be clearly "additional". Nuclear would not be used by most developing countries in the absence of the CDM mechanism.

A single 1,000 MW(e) nuclear power plant avoids the emission of about 6.5 million tonnes of carbon dioxide each year compared to a coal-fired plant of the same electrical output[17]. Over its lifetime of around 40 years, this single plant will avoid the emission of 260 million tonnes of CO_2. **NPPs can contribute much more significantly to CO_2 emission reductions than any other type of CDM project currently under consideration.**

The cost of generating electricity in NPPs is already only slightly more expensive than carbon-based technologies. The introduction of any market mechanism that disfavors CO_2 emissions will automatically favor NE in the Annex I countries.[18] The CDM is a mechanism that creates a simple way to also

stimulate more carbon-free, nuclear installations in non Annex I countries, where the major constraint is the lack of construction capital. And it offers a means of reducing GHG emissions while promoting the achievement of these countries' development goals. If properly implemented, the CDM will help enlarge developing countries' options for meeting their energy requirements for sustainable development by including nuclear power in the mix. Using this strategy, developing countries, their CDM partners in the industrialized world, and the global environment are all "winners".

For these reasons, the COP should give careful consideration to the opportunities NE presents in developing countries. It is important that future COP negotiations not explicitly preclude nuclear as a CDM option. It is in the interests of the developed countries to help developing countries, especially those with large emerging industrial economies, keep all available options on the table as the world seeks the most cost-effective way to deal with GHG emissions. Nuclear power offers a means for developing countries to expand their energy supplies without adding dangerously to the inventory of CO_2 in the atmosphere[19].

III. Two Implementation Strategies

The basic idea outlined above is easy to grasp: stimulate the use of nuclear power in developing countries through the CDM mechanism to simultaneously generate CO_2 offset credits and promote sustainable development. However the strategies for realizing this concept need to be carefully worked out on the basis of reasonable assumptions in order to appeal to investors and the international community[20]. There are at least two such strategies that would clearly be workable, and they could be implemented in parallel.

Existing Commercial Technology

The CDM is an ideal means for helping developing countries apply existing NPP technology – standard, off-the-shelf, commercially available installations – to meet their growing energy needs without emitting any CO_2. A simplified example shows how this approach might work in practice.

For the purposes of illustration, let us consider China as an example[21]. There, the construction cost for the Nth unit of a standard commercially available NPP is about US$ 2,400 per kW[22] (= US$ 2.4 billion for a 1,000 MW(e) unit). At a discount rate of 10% p.a., the total electricity generation cost from this plant would be $0.056 per kWh. In comparison, in China a coal-fired generator costs about US$ 1,200 per kW (= US$ 1.2 billion for a 1,000 MW(e) plant), and produces electricity at a total generating cost of $ 0.044 per kWh, again at a discount rate of 10% p.a. The cost/price disadvantage of the NPP must be weighed against the value of the CO_2 emissions avoided (260 million tonnes actual over 40 years, for a discounted value (at 10% p.a.) of 64 million tonnes).

In making projections about how emission trading might work in the future, planners use various values for tax rates on carbon fuels in Annex I countries, ranging from around $20 to more than $200 per tonne of CO_2 emitted. All these values are guesses, but a figure around $100 per tonne of carbon emitted is admissible for purposes of discussion. This value would mean that the operator a 1,000 MW(e) coal-fired plant in an Annex I country would pay $ 177 M per year in carbon taxes, or, at 10% p.a., a discounted value approaching $1.73 billion over the plant's 40 year lifetime. Would the owner of such a plant find it less expensive to pay the tax, or to invest in a 1,000 MW(e) NPP in China, for example, in exchange for the resulting CER credits?

As noted the extra investment for a 1,000 MW(e) NPP in China compared to a comparable coal-burning unit would be $ 1.2 billion. This is about $ 0.5 billion less than the discounted value of the carbon tax the operator of a similar sized coal-fired plant would pay to generate electricity in an Annex I country. The break-even point would be reached at a carbon tax rate of $ 69 per tonne. At a discount rate of 10% p.a., the CER credits spawned by the NPP would trade at a levelized rate of $ 19 per tonne of CO_2 emitted.[23] These figures are in approximate agreement with Paffenberger's conclusion that "Carbon values of roughly $ 25 - 35/tonne would bring nuclear power into competition with coal-fired power...."[24]

The key to this strategy is to make sure that the CDM operates in a way that encourages partnerships between utilities in developed countries with the need for emission credits, and their counterparts in developing countries with the capacity and infrastructure to operate NPPs.

This option should be particularly attractive to utilities which are familiar with existing nuclear electric technology, and which need to offset their existing CO_2 emissions by generating CER credits, rather than by paying carbon taxes, or by investing in new construction or plant modifications. The scenario outlined above is reasonable, but it contains a number of assumptions. The operation of market forces will lead to negotiations and compromises, and thus to the refinement of these assumptions. Left unfettered, the market place should guide us to the most cost-effective means for generating emission trading credits through the CDM.

Advanced Technology awaiting Demonstration

New technical options for nuclear power have matured to the point where they can and should be included in any discussion of how to meet the growing energy requirements of developing countries while minimizing GHG emissions. Several advanced designs are characterized by a high degree of maturity with respect to all their engineering aspects, and some have even passed major regulatory hurdles. They therefore will require neither long lead times for commercialization, nor vast sums of money for additional R&D. All the costliest research and development is complete.[25] Some advanced designs for the first time bring "walk-away safety"[26] to NPPs. They also hold out the quite realistic prospect of producing electricity at prices competitive with coal, even in the absence of a carbon tax.

What has prevented the demonstration and deployment to date of these advanced designs? The answers seem to be: nuclear stagnation in developed countries, and the lack of venture capital in developing ones. At the moment, there is little to be done about the former, but the latter can be addressed through the CDM mechanism.

At present, it does not seem to be sufficiently appreciated that the potential availability of this new safe and relatively inexpensive energy source opens opportunities for climate-friendly expansion of energy supplies in developing countries. Nor does anyone seem to have made a clear connection between the CDM and the new technology.

A hypothetical case will illustrate how the CDM could be used to break the logjam that now prevents deployment of the new technology[27]. For the sake of discussion, we assume that an autonomous authority in a developing country has sufficient financial resources and firm plans to deploy six coal-fired power stations, each of 1,000 MW(e) by the year 2025. We further assume that there is advanced modular NPP technology waiting to be demonstrated with a 100 MW(e) basic module costing $ 300 M (total of all R&D&D)[28]. The technology is sufficiently mature that the main purpose of the demonstration is to verify that the generating cost will be lower than that for coal, that is, in the range of $0.03 - 0.04 per kWh. If the target generating cost is achieved in practice, the autonomous authority agrees: a) to build 60 additional modules, in 6 installations each of 1,000 MW(e), in place of six coal-fired plants of the same capacity; and, b) to assign part or all of the CER credits generated by the entire project to the investor that supplied the venture capital for the R&D&D.

An analysis[29] of the resulting emission trading benefits (using levelized discounted costs) indicates that, at each respective commissioning date of the six 1,000 MW(e) installations, the present value of avoided CO_2 emissions is 6.35 million tonnes (actual = 26 million tonnes over 40 years). As of January 2006, the present value of avoided CO_2 emissions by the 61 units over 40 years would be about 166 million tonnes.

There are at least two ways to handle the financing and trading credits:

> If the outside investor bears the entire $300 M cost of the R&D&D and receives the rights to trade credits for all 61 modules, the emission trading rate would be $ 8.8 per tonne of carbon emitted.
>
> Alternatively, the autonomous authority in the host country might absorb some fraction of the R&D&D cost itself. If, for example, the authority were to pay one-third of the R&D&D cost, the emission trading rate for credits from the 61 modules would drop to $5.9 per tonne of carbon emitted.

The foregoing analysis reveals the high economic attractiveness of this strategy under the given assumptions. It should appeal especially to large, sophisticated electric utilities with nuclear know-how. In this scenario, a relatively small investment spawns a large quantity of CER credits which can be used to offset emissions, or traded with the prospect of substantial profit[30]. There is risk involved, but it has to do mostly with uncertainty about the actual cost of electricity generation with the advanced modular reactor. A detailed feasibility study would reduce this uncertainty substantially.

Using the CDM to enable an R&D&D project based on an advanced reactor design is a qualitatively different approach from one based on existing commercial NPPs. The goal in this case is not simply a one-at-a-time substitution of an NPP for a coal-fired generator. Instead, it is an exploration of a realistic way to fundamentally restructure the energy sector in large developing countries away from heavy reliance on carbon fuels. It seems likely that such a restructuring must be part of the global strategy to combat climate change. A century in which, for example, the annual energy use per capita of some 1.2 billion Chinese (877 kWh in 1996) rises to even half that in the USA (12,047 kWh) may be disastrous for the global climate if it is fuelled mostly by coal, oil, and gas. Expansion of renewable sources at a rate sufficient to meet the developing world's rising energy demands remains highly uncertain on technical grounds, but it is certain to be costly at best. In this context, it would seem not only logical but highly desirable to invest in a parallel exploration of advanced nuclear technology --- technology that holds out a realistic prospect for producing electricity in developing countries safely and cost-effectively.

IV. Summary and Conclusions

The Win-Win-Win strategy described here appears not to have been mentioned previously, probably because the developed world never looked seriously at the possibilities of deploying nuclear power in developing countries, and also because some interests do not wish to see nuclear promoted anywhere due to concerns over environmental and health risks.

The role of NE needs to be re-thought, given the extreme seriousness of the risk of rapid climate change, and the very few technically feasible means of avoiding it. At least there should be no constraints imposed on developing countries wishing to include nuclear power in their sustainable development plans. This freedom of choice is likely to be particularly important to emerging economies with existing nuclear know-how and extensive infrastructure.

It seems a certainty that nuclear energy will generate tradable CER credits among Annex I states. It would be highly discriminatory, and without basis in international law, to not allow developing countries to exercise this option as well.

The CDM reinforces the key role developing countries must play in solving the problem of limiting future CO_2 and other GHG emissions, while meeting their justifiable needs for sustainable development. It creates a means of financing NE projects in developing countries as a feasible way of meeting both goals.

It is therefore of great importance that the COP to the Kyoto Protocol elaborate the CDM mechanism in a way that allows market forces to determine what mix of energy sources, including nuclear energy, can best serve the twin aims of restricting GHG emissions, and allowing developing countries to respond to their pressing energy needs.

Acknowledgements

The authors gratefully acknowledge the substantial contributions of IAEA staff members H. H. Rogner and C. Hu to the development of this paper.