CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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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 $55.00 annually, $25.00 to retirees, $15.00 to students.

La SNC procure aux Canadiens intéressés à l'énergie nucléaire un forum où ils peuvent participer à des discussions de nature technique. Pour tous renseignements concernant les inscriptions, veuillez bien entrer en contact avec le bureau de la SNC, les membres du Conseil ou les responsables locaux. La cotisation annuelle est de 55.00 $, 25.00 $ pour les retraités, et 15.00 $ pour les étudiants.

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Editorials

A New Lease on Life

The first few months of this year have been eventful ones for the Canadian nuclear community.

Earlier in the year the Atomic Energy Control Board announced that it had received approval for a 30 per cent increase in staff over two years. Not only does this mean new opportunities for CNS members, it also heralds a new era in nuclear regulation. The AECB will be increasing its inspection activities and deepening its reviews of design and safety analyses. If licensees thought the AECB was difficult in the past, they can look forward to much more critical questioning of proposals and more extensive examination of operations. When this is combined with the cost-recovery policy announced earlier, the nuclear industry can anticipate both more regulation and a bill to pay for it.

The really encouraging news was the announcement by the Minister of Energy, Mines and Resources about the future of the nuclear program. With the promised new funding for nuclear research and development from the utilities and the restoration by the federal government of some of the money it had cut from its budget, AECL Research Company can proceed to expand the scientific and technical support so essential to a successful program. For the staff of CRNL and WNRE this should remove the uncertainty that has pervaded the sites. Now, needed research programs can be planned and needed upgrading of facilities can go ahead.

The future of CANDU Operations is less clear. However, even though the eventual structure of the organization will not be known for some time, staff there are assured of continuing design work on CANDU-3 and can look forward to excellent prospects for several projects in the future.

Perhaps 1990 will be remembered as the year the Canadian nuclear program was revived.

A Fond Farewell

The news of Eva Rosinger's appointment (as Director-General of the Council of Ministers of the Environment) was both welcome and saddening. It should be reassuring that someone as involved in the nuclear program as our president was named to such a post. While her selection was primarily a reflection of her abilities it nevertheless suggests that "nuclear" is no longer anathema in the political world of the "environment." Unfortunately, however, she will have to sever her active involvement in the CNS to avoid any perception of bias.

We will miss her.

The Bulletin

It is not easy to follow the former editors of the *Bulletin*, David Mosey and Keith Weaver. Certainly the editorial comment will be much less erudite. Although they have offered to continue to contribute, the pressure of their current work will, unfortunately, prevent this from being very extensive. Ontario Hydro's gain is the *Bulletin*'s loss.

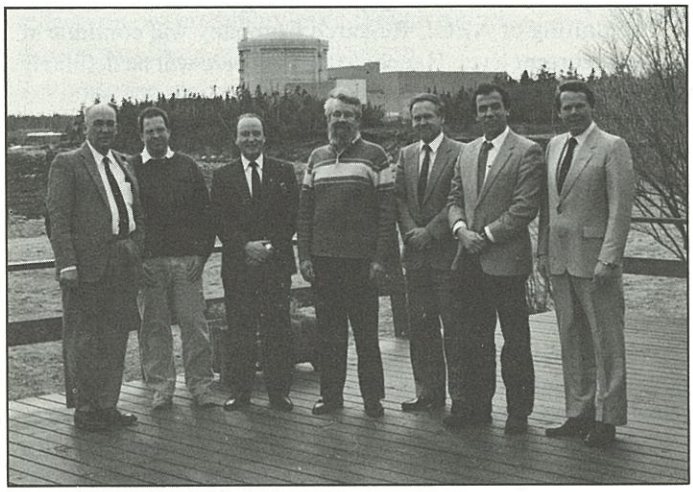
A change of personnel is an almost obvious occasion to re-examine the *Bulletin*, especially its objective. The CNS Council has conducted several discussions on the topic in recent months. Although no new explicit policy has emerged members of Council have indicated that the *Bulletin* should reflect the activities and interests of the members of the CNS.

The only way that can be achieved is through your contributions. We need news of the branches, appointments of members, viewpoints on relevant topics and succinct technical articles.

There appears to be relatively broad agreement that the *Bulletin* should not try to emulate peer-reviewed journals (despite the demise of the *Nuclear Journal of Canada*). We would be pleased, however, to print summaries of technical papers that would alert readers to the availability of the full paper elsewhere.

We welcome your comments.

Fred Boyd



The CNS Council held its March 1990 meeting at Point Lepreau. Shown during a break in their deliberations are (left to right): Roger Steed, Paul Thompson, Ken Talbot, Gil Phillips, Keith Bradley, Bill Midvidy, Dennis Bredahl.

Special Report

A Revitalized Nuclear Program

Ed. Note: ***On March 30 the Minister of Energy, Mines and Resources, Jake Epp, announced several initiatives designed to "revitalize" Atomic Energy of Canada Limited and the Canadian nuclear program. The following article is based on material provided by AECL and EMR and, in particular, on a special interview granted to the*** **Bulletin** ***by Dr. William Hancox, Corporate Vice-President, Technology and Planning, at AECL.***

The three "nuclear" utilities, Ontario Hydro, Hydro Quebec and New Brunswick Power have agreed to provide increased funding for AECL's research and development program and the federal government will maintain its funding at the current level, the Minister of Energy, Mines and Resources announced recently.

Specifically, Ontario Hydro will contribute an additional $30 million, Hydro Quebec $3 million and NBEPC $1 million, for seven years, indexed against inflation. With these increases their combined funding will be almost $80 million per year. In turn the federal government will "stabilize" its funding at the 1989/90 level for seven years, cancelling the decrease of $31.5 million scheduled for 1990/91 under the five year cut-back initiated in 1987. The utility contribution will be routed through the CANDU Owners Group program which coordinates research and development in support of the Canadian nuclear power program.

"We can now plan our R and D program for seven years," said Bill Hancox, AECL VicePresident for Technology and Planning. "Of immediate importance," he added, "we can now bring equipment and buildings back into good order."

The staffing of AECL Research Company will continue at about the current level, Hancox stated. "There will be definitely no reductions," he affirmed.

AECL plans to set up a Research Advisory Panel of external experts to serve as a peer review panel, somewhat analogous to the Technical Advisory Panel which has been reviewing the waste management program for several years.

The newest facility at the Chalk River Nuclear Laboratories, the MAPLE X-10 reactor, is not particularly affected by the new initiative. Its construction was based on commercial considerations as a producer of radioisotopes. "When completed (next year) it will allow NRU to concentrate on research," Hancox commented.

On the design side, CANDU Operations will proceed with the detailed design of CANDU-3, the new 450 MW CANDU intended for smaller Canadian utilities and the export market. The objective of the design is to achieve a simpler, lower-cost plant that can be built in a relatively short time and can be competitive with coal-fired plants. CANDU Operations, which has operated essentially as a separate commercial unit, is looking optimistically at the future of this design. The Minister announced that the Government of Canada will be entering into negotiations with New Brunswick for the construction of a prototype CANDU-3 at Point Lepreau.

One of the aspects that will be pursued during the completion of the CANDU-3 design is discussions with the Atomic Energy Control Board to resolve licensing issues before a specific project is begun. "We must remove uncertainty (of licensing) as much as possible," Hancox commented. "The (recently approved) new staff at the AECB should help," he added.

The government has also endorsed CANDU Operations negotiations for a second CANDU at Wolsong in Korea. In that case it would be a CANDU-6, essentially a twin of the Wolsong I plant. The major hurdle is that the plant must be competitive with coal-fired plants.

The Minister's statement also referred to a "restructuring" of the nuclear power industry, involving the creation of a new corporation to replace CANDU Operations, with the participation of utilities and private-sector firms as well as AECL. "The current structure of AECL does not permit it to have partial ownership," Hancox noted, which means that some legal modifications will be needed.

In addition to the good prospects for Lepreau 2 and Wolsong 2, the recent Ontario Hydro Demand/Supply Plan shows a preferred option of ten large CANDU units. This, plus expectations of additional work on the units being built in Romania has led to a renewed spirit of optimism at CANDU Operations.

"The prospects, both in the commercial area and in research and development are very good," Hancox commented. "With the stable funding (now committed) we can maintain a strong R and D program," he added.

For members of the Society Hancox had encouraging closing words. "There definitely will be opportunities in design," he said, "and the prospects for R and D are very good."

Time to Change our Image

With the advent of the environmental-awareness age, nuclear power generation appears to be on the verge of recapturing respectability and acceptance by the public. If impending doom as prognosticated by many environmental experts is to be avoided, then indeed the nuclear dream must become a reality.

Nuclear technology can claim, based on available evidence, that if environmental degradation, let alone a catastrophe, is to be avoided then that is sufficient reason to exploit nuclear energy which minimizes the ratio of environmental damage to energy consumption. But, does the public believe that?

Forty years ago the nuclear proponents had a dream which the public accepted, the promise of a utopian tomorrow based on almost limitless, safe, nuclear power. Twenty years ago the critics, both anti-nuclear activists and those with honest concerns, began questioning safety, waste disposal, risks of major and devastating accidents, and exploiting – by avoiding qualification – the association with nuclear weapons. Within a few years, the anti-nuclear activists had convinced enough of the public, and hence the politicians, that the uncertainties and risks of nuclear were sufficient cause to reject it.

But something else happened during the past decade. The environmentalists entered upon the scene; many technologies, excessive and wasteful consumption, selfish business interests, power-seeking politicians, all stood condemned. The thrust of the environmentalists' message was certainly quite justifiable; to protect the future, mankind needs to minimize damage to the environment and use resources wisely.

Today a significant fraction of the public, and hence many politicians, recognize and support the campaign to use energy efficiently and employ power-generation techniques that minimize environmental damage.

Nuclear qualifies under these criteria. But is that same fraction of the public, many of whom have condemned nuclear out-of-hand, aware of the relatively environmentally-benign nature of nuclear and ready to accept it? If not, can we persuade people that nuclear is not the villain, with respect to either risk or environment, that it has been portrayed to be?

The current picture for nuclear power in Canada, as judged by media reports, is encouraging: there is renewed interest by utilities and public acceptance is improving. Although the evidence is encouraging, there is no carved-in-stone guarantee that the industry is about to recover. To improve the likelihood of it happening, we must gain the public's trust, understanding and awareness that what we have to offer is not a threat, but a benefit with minimum risk and damage to the environment.

What is our public relations record? Many years ago, the media broadcast our science and technology with its attendant potential benefits to mankind. Then the critics began to gain attention, raising points such as: the potential for lethal radiation damage; accidents do happen; waste disposal; irradiation doses to atomic workers; exposure of neighbouring communities to leakage; the 'what-if' scenarios; all reinforced by association with nuclear weapons! How did we answer? We cited data, statistics, our rules and regulations, our honest science and technology, ad inf. But the message has not been effective. We have been unsuccessful in debating; we tabled dry facts, while our critics played upon emotions. And of course the Three Mile Island and Chernobyl accidents occurred. Forget the risk analysis; the one-in-a-million did happen. The destruction of the nuclear dream accelerated!

Recently the CNA became proactive and through advertising has been attempting to explain the industry to the public. It is a step in the right direction. But we cannot be content with that campaign alone. Given current needs and the time available, the public must be convinced quickly that the exploitation of nuclear power technology is to mankind's benefit. The CNS, because it should be less vulnerable to accusations of self-interest than is the CNA, should seek to recapture the public's trust of nuclear technology. If that can be done, then the politicians, confident of public backing, will support the industry.

Can the CNS contribute to improving the image of nuclear technology, and hence public acceptance of the nuclear industry? Consider these suggestions:

1. Take a lesson from our critics, and present a more human face to the public, one that has emotion and warmth, and is not composed only of 'facts'. That is not to say that technical data should be suppressed or hidden. Indeed they are central to our arguments. But they cannot be left to stand alone.

2. Demonstrate our credibility. We must not knowingly suppress negative data, nor allow others to misuse either positive or negative data. As an example, the current revisitation of Chernobyl with the revelations that the authorities there were less forthright in revealing the full consequences of the accident reflects on our credibility, even though suppression of the information was likely a political decision.

3. Phrase the message in lay terms that can be easily associated with daily experiences. That is not to say the public cannot understand nuclear jargon, nor would it be wise to talk down to the public, but the message is more likely to be absorbed when less mental conversion is required.

4. Focus on the immediate future. If mankind cannot solve the problems currently threatening the environment, long-term problems such as permanent waste disposal, will become highly irrelevant.

5. Change our image; find words to describe the technology that don't instantly conjure up visions of Chernobyl or nuclear weapons. A difficult order to fill, but not impossible; and well worthwhile if successful.

Overcoming public reluctance to accept nuclear power won't be simple. But some new and positive ideas, well thought out, cannot but help. If indeed the global environment is at risk, nuclear power, which can be a major contributor to the reduction of that risk needs to be utilized.

A.W.L. (Duke) Segal

The Greenhouse Effect ... the real nuclear safety story?

Duane Pendergast

1 Introduction

We've heard a lot about the greenhouse effect from the press and defenders of the earth and environment since last summer. These are essentially the same people who promoted wind and solar power fifteen years ago and convinced governments to fund large research projects.

The disappointing performance of that heavily ballyhooed "alternative energy technology" led me to question whether the greenhouse effect is real or just another release of hot air from a small group of overly enthusiastic crusaders. If it is real can nuclear energy possibly make a difference? Can nuclear power really significantly replace fossil fuels with the great diversity of energy applications? How many nuclear plants are needed? Do we have enough fuel for them? Are construction materials available in sufficient supply?

The deluge of information we've been exposed to is in the form of disconnected snippets. I decided much of what I was reading and hearing didn't make sense, so I decided to review the situation myself to get sufficient information to form a considered opinion as to the reality of the greenhouse effect. It turns out that a large body of soundly based knowledge of the climate and energy supplies is available for that purpose.

2 The consensus global greenhouse scenario

Here is the situation as summarized by Professor Hare[1].

- Global surface atmospheric temperatures will increase between 1.5 and 4.5 degrees C over the next 40 years - based on the equivalent of doubling carbon dioxide in the atmosphere. (There are several other trace gases in the atmosphere as a result of man's activities. These contribute about as much to atmospheric heating as carbon dioxide. The "equivalent of doubling carbon dioxide" is thus taken to be a 50% increase in carbon dioxide throughout this discussion.)
- High latitudes will warm the most with warmer winters. Equatorial regions will warm to a lesser degree.
- It's likely that soil moisture will be less in mid latitudes - which include the chief wheat and corn growing areas.
- Sea-level may rise between 20 and 140 cm during the warming.
- These predictions are based on estimates of energy use and elaborate modelling of economic and ocean-atmospheric systems.

Professor Hare states that "this might mislead a listener unaccustomed to geophysical magnitudes". I think he means it sounds like a trivial effect. I agree. In fact it sounds so trivial that many Canadians express appreciation for the warmer winters the greenhouse effect is expected to bring. Quebec may be better able to grow grapes.[2] Professor Hare goes on to state; **"I have no doubt that we are discussing the central environmental problem of our times."** He and many other climatologists clearly believe this is a very serious problem and that adapting to these changes will pose great hardship. What is really driving their concern? What is all the fuss about?

3 The basis for the greenhouse scenario

Oxygen and nitrogen, the main components of the atmosphere, are transparent to radiation to and from the earth's surface. Water vapour, carbon dioxide and other trace gases in the atmosphere are transparent to energy coming from the sun but absorb reradiated energy from the earth's surface. This heats the atmosphere in a manner somewhat analogous to the heating of your car in the sun - or a greenhouse.

Carbon dioxide levels in the atmosphere are measurably increasing. Other greenhouse gases are increasing as well and provide a comparable heating effect.

Computer modelling of this radiative heating effect along with solar heat input variations, atmosphere to ocean energy exchange, atmosphere and ocean circulation, cloud cover effects and other influences provide the predictions leading to the summary from Professor Hare. His summary is based on the somewhat arbitrary assumption that greenhouse gases released to the atmosphere will be equivalent to doubling of carbon dioxide levels prevailing about a hundred years ago. Actual levels will be strongly dependent on world economies and energy use patterns. "Best estimate" projections lead to a doubling in about 50 years.

4 Overview, validation, and the big picture

Models of physical processes are only helpful to the extent that they are based on reality and give results which agree with reality. Complex computer models in particular need comparison with measured reality to provide believability (validation).

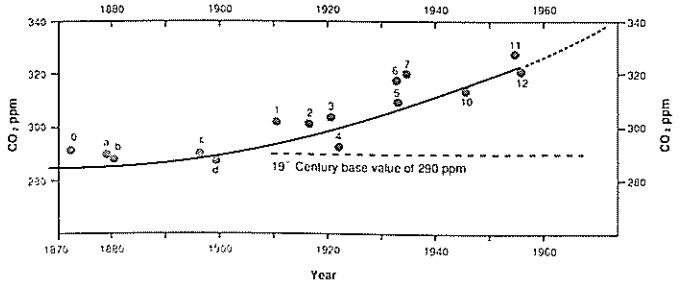


FIGURE 1 CO_2 IN NORTH ATLANTIC AIR 1870 - 1956

Carbon dioxide levels are most assuredly increasing. Figure 1 shows measured results back to 1870 retrieved from various sources and presented by Callendar[3] in 1956. An increase was already evident then. Figure 2[4] shows a subsequent continuity of rising levels at three locations remote from sources of carbon dioxide in the northern hemisphere from 1960 to 1988. Other studies have shown similar increases around the world. Carbon dioxide levels in the southern hemisphere lag behind northern levels. This is attributed to the relatively slow mixing[5] of the northern atmosphere, where 90% of fossil fuel emissions take place, with the southern atmosphere.

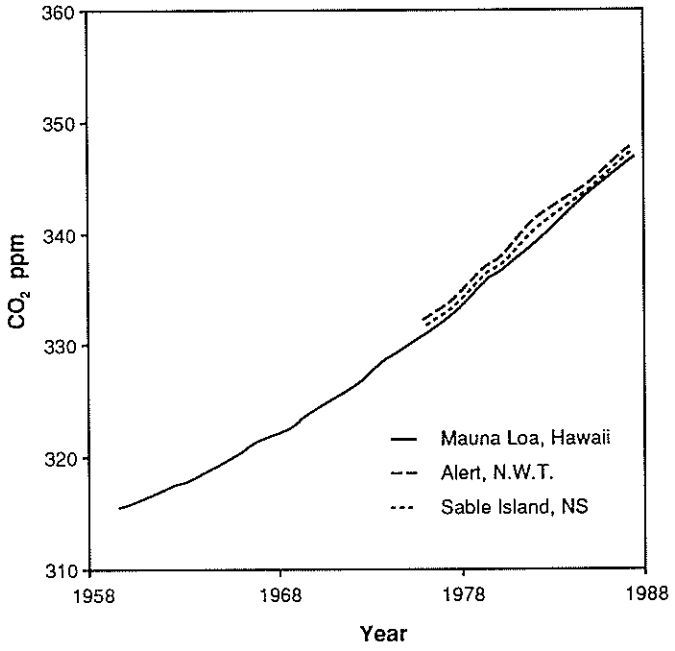


FIGURE 2 CO_2 AT SEVERAL SITES SHOWING MIXING

Recent rapid rises correlate with increasing fossil fuel use as demonstrated in Figure 3.[6] Figure 3 also gives an indication of carbon dioxide releases from changing land use including deforestation. Although it's hard to tell from the popular press which is most significant the information in Figure 3 suggests that fossil fuels must be the major contributor to atmospheric carbon dioxide. Measurements[7,4] of carbon 14 which is formed in the atmosphere and deposited in tree rings provides additional evidence that fossil fuels are a major source. Carbon 14 is not present in fossil fuels which are very old but is present in tree rings which are generally much younger than the 5730 year half life of carbon 14. The measurements indicate that carbon 14 levels in the atmosphere decreased until 1952 when nuclear bomb tests substantially increased atmospheric levels of carbon 14. This dilution of carbon 14 levels establishes little doubt that fossil fuels are the major contributors to atmospheric carbon dioxide.

A great deal of information on the quantities[8] and flows[9] of carbon from fossil fuels, plants, the atmosphere and the oceans is shown in Figure 4.[10] We can deduce from the information contained in Figure 4 that;

- The atmosphere contains about 700 billion tons of carbon in carbon dioxide.
- Plants consume and release the carbon dioxide in the atmosphere in about seven years. Some of this exchange involves interchange with the earth's soil through death and decay of plants.
- The oceans also absorb and release the atmosphere's carbon dioxide content in about seven years.
- Plants contain about as much carbon as the atmosphere.
- About 7 billion tons of carbon as carbon dioxide is released to the atmosphere annually. About 5 billion tons of this is from fossil fuels and the remainder is from changing land use. Four billion tons are absorbed by the oceans leaving an additional 3 billion tons to accumulate in the atmosphere each year.
- Recoverable fossil fuels contain about 7 times as much carbon as the atmosphere.
- The oceans contain about 70 times as much carbon as the atmosphere. A small fraction of this carbon is close to the surface and the atmosphere.
- The earth's soil contains substantially more carbon than the atmosphere.

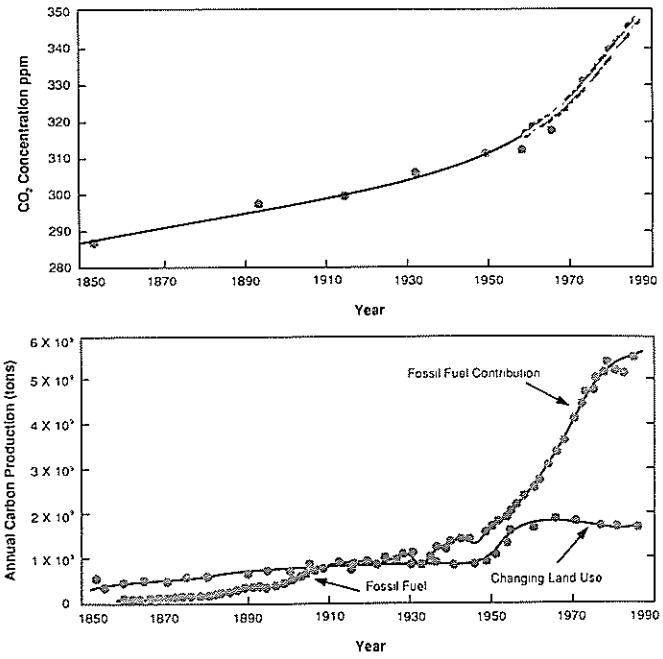


FIGURE 3 GREENHOUSE GASES AND FUEL USE

This information reveals the difficulty of modelling future atmospheric carbon dioxide content. Not only is the annual addition to the atmosphere small in comparison with net flows to and from plants and oceans - future energy use is not easy to predict either. Engineers and scientists thus seem to base their estimates of future carbon dioxide content on extrapolations of measured atmospheric carbon dioxide adjusted for revisions in energy use patterns. "Best" estimates of short term projections suggest an effective (taking into account the other greenhouse gases) doubling of carbon dioxide by about the year 2030[11]. Thus many detailed projections of consequence focus on a doubling of carbon dioxide. Most of the fossil fuel reserves would remain for further additions to the atmosphere. Some discussion of validation studies follows.

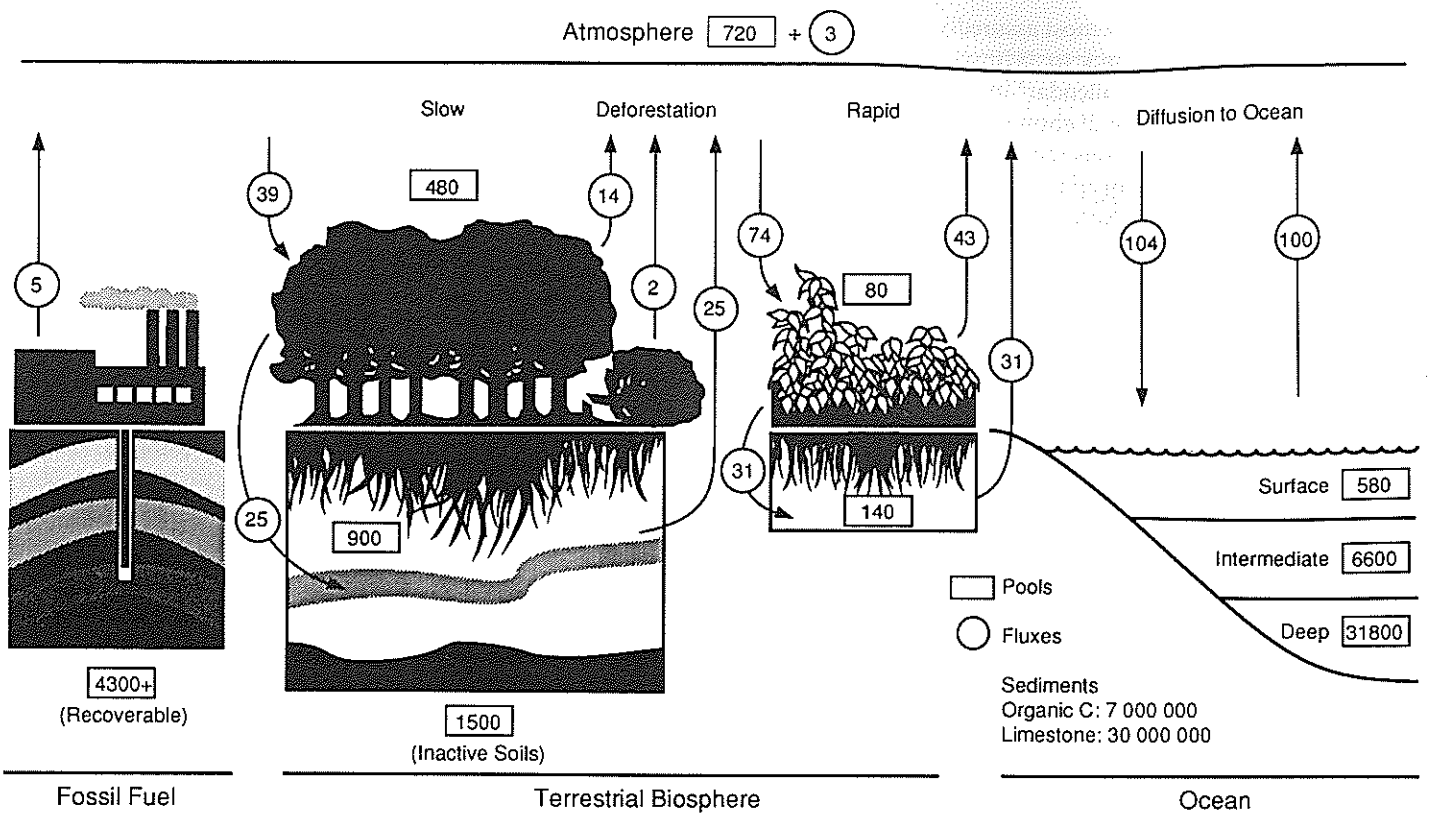


FIGURE 4 GLOBAL CARBON CYCLE POOLS AND FLUXES BILLIONS OF TONS AND BILLIONS OF TONS / YEAR

The estimated increase in mean temperature for the past 100 years when records have been kept and fossil fuel has been burnt is only about 0.5 degree C. This is lost in normal weather variations and on our senses. Nevertheless models for mean global temperature increase show a degree of agreement with measurements when volcanic effects, solar heating changes, and heat exchange with the oceans is factored in. Work done by Hansen in 1980 is shown in Figure 5.[12] The agreement with measurement is quite satisfying but is not taken as proof that carbon dioxide is increasing the temperature. Another two decades of "business as usual" was expected to yield a clear signal in 1984.[13] We should thus expect to clearly measure greenhouse heating shortly after the year 2000.

Three dimensional time dependent computer models have evolved as a byproduct of numerical weather prediction models. These are the only source of predictions of local environmental changes as a consequence of carbon dioxide induced heating. Stephen Schneider discusses validation of these models in a recent issue of *Trends in Computing*.[14] He compares model predictions with seasonal variations of climate and with changes occurring following the last ice age. The seasonal variations are very satisfying to those of us who have used related models to predict some aspects of reactor operation. (The post ice age predictions are – well?? – a bit fuzzy! At least to those of us who model the better defined fluid flow conditions relating to nuclear reactors!) Schneider goes on to discuss three dimensional models of the greenhouse effect and concludes that they are not only too consumptive of computer time to predict the next century but are also not yet sufficiently trustworthy.

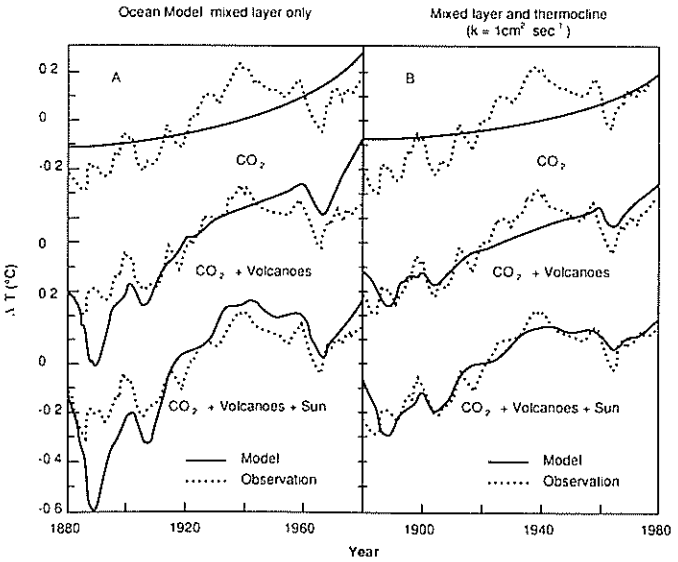


FIGURE 5 GLOBAL TEMPERATURE TREND FROM MODEL
A 100-m mixed ocean layer
B 1000-m mixed ocean layer

I found another article from *Scientific American*[15] which discusses recently[16] obtained ice cores going back more than 150,000 years to be particularly interesting. Gas trapped in bubbles in the ice provides evidence of carbon dioxide and methane levels as a function of time. Directly measured atmospheric carbon dioxide levels (Figures 1 and 2) correlate well

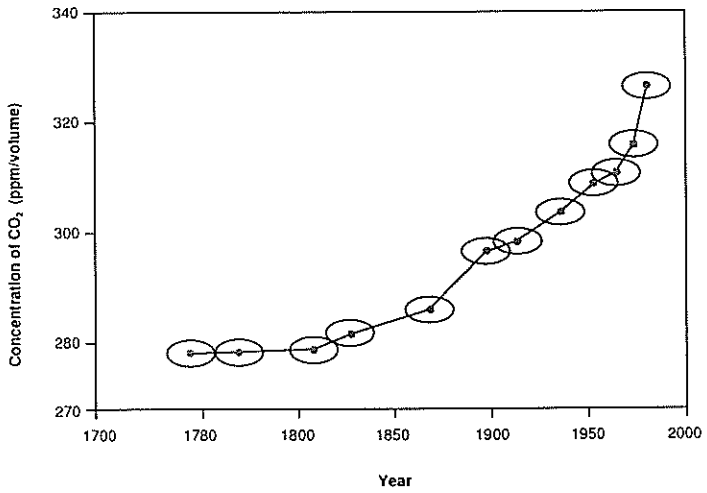


FIGURE 6 CO_2 IN GLACIER AIR BUBBLES - RECENT

with the ice core bubble measurements (Figure 6[17]) as far back as 1870. Oxygen 16 to oxygen 18 ratios in the core give a measure of past temperatures as well. Temperature and carbon dioxide levels rise and fall together(Figure 7[18]) although climatologists do not assign a cause and effect relationship to this observation. I was particularly impressed by the small variation of carbon dioxide over the past 160,000 years compared with the potential changes man could bring about through enthusiastic increases in consumption of our fossil fuel reserves.The ice core data seems to be great material for further validation of models.

I've noted that climatologists seem to be particularly concerned with being accused of "crying wolf". The press has picked up on the consensus position outlined in Section 2 above. This is a pretty middle of the road position. It's a wide road. Predictions of climate and fuel use are quite uncertain. The big picture seems to be that there is sufficient fossil fuel and we're currently using it quickly enough to make the greenhouse effect much worse in the long run than the consensus 50 year projection. Another one or two hundred years of fossil fuel use at current rates, or higher, could cause much larger heating which in turn would result in more flooding and other adverse effects. I suspect the uncertainties and worse case scenarios are driving the strong expressions of concern from our climatologists.

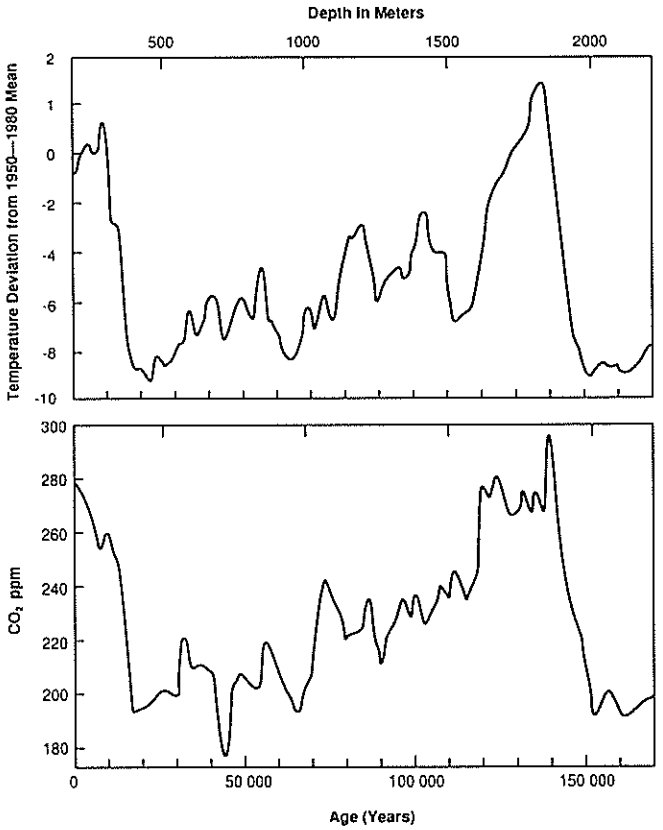


FIGURE 7 CO_2 IN GLACIER BUBBLES AND TEMPERATURE

5 Can nuclear energy help?

The world uses a lot of energy for electricity, heating, transportation and chemical processes. Data on world generating capacity[19] and the fraction used for electricity generation[20] suggests that seventy five hundred 1000 megawatt power plants would be able to replace all this energy. I'm not quibbling over capacity factors or efficiency of various applications. About ⅓ of world energy consumption is used for electricity production at present. Thus twenty five hundred 1000 megawatt nuclear power plants would replace existing electricity generating capacity.

Nuclear power already makes a significant contribution to electricity production[21] of around 15%. Water power contributes 20%. Fossil fuels contribute the rest including most heating, transportation, and process needs.

Nuclear and water power are potential solutions to the greenhouse problem as their operation contributes very little carbon dioxide to the atmosphere. Since large water power sites are limited only nuclear power remains as a "here now" technology to replace power from polluting fossil fuel plants.

We've built about 500 plants in the short time we've been dabbling in nuclear power. I don't think it takes a big stretch of imagination to consider building another 2000 of them to replace current means of electricity production. This would reduce carbon dioxide emissions about 25% but would not go very far in ameliorating the greenhouse effect on its own. In fact this would amount to only a 10% to 15% reduction of current greenhouse gas production since it would have little effect on the other greenhouse gases man is responsible for generating.

Converting some systems such as transportation to nuclear power to further ameliorate the greenhouse effect requires more effort. Hydrogen fuel generation may be one feasible route to maintaining existing lifestyles and population. Nuclear plants could generate the electricity to produce the hydrogen. The cost of needed power plants is judged to be within the realm of possibility even by those who are not in favour of a "nuclear response[22]" to the greenhouse problem. I think feasibility must take into account the massive economic feedback effects which would result from such a huge commitment to nuclear power. What else might we do to ameliorate the greenhouse effect?

6 Some additional potential solutions

Grow more forests? The data from Figure 4 indicates existing forests contain about $\frac{1}{10}$ as much carbon as the reserve of fossil fuel. If we could force the growth of 10 times the current forest mass over the projected life of fossil fuel reserves (500 - 1000 years) and stockpile the wood we would solve the carbon dioxide problem while happily burning up all of our fossil fuel reserves. One author[23] suggests additional forest three times the size of Alaska would absorb the three billion tons of carbon dioxide annually added to the atmosphere at current rates. A

greater amount of formerly forested land is thought to be available for this purpose.

Conservation is cited as a major means of coping with the greenhouse. This has substantial potential. The energy crisis of the early 1970's, resultant high prices, and legislated automotive fuel economy did reduce oil use[24] temporarily. Bill Keepin and Gregory Kats present an analysis[25] which purports to show that efficiency improvement alone is 2.5 to 10 times more cost effective in reducing carbon dioxide than revitalizing nuclear power.

Others advocate a switch from coal to natural gas. This reduces carbon dioxide, for a given energy output, by about half.[26] I see this as a short term partial solution until natural gas runs out.

7 What does this have to do with nuclear safety?

The title of this article asks if the real nuclear safety story hinges on the greenhouse effect. Where does safety come into this? Continued heavy burning of fossil fuels poses a significant risk to world population through greenhouse heating and pollution of our living space. Nuclear power is the only credible low carbon dioxide producing alternative in hand in sufficient quantities to replace fossil fuel. Waste products from the nuclear fuel cycle are sufficiently small to be contained. If risk from nuclear power is smaller than risk from fossil fuel then nuclear power is *the* safer energy source.

8 Review and discussion

We are burning fossil fuels at an unprecedented rate and releasing carbon dioxide to the atmosphere which natural processes cannot remove quickly enough to avoid increased carbon dioxide in the atmosphere. Computer models indicate a carbon dioxide induced heating effect which climatologists believe will lead to profound changes in our way of life.

Nuclear power may well have a major role to play in reducing carbon dioxide emissions from energy production. The nuclear industry has a responsibility to understand and propagate understanding of the role nuclear energy has to play in protecting the environment. In view of the complexity of the technical problem and its intertwined relationship with the world economy this will be a difficult task. I raised some questions on nuclear fuel and material supplies in the introduction. I suspect this will be queried by our critics in coming months and intend to follow up this note with a review of nuclear material availability. I also mentioned conservation in Section 6. I intend to examine the credibility of that alternative.

9 Conclusions

I set out to evaluate the reality of the greenhouse effect in the light of my earlier disappointment with the alternative energy movement. I'm convinced that the hue and cry we've been hearing for the past year *is* based on solid research. A systematic research program extends back in time about 30 years and continues. The greenhouse issue does have more substance than windmills and solar power.

Nuclear power has substantial potential to ameliorate the greenhouse effect while maintaining us in the style to which we have become accustomed. In fact nuclear power may well turn out to be *the* safe energy option.

Further Reading

Some useful and readable articles have been published since I prepared this. In particular I recommend a series of three articles appearing in *Popular Science* magazine starting with the August 1989 issue.

The September 11th issue of the *New Yorker* includes a near book length article titled, "The End of Nature". This informative and somewhat melancholy review concludes that we should curtail our endless growth and give nature a second chance.

The September issue of *Scientific American* is devoted to the theme, "Managing Planet Earth". Articles on the climate, the atmosphere and energy use are of particular relevance to the greenhouse effect.

Finally, should you wish to get into this in detail, Reference 5 below provides a lot of information and several hundred additional references to the scientific literature.

Acknowlegements

My thanks to Ernie Siddall and Professor F. Kenneth Hare for technical reviews and helpful advice, John MacPherson for his technical editing and to Jo-Anne Prinzen for her help with finding information.

References

1. Hare, F. Kenneth, The Global Greenhouse Effect, **Proceedings of the Toronto Conference on the Environment,** World Meteorological Association, WMO - 710, Toronto, 1988, pp. 59-68.
2. Singh, B., The Implications of Climate Change - Quebec, **Environment Canada**, 1988.
3. Callendar, G.S., On the Amount of Carbon Dioxide in the Atmosphere, **Tellus X(1958) II**, pp. 243-248.
4. *Loc. cit.* 1. - Figure 2 is adapted from Figure 1 of Ref. 1.
5. Bolin, B., 1986. How Much Carbon Dioxide Will Remain in the Atmosphere? In: The Greenhouse Effect, Climatic Change, and Ecosystems, Bolin, B. et al (Eds.), SCOPE 29, Wiley.
6. Houghton, R.A., and Woodwell, G.M., Global Climatic Change, **Scientific American**, Vol. 280, No. 4, April 1989.
7. *Loc. cit.* 5, Sect. 3.3.3., pp. 101.
8. Rotty, R.M., The Nature of the CO_2 Problem: Certainties and Uncertainties, **Environmental Progress**, Vol. 3, No. 4, November, 1984.
9. *Loc. cit.* 6, Figure 3 adapted from figure on page 39.
10. Figure 4 is based on information from Ref. 8 and Ref. 6 for quantities and flows respectively.
11. *Loc. cit.* 1, Sect. 3.
12. Figure 5 is adapted from Ref. 8.
13. *Loc. cit.* 8, pp. 257.
14. Schneider, S.H., Climate Modelling, Trends in Computing, Vol. 1, No. 1, pp. 132-139: Reprinted from **Scientific American**, May, 1987.
15. *Loc. cit.* 6, pp. 39-40.
16. Barnola, J.M., *et al*, Vostok Ice Core Provides 160,000-Year Record of Atmospheric Carbon Dioxide, **Nature**, Vol. 329, No. 1, (October) 1987.
17. Neftel, A., *et al*, Evidence from Polar Ice Cores for the Increase in Atmospheric Carbon Dioxide in the past two Centuries, **Nature**, Vol. 315, No. 2, (May) 1985: Adapted from Figure 1.
18. Adapted from Ref. 6 and 16.
19. FOCUS, **Atomic Energy of Canada Limited**, AECL 9726-2, Fall/Winter 1988, Part C, Table 14.

20. *Loc. cit.* 19, Part C, Table 16.
21. *Loc. cit.* 19, Part C, Table 9.
22. Keepin, Bill and Gregory Kats, Greenhouse Warming: Comparative Analysis of Nuclear and Efficiency Abatement Strategies, **Energy Policy**, (December) 1988.
23. *Loc. cit.* 6, p. 44.
24. *Loc. cit.* 8, Figure 3.
25. *Loc. cit.* 22.
26. *Loc. cit.* 22, Endnote 26.

Technical Note

Who's Afraid of the Doomsday Argument?

George F. Schumm

Here's a depressing thought. Suppose you were entered in a lottery, a large one or a small one, though you did not know which. Suppose you won. You would then have evidence that you were entered in the small one, perhaps very strong evidence depending upon the sizes of the two lotteries. This is because the probability of your winning is greater given that you were entered in the small one than given that you were entered in the large one. By parity of reasoning, the human race will either enjoy a relatively short run, ending by, say, 2050 A.D., or else survive beyond that date. But the probability that you are alive today given that the race will end by 2050 A.D. is greater than the probability that you are alive today given that it will not. So the fact that you are alive today is evidence that the human race will meet its demise by the year 2050. Moreover, the more optimistic one is about the future of the race should make it past 2050, the stronger the evidence your present life is of impending disaster.

This Doomsday Argument has been defended recently by Professor John Leslie and used to motivate a plea for greater caution in risk assessment. (See 'Risking the World's End', this *Bulletin*, 10 [May/June, 1989], pp. 1-6.) If the argument works at all, it shows that any risk of human extinction is far worse than one ever would have imagined. Paraphrasing slightly:

> To illustrate, let us simplify and say that there are just two possibilities. The first is that the human race will end before 2050; the second that it will survive for many millions of years but be confined to our solar system. Simplifying again, let us say that the chance that any particular human picked at random out of the entire temporal career of the race is alive today is 0.1 if the race ends before 2050, while otherwise it is only 0.001. And finally, let us suppose that after considering all threats to humanity's survival, you conclude that the chance of the race meeting disaster by 2050 is only 1 per cent. That is to say: 1 per cent is your estimate prior to letting the harsh light of the Doomsday Argument shine on the fact that you yourself are alive today. Let '*E*' and '*A*' abbreviate the statements 'The human race will end before 2050' and 'You are alive today,' respectively. Then by Bayes' Theorem, we find that

$$Pr(E|A) = \frac{Pr(E) \times Pr(A|E)}{(Pr(E) \times Pr(A|E)) + (Pr(\ E) \times Pr(A|{\sim}E))}$$

$$= \frac{(.01 \times \tfrac{1}{2})}{(.01 \times .1) + (.99 \times .001)}$$

$$= 0.5, \text{ plus a tad.}$$

> In other words, your estimate of the chance of disaster should be revised upwards to a frightening 50 per cent.
>
> When it is assumed that the human race, if it passed 2050 safely, would spread so widely beyond the solar system that 0.001 needs to be replaced by 0.000001, then the estimated chance of a disaster rises much further, to almost exactly 99.9 per cent. (p. 2)

The problem with this argument is that *you* are not a randomly selected individual. Indeed, you are quite atypical among humans who live prior to 2050 in that you are alive today, and you were selected for the argument precisely because of that atypicality. Thus, from the fact that $Pr(x \text{ is alive today} / E) = 0.1$ for any randomly selected x, one may not infer that $Pr(A|E) = 0.1$. On the contrary. By the Requirement of Total Evidence, $Pr(A|E)$ must be computed relative to all available background information bearing upon your being alive today, and presumably that includes the very fact that you *are* alive today. So, when properly computed, $Pr(A|E) = 1$. Likewise, $Pr(A|{\sim}E) = 1$. And when we now run these numbers back through Bayes' Theorem, we find that $Pr(E|A) = 0.01 = Pr(E)$, just as one would expect. Intuitively, your being alive today has no bearing upon the fate of the human race beyond that already packed into $Pr(E)$.

For the Doomsday Argument to work, you (or someone) would have to be selected at random and be found to be alive today. But no such person has ever been picked, nor is there any reason to think that one ever will be. Or could be. Not knowing what humans will be born between now and 2050, let alone whether or not the human race will end before that date, neither does one know what the applicable reference class is and hence what names to put into the hat.

I have been interpreting probabilities objectively, as seems to have been the intent. What if we go subjectivist instead? You *could* coherently have degree of belief 0.1 that you are alive today given that the human race will end before 2050 and also degree of belief 0.001 given that the race will not end. (Perhaps you were duped into swallowing Professor Leslie's fallacious inference.) In that case, the Doomsday Argument would indeed dictate a dramatic increase in your subjective degree of belief as you move from $Pr(E)$ to $Pr(E|A)$. But this gives you no cause to anticipate disaster since you (strongly) doubt that you are alive today! Or do if you are rational, because rationality requires that

$$Pr(A) = (Pr(E) \times Pr(A|E)) + (Pr({\sim}E) \times Pr(A|{\sim}E))$$

$$= (.01 \times .1) + (.99 \times .001)$$

$$= 0.00199.$$

Of course, you might stop being silly (perhaps by reading and taking to heart the preceding paragraphs) and come to believe that you are alive after all. But this is of little help since for any reasonable person (i.e., someone whose degrees of belief are both content and sensible), the Doomsday Argument cannot provide grounds for pessimism. The reason is not hard to see. By Bayes' Theorem,

$$Pr(E|A) \times Pr(A) = Pr(E) \times Pr(A|E).$$

Now if you are reasonable, $Pr(E)$ is close to 0. Remember, we are talking here about the end of the *entire* human race – every last specimen – in the next sixty years, something even a nuclear holocaust is unlikely to achieve. So $Pr(E) \times Pr(A|E)$ must be close to 0. That means that $Pr(E|A) \times Pr(A)$ is also close to 0. Presumably, however, $Pr(A)$ is close to 1. No need to be dogmatic about it. Even a reasonable person might want to allow for the slim possibility that he has died and gone to Heaven deluded. But surely you have overwhelming evidence that you are presently alive, and this will be reflected in your degree of belief (reasonable soul that you are). $Pr(E|A)$ will therefore have to be close to 0.

If you are a reasonable person, $Pr(E|A)$ can be only marginally greater than $Pr(E)$. For $Pr(E|A)$ to be significantly greater, as is required for the Doomsday Argument to succeed, you would already have to be unrealistically pessimistic either about the future of the human race or about being alive. And this robs the argument of any interest on a subjectivist reading. If you start out with silly beliefs, it should hardly be surprising when rationality dictates that you have other silly beliefs as well. Garbage in, garbage out.

None of this, of course, impugns the need for caution in risk assessment in general, and it leaves untouched Professor Leslie's independent (and rather chilling) argument for special care in the area of high-energy physics. The world is scary enough, even without the Doomsday Argument.

Acknowledgements

My thanks to Stewart Shapiro for helpful discussion and to Calvin Normore for bringing the Doomsday Argument to my attention.

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The Social Impact of the Chernobyl Disaster

David R. Marples. Introduction by Victor G. Snell. U. of Alberta Press (1988). ISBN 0-88864-136-2

Reviewed by Ric Fluke

David Marples draws on his expertise in East European studies, and in particular the Soviet Ukraine, in presenting a comprehensive and objective analysis of the events following the reactor accident at Chernobyl, and their social consequences, in his book, *The Social Impact of the Chernobyl Disaster.* But because he lacks expertise in nuclear technology, he obtained the services of Victor Snell, Manager of Safety Engineering, Atomic Energy of Canada, Limited, to provide an introduction to the technical aspects of nuclear reactors and the Chernobyl accident.

The Chernobyl accident has been by far the worst in the history of nuclear electric generation, measured by the 32 casualties, and by the far-reaching release of radionuclides. The long-lived Cesium isotopes in the fallout have contaminated land and food as far away as Sweden, which has drastically disturbed the livelihood of the Lapplanders who depend on reindeer, which feed on the contaminated vegetation. But the damaging "fall-out" after the accident was not all radioactive; some of the damage was preventable, because it was spurred by information of the most dangerous sort: misinformation! For example, David Marples discusses radiophobia, the paranoic fear of radiation. Radiophobia caused more sickness and ill health among residents in the Ukraine region than did the actual radiation. Probably as a result of distrust for the authorities, many people feared contamination of food that was quite safe, and so they did not eat meat, fresh produce nor dairy products, which resulted in poor health. Some overuse of thyroid pills was cited, which led to some suffering. Sadly, some pregnant mothers had evidently obtained abortions, against medical advice, because of these radiophobic perversions. Radiophobia was certainly not allayed by "that expert from the West," Dr. Robert Gale, with his dire predictions of tens of thousands of cancer deaths from the radioactive contamination. The major cause of radiophobia, according to Marples, is dissemination of inaccurate information about radiation. David Marples appears to have spared no effort in order to present views of great diversity among the "experts," Western as well as Soviet. Such diversity of opinion can only fuel the problem of radiophobia, just as a lack of information can.

The social impacts discussed by Marples form an impressive list with an extensive coverage: the victims, those who died fighting the reactor fire as well as the controversial number of ultimate casualties; the general state of confusion and mismanagement of the emergency response; the attitudes and fears of those directly affected; the impact on energy supplies during the winter that followed; the special efforts to contain the radionuclides and prevent contamination of the water reservoirs; and even the impact of the nuclear debate that followed, which now is leaning in the anti-nuclear direction. These discussions are quite detailed, well documented and certainly well researched, resulting in a well balanced, objective analysis. Some new insights as to why the town of Prypyat was not evacuated until 40 hours after the accident, for example, are presented. But the primary goal of Marples was to assess whether or not Soviet thinking about nuclear power and safety has been fundamentally changed as a result of Chernobyl.

In presenting his analysis and citing his references, numerous examples of inconsistency in the information from official Soviet sources are indicated. So many so, that I felt a hint that Marples was "Soviet Bashing." Nevertheless, it is difficult, based on Marples' sources of information, to distinguish whether a statement on policy made by a Soviet official is based on logical deduction of events and circumstances, or based on "party line" retroanalysis. This could be the result of two needs: protection and compensation for the local residents affected by the accident; or, "propatection" of a dynamically ineffective bureaucracy. According to Marples, the land around Chernobyl is not particularly important for agriculture, and the power output of the Chernobyl station is a drop in the bucket for the grid. Much larger areas of prime agricultural land have been sacrificed and their residents relocated for the development of hydro electric power dams. Therefore, the marginal lands of the "Special Zone" 30 km around the accident site could easily have been declared a "dead zone" and simply forgotten, with very little impact on agriculture or power production. However, this would be inconceivable for the Soviets. Official Soviet history records that Chernobyl was a success. It is important to the Soviets that they demonstrate that the land affected by the accident can be made productive again, that the people can return to their native lands, and that the nuclear station can be put back into production. Such objectives, however, are often masked by more socially oriented goals to protect and compensate the people. As a result, there were inconsistencies in the areas where food supplies were controlled or restricted compared to reports on radiation levels for those areas. In one example cited, fishing was banned in waters that had less contamination than where fishing was permitted.

Why did such inconsistencies occur? The offical Soviet response as cited by Marples was that it was a consequence of poor coordination. In Marples view, however, "The dead zone had been revived, against all odds, and seemingly against all reason." But whether these inconsistencies were the result of some hidden agenda of conscious parallelism, or as the Soviets claim, a poorly organized bureaucracy, makes for interesting speculation but is not really all that important. The importance lies in the lessons learned and how the negative social impacts of any crisis, radiophobia for example, can be minimized.

Because Marples has only a limited knowledge of nuclear technology, he obtained the expertise of Victor Snell, of AECL, to write an introduction to the book. Snell does this in a laid-back manner which facilitates easy understanding, while not sacrificing the necessary technical details. He explains the workings of nuclear reactors in an easy-going manner, and discusses some of the similarities and differences between the Soviet RBMK design and the CANDU. Even the complexity of how a shutoff rod can actually insert positive reactivity, with the opposite from desired outcome, is explained with ease.

In my opinion, however, this technical introduction is not relevant to the main topic (social impact), and furthermore, it distracts from an otherwise excellent dissertation on the social aspects of the accident. Certainly, I believe, the cause of the Chernobyl accident does not require a technical explanation, because the machine, really, "performed" as expected. Using Snell's gasoline engine as an analogy, if that engine were to be operated by a bear, with the throttle butterfly removed, the centrifugal governor disconnected, the oil pump blocked, the ignition switch jumpered closed, and the gasoline replaced by nitro-methanol, then the engine would "perform" as expected: it would be blown apart. Indeed, I believe that the accident was a social event entirely, because it was the social system of the nuclear technology that failed.

Having expressed my positive views on the introduction, there are three aspects which I feel must be challenged. First, the use of "Canadian Position" is very inappropriate. Second, some of the statements are misleading to those outside the Canadian nuclear industry. Finally, there are some errors.

The "Canadian Position" in the context of the introduction is only the opinion of the author, and to some extent, AECL. The term is wrong and should have been referred to as "Snell's Position," or something like "(Us Bunch Who Did Some Physics Calculations)'s Position." The positive scram theory is not necessary to explain the reactivity runaway, and is in fact disputed according to "(Another Bunch Who Did Some Physics Calculations)'s Position" (see Luxat, J.C. and Spencer, B.W., "Insights to the Phenomenology and Energetics of Reactivity Initiated Accidents," *NUCSAFE 88*, 2-7 October, 1988, Avignon, France). Furthermore, to have any theory accepted by the Soviets as "plausible" is not exactly my idea of "Canadians filling in the holes." This use of poetic licence is not justified. It fails to acknowledge the fact that some of the "Canadian Experts" that helped to "fill in the holes" do not share the relevance of the positive scram theory, and were not all members of AECL!

There is a misleading impression given by Snell's statements about the containment design for Canadian nuclear reactors. He describes "the Canadian Design" of a single unit containment system enveloping the entire reactor system. In describing the Chernobyl design, he notes that the containment structure and suppression pool protect against a large pipe break, but that there are many smaller pipes outside this containment structure, surrounded by an enclosure "of ordinary construction." He states that he cannot understand this. "Why not build containment around the whole reactor and all its piping?" he asks. Does this imply that AECL no longer supports "the Canadian Design" of 12 CANDU reactors? From the Soviet viewpoint, Chernobyl containment was designed for postulated accidents that could reasonably be anticipated. I am not aware of any different approach in Canada, or any other country, except that "reasonably anticipated" may vary in depth and extent.

The comments made by Snell about containment design, positive scram, and fast shutdown systems are consistent with his premise, that the accident was "caused" by human error and design weaknesses. With such oversimplifications, it is easy in hindsight to point the finger at any number of design changes that could have prevented the accident. Such changes are a good thing, and according to Marples, were a primary reason for the Soviet energy crisis in the winter following the accident: the nation's reactors were shut down systematically to install many of these design changes. But the design weakness *per se* did not cause the accident. Nor did "human error," really, because they all did what they were told to do. Thus, the "cause" of the accident according to Snell is incorrect, and is inconsistent with the conclusion of Marples in the main text of his book. The cause given by Marples was "running nuclear power plants improperly and an insufficiently vigilant attitude toward the dangers of the atom." Human error itself can certainly be the sole cause of an accident, and is a convenient scapegoat for a larger problem that may exist: failure of the social infrastructure that makes up the industry, from design, regulation, and operation. This "failure" could be a lack of understanding of the interrelationship between human and machine. It could be a failure to anticipate that a human may attempt to circumvent rules or procedures for some larger motive.

At the risk of becoming overly critical of a commendable effort in describing a complex technology in simple language, there is a small albeit inexcusable error in Snell's translation of the acronym "RBMK", *viz.* "reactor cooled by water and moderated by graphite." He calls it a rough translation, but it is wrong. RBMK is applied to reactors of that description, but it means something about as descriptive as the name we use in Canada (RWBB) to describe a black bird with red wings: RBMK = (Reactor Bolshoi Moschnosti Kipyashiy) Large Power Boiling Reactor.

Letter to the Editor

Dear Sir:

The Autumn 1989 issue of the *Bulletin* includes an article "The Road to CANDU" which is based on my notes for two talks I gave last year. It was understood that I would be given an opportunity to comment on the text before it was published. This was not done.

Editing has resulted in many improvements, but it has also introduced questionable changes and some errors. I discuss a few examples of the latter types: On page 18, right hand column, line 7, "those irradiated slugs" should read "the early fuel rods"; on page 19, right hand column, line 4 under Fuel, "and I" should be replaced by "and a metallurgist"; here and elsewhere I am given credit which I neither claimed nor deserve; in lines 8 to 10 of this section the editor treats bonding as a standard U.S. practice whereas I understood it was merely being considered; on page 19, left hand column, line 4 from bottom, I wrote that NRX was the "best research reactor"; if the editor knows that I am mistaken the appropriate change would have been "one of the best"; the editor's term "most powerful" has little significance.

D.G. Hurst

Ed. Note: Our apologies to Dr. Hurst. The copy and his request were caught up in the changeover of editors.

TECHNICAL SUPPLEMENT

CNS Bulletin Spring 1990 Canadian Nuclear Society

INSPECTION AND MONITORING OF CANDU REACTOR FUEL CHANNELS

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ABSTRACT

Inspection and monitoring of CANDU Reactor fuel channels is performed to satisfy regulatory requirements, to provide information about known or suspected problems, and to provide information to assist in maintenance and future components design. In order to satisfy these requirements with minimum shutdown time and manrem expenditure many techniques and systems have been developed. This paper provides an overview of these capabilities.

1.0 INTRODUCTION

Ontario Hydro's CANDU (Canadian Deuterium Uranium) nuclear reactors produce approximately half of the total electricity demand for the Province of Ontario.

The CANDU design is characterized by natural uranium fuel, heavy water moderator, pressure tube containment of primary coolant, bundle fuel and on power refuelling, Figure 1. The most significant feature in the design is the use of a multiple fuel channel configuration rather than a single large pressure containment vessel. Each reactor has between 390 and 480 fuel channels, depending on its capacity. They are mounted horizontally within a horizontal cylindrical vessel, the calandria, and are surrounded by the low pressure, low temperature heavy water moderator.

Each fuel channel assembly, Figure 2, is made up of a zirconium–2.5% niobium alloy pressure tube of nominal 103.4 mm inside diameter, 4.3 mm wall thickness, and a length of 6.3 m. Each end of the tube is attached by means of a cold rolled joint to a stainless steel endfitting. Each endfitting has a coolant piping connection and contains a closure plug that can be removed by automated machines to allow on–power refuelling. External and concentric with the pressure tube is a thinner tube of Zircalloy–alloy, known as the calandria tube, that separates the hot pressure tube from the cool moderator. Dry nitrogen or carbon dioxide gas fills the annular space between the tubes and up to four "garter spring" spacers keep the tubes from touching each other.

Because of the critically–important role of the pressure tubes as part of the primary pressure boundary, it is necessary to confirm their structural integrity and collect data related to changes in their material properties. Also, changes in the geometry of the pressure tube and the condition and relative position of other fuel channel components must be monitored in order to predict maintenance requirements and assist in the design process. In order to address these needs, Ontario Hydro maintains two inspection programs for pressure tubes. The Periodic Inspection Program (PIP) involves inspecting a small sample of tubes in each reactor on a recurring basis, to ensure the detection of generic problems. The requirements of PIP are mandated by the regulatory authority, the Atomic Energy Control Board (AECB). The second program, the In–Service Inspection Program (ISI), is directed

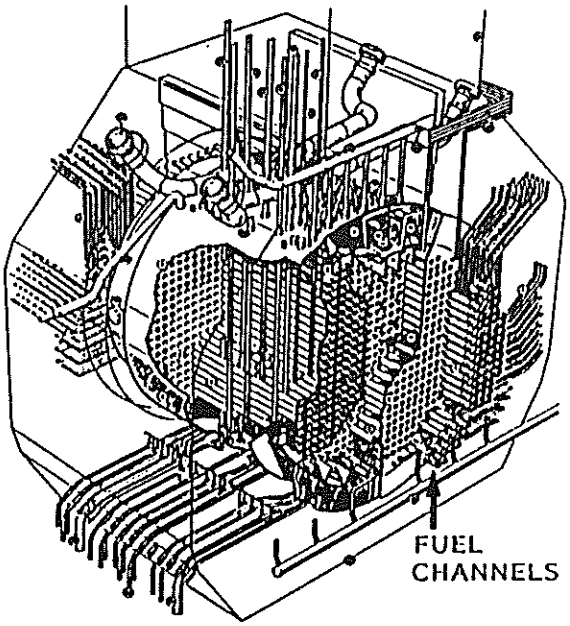


FIGURE 1
CANDU REACTOR ASSEMBLY

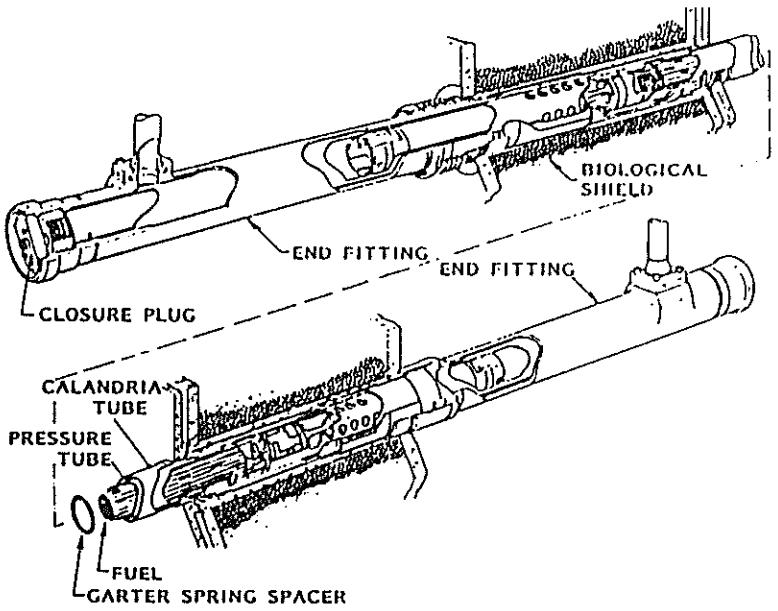


FIGURE 2
TYPICAL CANDU FUEL CHANNEL

by Ontario Hydro with AECB concurrence. It aims to provide specific information about known or suspected problems. The objectives of the ISI program are changed as the requirements for information change.

In order to satisfy these requirements and also minimize both outage time and radiation exposure to personnel, many techniques and inspection systems, some of them highly-automated and multifunctional, have been developed. Part 2 reviews the measurement techniques that are now available for the inspection and monitoring of fuel channel components. Part 3 briefly describes some of the multifunctional systems that have been developed to implement these methods.

2.0 FUEL CHANNEL INSPECTION AND MONITORING METHODS

2.1 Summary

Fuel channel inspection and monitoring capabilities have been developed progressively as needs have been recognized. AECL instituted monitoring programs for the NPD and Douglas Point reactors involving in-channel gauging and also tube removals. When Ontario Hydro's first CANDU reactors at Pickering were commissioned, the periodic inspection program required that the inside diameter, sag profile, length and surface profilometry of a small number of tubes be measured every 5 years. The diameter, sag and length were required to confirm that the irradiation creep and growth of the pressure tube was in agreement with the design equations. Profilometry was used to assure that the fuel bundle bearing pads were not unduly wearing the tube surface. The equipment used for this inspection, known as the Dry Channel Gauging Equipment, is described in Section 3.1. Operating experience at Pickering and later reactors rapidly broadened the scope of inspection methods that were required.

A summary of current inspection methods and systems that have been developed to meet these needs is presented in Table 1. The following paragraphs provide an overview of these developments. For more information on particular methods or systems, references are cited in Table 1.

2.2 Pressure Tube Flaw Detection

2.2.1 **Volumetric Inspection Methods**

Prior to 1974 in-service volumetric inspection of pressure tubes (inspection of the full volume of the metal for flaws rather than just its surface) was not believed to be necessary. The tubes were volumetrically inspected during manufacture; operating conditions were not thought to be conducive to flaw development and there was no previous experience of flaw growth. However, in 1974, leaks developed in some Pickering Units 3 and 4 fuel channels. The cause was found to be cracks that had developed in the pressure tubes at the rolled joints due, in part, to improper installation procedures. The leaking channels were located using acoustic emission techniques described in Section 2.6. However, many other channels had partial cracks that had to be located to prevent future problems. Ultrasonic rolled joint inspection equipment was developed by AECL and Ontario Hydro to locate these flaws. The equipment and its capabilities are discussed in section 3.2.

Bruce NGS A was under construction at this time and pressure tubes had already been installed in Units 1 and 2 using similar procedures as those used for Pickering 3 and 4. Remedial measures (stress relieving of the rolled joints) were undertaken

TABLE 1 FUEL CHANNEL INSPECTION & MONITORING TECHNIQUES

FUNCTION	TECHNIQUES	EQUIPMENT/SYSTEM	REACTOR STATE DURING USE	FURTHER INFO REF. #
Pressure Tube Integrity Monitoring				
- Flaw Detection, Characterization and Sizing	Ultrasonic Inspection	CIGAR*, PIPE*, SLAR	SD - wet*	1, 2, 17
	Eddy Current Inspection	AECL-SPAR STEM Drive	SD - dry	
		CIGAR (late 1989)	SD - wet	1
	EMATs (ElectroMagnetic Acoustic Transducers)	Under development	O.P.	
- Surface Profilometry	LVDT (Linear Variable Displacement Transformer) Stylus Probe	CIGAR	SD - wet	1, 16
	Mini Gauging Equipment		SD - dry	
	Super Mini Gauging Equipment		SD - dry	
- Visual	Silicone Rubber Replication	Replica equipment	SD - dry, only used preservice todate	
	CCTV (Closed Circuit Television)	AECL SPAR-STEM drive	SD - dry	
		CIGAR (late 1989)	SD - wet	
Pressure Tube Geometry Monitoring				
- Diameter	Ultrasonic Gauging	CIGAR	SD - wet	1
	LVDT	Dry Channel Gauging Equipment	SD - dry	
- Wall Thickness	Ultrasonic Gauging	CIGAR	SD - wet	1
	Ultrasonic Gauging	SLAR	SD - wet	3
- SAG Measurement	Servo-inclineometer	CIGAR	SD - wet	1
	Laser Deflection	Laser Sag Measurement Equipment	SD - dry	4
- Elongation	Linear Displacement Measurement	STEM	O.P./SD	5,10
- Bearing Travel	Linear Displacement Measurement	Yoke Nut Gap Measurement Tools	SD - wet	6
		Stud Measurement Tools	SD - wet	11
		Spotface Measurement Tools	SD - wet	8
Pressure Tube Hydrogen Content	Sample scraping	Dry channel scraper	SD - dry	
		- Wet channel scraper (under development)	SD - wet	
Calandria Tube Geometry				
- Diameter	LVDT Measurement	Dry Channel Gauging Equipment	SD - dry PT removed	19
- SAG Measurement	Integrated curvature method	Dry Channel Gauging Equipment	SD - dry PT removed	19
- Elongation (Endshield Separation)	Theodolite survey method	Theodolite & Laser Survey Equipment	SD - wet	7
	invar tape measurement	Invar Tape Tooling	SD - dry	9
	Absolute endshield measurement with respect to vault structure	Endshield Measurement Tooling	O.P.	12
Calandria Tube - Horizontal Control Mechanism Clearance	Ultrasonic gauging from Mechanisms	Under development	SD - wet	
	Eddy current gauging from pressure tube	Under development	SD - wet	
Garter Spring Spacer Location	Eddy Current Method	CIGAR	SD - wet	1, 15
	Eddy Current Method	SLAR	SD - wet	3, 18
	Eddy Current Method	BLIP	SD - wet	15
	Eddy Current Method	SLAP (under development)	O.P.	
	Pressure Tube Curvature Method	COG/CRNL curvature tool (under development)	O.P.	
Annulus Gas PT-CT Gap	Eddy Current	SLAR	SD - wet	3, 18
		CIGAR (late 1989)	SD - wet	
Annulus Gas Flow Measurement	Laser Thermography	Under development	SD - wet	
Channel Leak Location	Acoustic Emission (AE) (feeder connection leaks, closure plug leaks, pressure tube leaks)	Remotely operated AE leak detection system	O.P./SD	13, 20
	Ultrasonic detection of water in pigtails	Pigtail probe	SD - wet	14
	Primary Heat Transport Temperature Depression	Reactor instrumentation	SD - wet	
	D2O Analyser	AGS wet string locator	SD - wet	

*CIGAR - Channel Inspection and Gauging Apparatus for Reactors
AECL SPAR-STEM drive - Delivery system developed by AECL based on a SPAR Aerospace STEM (registered Trademark) drive unit
SLAR - Spacer Location and Repositioning
STEM - Scanning Tool for Elongation Measurement
PIPE - Packaged Inspection Probe
BLIP - Blister & Spacer Location Inspection with PIPE
SLAP - Spacer Location on Power
COG - CANDU Owners Group
AECL - Atomic Energy Canada Limited
CRNL - AECL - Chalk River Nuclear Laboratories

SD - wet Reactor shutdown, cold, and depressurized - water in the channel being investigated
SD - dry Reactor shutdown, cold and depressurized - channel being investigated is isolated from the system and drained
OP Reactor On Power - hot and pressurized

and a reinspection of the full length of the pressure tubes was performed using eddy current inspection techniques delivered by the SPAR-STEM delivery system developed by AECL/CRNL.

This equipment and its capabilities are discussed in section 3.3 During the pre-service eddy current inspection of Bruce 1 and 2 tubes, a defect was discovered in one tube. Further investigation revealed that it was introduced during manufacture of the tube and had not been detected by the manufacture's inspection. Changes were subsequently made to the tube manufacturing and inspection procedures to reduce the possibility of this type of flaw re-occurring.

The development of rolled joint cracks and the discovery of a manufacturing flaw in a tube in reactor highlighted the need for a new inspection system capable of performing volumetric flaw detection in addition to other periodic inspection requirements. The system had to operate quickly and require very little radiation exposure to operating personnel. To meet these needs, the CIGAR system (Channel Inspection and Gauging Apparatus for Reactors) was developed. This equipment and its capabilities are discussed in section 3.4. It came into service in 1985 and has become the primary fuel channel inspection and gauging system in use since then. The CIGAR drive, a complex automated system, was just entering its commissioning phase when the catastrophic failure of pressure tube G16 occurred at Pickering Unit 1 in August 1983. CIGAR's capabilities were required but attempting to use such a complex system untested in a radioactive environment was out of the question. A small manually installed drive system was quickly developed by AECL-SPEL that operated with the CIGAR inspection heads, drive rods and inspection instrumentation. The system, christened CIGARette, fulfilled the immediate inspection need by determining that the conditions that had caused the failure of G16 were present in many other fuel channels in both Pickering Units 1 and 2. The CIGARette equipment and its capabilities are described in section 3.5.

Another catastrophic event lead to further developments. In 1986 Bruce Unit 2 pressure tube NO6 started to leak and subsequently failed. Investigation showed that the leak was caused by a crack that grew from a manufacturing defect of similar origin to that mentioned earlier. Concern was raised about the possibility of other manufacturing defects being present in Bruce 1 and 2 and Pickering 3 and 4 pressure tubes. (Pickering 1 and 2 were being retubed and the tubes in later reactors had been subjected to improve manufacturing inspection).

From a knowledge of the manufacturing process, these flaws are expected to occur only in certain tubes (known as deep pipe tubes), and only at one end of the tube, ie, through the rolled joint region. Three separate programs have been undertaken to address this manufacturing defect concern.

First, an in-service inspection program has been established to perform full length volumetric inspection of all installed "deep pipe" pressure tubes using CIGAR.

Second, special equipment was developed and a program established to inspect the offcuts (rings of pressure tube material cut off each end of every pressure tube when it is installed and kept in archives) of all tubes installed in Ontario Hydro's reactors/23/. This reinspection includes the use of a high frequency ultrasonic method that was found to have better detection sensitivity to some manufacturing flaws than the conventionally used methods. (This method is also now required for the manufacturing inspection of all new tubes made for Ontario Hydro).

Finally, it was decided that a new system was required to rapidly inspect only the rolled joint region of pressure tubes in Ontario Hydro's older reactors. The CIGAR system can inspect only 2 channels/day. The new system, PIPE (Packaged Inspection Probe), can inspect approximately 24 rolled joints/day. The system was first used in Bruce Unit 2 in 1987. A description of the equipment and its capabilities is given in section 3.6.

2.2.2 **Surface Profilometry**

The Dry Channel Gauging equipment used for periodic inspection of pressure tubes prior to the introduction of the CIGAR system had a strain gauge stylus type surface profilometer. Its primary function was monitoring the depth of fuel bundle bearing fret marks and fuelling scratches on the bottom of the tubes. By the time CIGAR was being developed, it had been determined that fuel fret marks were not a serious problem and that monitoring of them could be carried out by eddy current methods. Consequently, a profilometry capability was not developed for CIGAR at that time. Later, concern arose about possible fretting of some pressure tubes in a Pickering B unit by debris that might have escaped from a broken strainer during commissioning of the unit. An LVDT (Linear Variable Differential Transformer) stylus type profilometer that can be used in the waterfilled channel was developed for CIGAR and used successfully to measure the depth of fretting damage located by the ultrasonic flaw detection system.

A more widespread fretting problem in a Pickering B reactor led to the development of a number of other surface inspection systems. During the commissioning of Pickering Unit 8, cast iron weights with special bearing sleeves were placed in the pressure tubes to stop vibration from moving the garter spring spacers. Some of the sleeves caused fretting damage to the inside surface of the pressure tubes. Initially, the affected tubes were located using eddy current methods. The extent of damage at each location was then determined using one or more of the following tools developed by Ontario Hydro's Central Nuclear Services, Inspection and Maintenance Department, and AECL for assessment of this problem.

The mini-gauging system is a stylus type surface profilometry head attached to the AECL-SPAR STEM delivery system. The unit can measure depths up to 0.8 mm.

The super mini-gauging system is similar to the mini-gauging system but contains a Welch-Allyn Video Probe to allow the operator to view the area being profiled by the stylus.

CIRT (Circumferential In-service Replicating Tool) is a device which allows a 150 mm long full circumferential section silicon rubber replica to be made of the inside surface of a pressure tube. Excellent surface detail is obtained from which accurate depth measurements can be made.

These three tools developed for use in Pickering Unit 8 have only been used in a pre-service reactor. However, with some modification they should be capable of operating in in-service reactors if the need arises.

2.2.3 **Pressure Tube Visual Inspection**

A visual inspection capability based on a radiation resistant hermetically sealed Westinghouse CCTV (closed circuit television) system has been developed and used for inspection assessment of a number of in-service pressure tubes. The camera

head is mounted to the AECL–SPAR–STEM delivery system and must be used in an isolated and drained channel. Both axial and radial viewing heads are available. Head positioning, light intensity, focus adjustment and data recording are controlled from a location outside containment.

A new camera system that can operate under water and can be delivered by the CIGAR system is under development. This will allow wider use of visual inspection because it will not require the time and radiation exposure of personnel to isolate and drain the channels to be viewed.

2.3 Pressure Tube Geometry Monitoring

2.3.1 **Diameter and Wall Thickness Measurement**

The periodic monitoring of pressure tube diameter is important to assure that diametral creep and growth stay within the limits defined by the design equations. As mentioned in section 2.1, in the early 1970's pressure tube diameter gauging was performed using an LVDT measurement device on the Dry Channel gauging equipment. This equipment is still available but preference is now given to the CIGAR system that can be used in a wet fuel channel avoiding the problems of draining the channel. CIGAR uses an ultrasonic gauging system that measures wall thickness as well as diameter at 60 positions around the tube at 3 mm axial intervals along its length.

2.3.2 **Sag Measurement**

Measurement of the pressure tube displacement profile and the maximum vertical deflection (sag) are also a periodic inspection requirement. The Dry Channel gauging equipment measured the local curvature at many positions along the tube using an LVDT device. Displacement and maximum sag were calculated by double integration of this data. Although this equipment is still available, the CIGAR system is now preferred. It uses a servo inclinometer to measure the slope at many positions along the tube and calculates the displacement profile by single integration.

Another method that has been used to provide a quick but less accurate estimate of maximum pressure tube sag is Laser Sag Measurement. In this method, a laser beam is aligned to pass through the centre of the end of each end fitting. The beam is then raised until it just grazes the top of the sagged pressure tube and the magnitude of sag is calculated from the beam movements.

2.3.3 **Pressure Tube Elongation and Related Matters**

After only a few years of operation, length measurements indicated that Pickering pressure tubes were elongating somewhat faster than had been predicted. The dry channel gauging equipment required one to two days to perform measurements on each channel and a faster method of measuring length was required. Hand operated "spot face tools" were designed to measure the distance from the end of each endfitting to the spotfaces on the reactor endshields. Since the fuel channels were fixed to the endshield at the west face of the reactor, and free to expand on the east face, spotface measurements on the east end quickly gave a relative measure of the elongation of many channels. These tools, and the equivalent "stud tools" developed for Bruce and Darlington reactors are still used occasionally and have undergone considerable improvements since the originals.

The immediate concern about increased elongation at Pickering in 1976 was the need to adjust the "Yoke Nut Gap", a clearance between components to allow the fuel channel to freely expand when heated to operating temperature. Manually operated, "Yoke Nut Gap tools" were developed to allow this clearance to be measured before and after adjustment.

The increased number of elongation measurements showed that elongation rates vary slightly from channel to channel. Making manual measurements was time consuming and subjected personnel to radiation exposure. To allow the elongation of all channels to be measured quickly and without radiation exposure, a new device, STEM (Scanning Tool for Elongation Measurement) was developed. Different versions have subsequently been developed for all reactors. Measurements are made periodically and can be made either with the reactor shutdown (cold) or on power (hot). Being able to measure the change in length of the channel when it was hot provided assurance that the yoke nut gaps were properly set and that no other mechanism was constraining the channel from expanding as it should.
The increased data base available using the new tools confirmed the variation in elongation rates of different pressure tubes. This led to a concern that feeder pipes attached to adjacent channels with different lengths could contact and cause fretting damage. A wide variety of different hand tools were developed to measure feeder pipe clearance both in in-service reactors and to perform pre-service checks on new units under construction to assure that future problems could not occur. These tools ranged from simple devices such as hardwood sticks of varying thickness to complex mechanisms using motor driven airborne ultrasound transducers to sense feeder pipe position and distance.

2.4 Spacers, Blisters, Contact, Gap and Hydrogen Measurement

2.4.1 **Spacers**

Shortly after the failure of Pickering Unit 2 pressure tube G16, the cause was determined. "Garter spring" spacers that separate the hot pressure tube from the cooler calandria tube had moved from their design location allowing the two tubes to contact. High hydrogen in the tube had led to the formation of hydride blisters at the contact location. Cracks formed in the blisters when they got large and these eventually led to the failure.

Prior to the failure, the need to determine spacer location had not been considered. Within a few weeks, Ontario Hydro Research Division (OHRD), AECL-CRNL and New Brunswick Research and Productivity Council (NB-RPC) had developed eddy current devices capable of detecting the spacers. The AECL design proved to be superior and is now the standard used on CIGAR for in-service and periodic inspection and with SPAR STEM equipment for dry channel and reactor construction checks.

2.4.2 **Contact**

The spacer location coils and CIGAR ultrasonic flaw detection system were the primary inspection tools used during the inspection of Pickering 1 and 2 after the G16 failure. When a spacer was found to be significantly out of position, ultrasonic inspection usually detected a response on the bottom of the tube midway between the spacers. Cracks in the blisters gave fairly high amplitude response. Patches of lower amplitude response around and between the blisters were later shown to coincide with surface roughness and white oxide in the contact zone.

Inspections performed in other reactors (all of which have pressure tubes made of a newer alloy, zirconium 2.5% wt. niobium (Zr 2.5Nb)) have located some fuel channels with spacers significantly displaced from their design location. In these cases, low amplitude ultrasonic indications, interpreted as roughness and oxide, have been observed on the outside surface at the expected contact location. Some of these tubes have been removed and metallography confirmed that no blisters were present.

2.4.3 Blisters

Although no blisters have yet been found in reactors with Zr 2.5% Nb tubes, laboratory tests have demonstrated that they could occur in future. Hence, misplaced spacers and pressure tube/calandria tube contact is considered undesirable. Consequently, a Spacer Location And Repositioning system (SLAR) has been developed by the Candu Owner's Group (COG). While SLAR's primary function is not inspection, a number of new fuel channel inspection systems have had to be developed in order for it to perform its mission.

The SLAR system introduces significant bending stress in the pressure tube during the repositioning operation. If blisters were already present in a tube, the bending might cause them to crack or enhance existing cracking. A volumetric inspection system capable of rapidly detecting cracked blisters during a single axial pass through the pressure tube was required. OHRD developed the fastscan blister detection system. It uses 6 line focussed ultrasonic transducers that inspect the outside surface of the bottom 60 degrees of the pressure tube during a single axial pass through the tube.

More recently, a new inspection system dedicated to rapidly locating blisters and spacers has been developed for Pickering reactors. Known as BLIP (Blister and Spacer Location Inspection with PIPE), it utilizes the SLAR type fastscan blister detection system combined with CIGAR spacer detection methods. A description of BLIP is given in section 3.7.

2.4.4 Gap

In order for the SLAR system to reposition a spacer, it must centralize the pressure tube in the calandria tube to unpinch the spacer. A method was required to monitor the gap during the centralizing operation. AECL-CRNL developed a gap measurement system that uses both eddy current and ultrasonic inspection equipment. The primary gap measurement is made by a send-receive eddy current method. The result is sensitive to small variations in the pressure tube wall thickness. An ultrasonic pressure tube wall thickness measurement system is used to measure these variations and compensate the gap measurement for them. A version of this gap measurement system has now been developed for use with the CIGAR inspection system.

2.4.5 Hydrogen Measurement

The formation of hydride blisters at the contact between a pressure tube and calandria tube requires a high level of hydrogen (or its isotopes, deuterium and tritium) in the tube. At present, the only available method of determining the amount of hydrogen in a pressure tube is to remove a sample of tube material and analyze it. Dry scraper tools have been developed by AECL-CRNL which first remove the surface oxide layer and then scrape a 0.1 mm thick sliver of clean

material from a small area of the pressure tube. The present tools are manually operated. They require the fuel channel that is being inspected to be defuelled, isolated by freeze plugs in the feeders, blanked, drained and swabbed before the samples are taken. This is a fairly lengthy process requiring some radiation exposure to personnel. A new wet scraper tool is being developed by AECL-CRNL and Ontario Hydro Design and Development that can be put into a fuel channel and operated by a fuelling machine. This should allow faster measurements with less radiation exposure.

The number of scrape samples, and therefore, the number of axial positions at which hydrogen can be determined using this method, is limited in practice by time. Also, although the samples are small, a method that does not remove material from the tube would be preferable. Investigation has shown that electrical resistivity and ultrasonic shearwave velocity are parameters that might be related to hydrogen content. COG funded development of hydrogen measurement methods based on these concepts is underway but they are not yet available for in reactor use.

2.5 Calandria Tube Geometry Monitoring

2.5.1 **Calandria Tube Dimensional Gauging and Inspection**

Calandria tubes are inaccessible except when a pressure tube is being removed. There are no mandatory requirements to inspect or gauge calandria tubes. However, it is desirable to perform measurements when opportunities arise to assure that unexpected changes are not occurring. To allow this, calandria tube gauging, profilometry and curvature measurement heads have been developed to operate with the Dry Channel Gauging Equipment described in section 3.1. This allows measurements of the tube's overall length, diameter and ovality at many cross-sections; sag profile and maximum displacement; and surface condition at garter spring, contact and other locations. Tooling has also been developed to allow CCTV visual examination of the tube inside surface using the AECL-SPAR STEM delivered visual inspection equipment.

2.5.2 **Calandria Tube Elongation**

The measurement of increased pressure tube elongation led to concerns that calandria tubes might also grow, albeit at a much lower rate because of their lower operating temperature. The ends of the calandria tubes are rolled into the endshields of the calandria vessel. Hence, it was not possible to measure the elongation of an individual calandria tube in the reactor. Collectively, the elongations of all the calandria tubes would cause the endshields to be pushed apart. Although the reactor design allows for some change due to thermal expansion, pressure, etc. unexpected amounts due to elongation might cause future problems. Hence, methods of monitoring the separation of the endshields with time were developed. The first method used custom built tools, optical tooling and laser distance measuring equipment to survey a traverse around the reactor and measure the absolute separation of the endshields. Measurements were made on Pickering Unit 1 in 1975 and again in 1977. The results were somewhat inconclusive. If calandria tube elongation was occurring, the rate was less than could be measured by this method.

Another method was developed to measure the endshield separation that used a calibrated Invar tape to determine the overall length of a drained defuelled channel through its bore and spotface tools to measure the distance from the ends of the endfittings back to the endshields. This method has seen limited use because of the high cost of blanking and draining channels.

The last method employed radiation resistant measuring devices that were permanently mounted between the reactor vault floor and endshield cooling pipes attached to the bottom of the endshields. These devices were installed in Pickering Units 1 and 3 in 1982. Measurements could be made from outside the reactor vault both during shutdown and full power operation. Periodic monitoring of these devices over a 4 year period did not show changes that could be attributed to calandria tube elongation.

In the intervening period, AECL-CRNL have carried out accelerated specimen tests that indicate that calandria tube elongation rates will not be higher than assumed during the reactor design/25/.

2.6 Acoustic Emission Leak Location

A CANDU reactor's primary heat transport system consists of a large number of separate pressure boundary components; up to 480 fuel channels each with inlet and outlet feeder pipe connections and closure plugs for on power refuelling. Also, there are heavy water moderator and various light water cooling systems within the reactor that could possibly develop leaks. Despite the apparent potential, careful design, construction, operation and maintenance of these reactors has resulted in very few leaks occurring. However, it is very important to be able to detect a leak if it occurs and to quickly determine the location of the leak.

Leak detection systems are designed into the reactor. The annulus gas (carbon dioxide or nitrogen) flows through each fuel channel between the pressure tube and the calandria tube. The moisture content of this gas is constantly monitored during reactor operation. Also, air from the reactor vaults is circulated through driers and the collection rate is carefully monitored. An increase in annulus gas system moisture or dryer collection indicates that a leak exists. Analysis of the chemical, radiochemical and isotopic content of the collected water identifies which system is leaking.

To date all fuel channel leaks have been associated with the high pressure primary heat transport system and have been due to either feeder pipe connection leaks, closure plug leaks or through cracks that have occurred at pressure tube rolled joints due to improper installation or maintenance procedures.

To locate the specific component that is leaking, an acoustic emission (AE) system has been developed. It consists of instrumentation located outside containment connected via cables and preamplifiers to a sensor head mounted on the front of a fuelling machine. The sensor head consists of a round metal plate to which is attached a low frequency ultrasonic leak detection horn and one or more piezoelectric AE transducers with different frequency ranges. The round plate is acoustically isolated from the fuelling machine.

Location of the instrumentation outside containment allows the equipment to be used either during shutdown or full power operation. During use the device can be moved about in front of the fuel channels by changing the fuelling machine posi-

tion. In this mode, the low frequency ultrasonic leak detector senses airborne noise from closure plug leaks or local areas of higher than average airborne noise from feeder pipe leaks. A second mode of operation requires the fuelling machine to press the sensing plate hard against the end of a fuel channel endfitting. This allows higher frequency acoustic activity from leaks remote from the sensors, for example at the feeder connection or at the pressure tube rolled joint to be detected. The acoustic frequency spectra of a leak usually distinguishes it from other sources within the reactor. Experience has shown that feeder connection leaks > 1.0 kg/h and pressure tube leaks > 0.5 kg/h can be located with this system.

In 1982, a leak rate less than 0.5 kg/h was detected in Bruce Unit 2. Attempts to locate the leak with AE were unsuccessful so other methods were developed.

The "pigtail" tool is a pole with a pair of ultrasonic transducers on the end. When manually positioned on an annulus gas pigtail (small tubes joining one fuel channel annulus to another) it detects the presence or absence of water in the tube. Using these tools, the areas within the reactor where the leaks were occurring were localized.

The primary heat transport (PHT) temperature depression method provided similar information. After drying the annulus gas system, the reactor was heated and pressurized. The PHT temperature of all channels was monitored over a 36 hour period. As water entered the annulii of channels with leaks, more heat was lost to the moderator and the PHT outlet temperature was slightly depressed. Because many annulii are interconnected, this method and the pigtail tools can only determine the locality of the leak rather than the specific channel.

Two separate strings of channels were located using these methods and one leaking channel in each was then identified by ultrasonic inspection.

Another system developed but as yet not used for detecting small pressure tube leaks is the annulus gas "sniffer". It consists of flexible devices that are threaded into the inlet and outlet Annulus Gas System (AGS) headers to isolate and allow a gas sample to be drawn from a single AGS string. The sample is monitored for D_2O content. By drawing the sample alternately from each end of the string, the position of the leak might be located.

3.0 MULTIFUNCTIONAL SYSTEMS FOR FUEL CHANNEL INSPECTION

3.1 Dry Channel Gauging Equipment

The Dry Channel Gauging Equipment, developed by Atomic Energy of Canada Limited's Chalk River Nuclear Laboratories (AECL-CRNL) and Orenda Ltd., was purchased by Ontario Hydro for PIP pressure tube monitoring at Pickering NGS A in the early 1970's/19/. It has recently been upgraded and modified to perform calandria tube gauging.

It is capable of measuring:

(i) The local curvature at many points along the tube from which the sag profile of the tube can be calculated. In some cases, the location of the "garter spring" spacers can also be deduced from the curvature information.

(ii) The tube minimum and maximum inside diameter at 12.7 mm intervals along the tube length.

(iii) The profile of the tube inside surface from which the depth of scratches or fret marks can be determined.

The use of this equipment requires time consuming procedures during which operating personnel are exposed to radiation. Its delivery and data collection systems have been improved to minimize these undesirable features. Since its capabilities for pressure tubes have been superseded by later equipment (CIGAR – Section 3.4) the Dry Channel Inspection Equipment is kept operational primarily for calandria tube gauging.

3.2 Rolled Joint Ultrasonic Inspection Equipment

In 1974 cracks, initiated by improper rolling procedures during installation, had developed in some Pickering Units 3 and 4 pressure tube rolled joints. The rolled joint ultrasonic inspection equipment was developed by Atomic Energy of Canada Limited – Sheridan Park Engineering Laboratory (AECL–SPEL) and Ontario Hydro to determine which joints contained cracks/26/.

It is capable of performing a two transducer circumferential shearwave ultrasonic volumetric inspection of the rolled joint region of the pressure tube. The 5 MHz, 6.25 mm diameter unfocussed transducers are scanned in a 3 mm pitch circumferential raster from the pressure tube end to 150 mm inboard.

The use of this equipment required the fuelling machine to install the transducer probe into the endfitting of the channel to be inspected. The probe drive was then manually mounted onto the endfitting and connected to the probe. The control console was located in the reactor vault and data collection was rudimentary. The limited capabilities and the radiation exposure to operating personnel have rendered this equipment obsolete.

3.3 SPAR–STEM Inspection Delivery Equipment

The SPAR–STEM inspection delivery equipment was originally developed by AECL–CRNL for pre–service eddy current evaluation of Bruce Units 1 and 2 pressure tubes.

The delivery system is capable of scanning an inspection probe axially through the full length of a dry pressure tube. Probes with rotational capability may be fitted. This system has been used to perform eddy current volumetric inspection with one or more probes of various types, "garter spring" spacer location scans, and CCTV video visual examinations of the insides of pressure tubes and calandria tubes.

This equipment has been used extensively for pre–service inspections. Because its use on in–service reactor pressure tubes requires the time and exposure intensive process of isolating and draining the channel, it is used only for special inspections.

3.4 CIGAR

CIGAR (Channel Inspection and Gauging Apparatus for Reactors) was developed by Ontario Hydro in recognition of the need for a system capable of performing a wide range of measurements on any of its reactors quickly and with minimum

radiation exposure to its operators/1/. The system has been operational since 1985 and has inspected over 200 fuel channels in most of Ontario Hydro's reactors as well as Quebec Hydro's Gentilly and New Brunswick's Pt. Lepreau CANDU 600 reactors.

CIGAR is capable of the following:

(i) Flaw Detection – Ultrasonic volumetric inspection of the pressure tube using four 45 degree shearwave transducers arranged as a circumferential and an axial pair, and one normal beam transducer.

(ii) Diameter Measurement – Ultrasonic gauging of the pressure tube inside diameter is performed at 18 degree intervals around the circumference at approximately 2000 axial positions along the tube. Tables and graphs of minimum and maximum diameter, their orientations and tube ovality can be obtained.

(iii) Wall Thickness – Ultrasonic gauging of pressure tube wall thickness is performed at the same time as diameter gauging and similar outputs are available.

(iv) Sag Measurement – The sag profile of the pressure tube is calculated from servo inclinometer slope measurements made at 30 mm intervals along the tube.

(v) Spacer Location – The axial position of the "garter spring" spacers are located using a send-differential-receive eddy current coil.

(vi) Inside Surface Profilometry – A stylus profilometer for measuring the depth of inside surface imperfections such as fuelling scratches, fuel bundle fret marks or fretting due to debris has been developed. It requires a special inspection head configuration and is used only for special inspections as required.

Additional capabilities that are being developed for the CIGAR system are:

(i) Gap Measurement – A system for measuring the gap between the pressure tube and the calandria tube has been developed. It utilizes a far-field send-absolute receive eddy current coil and requires ultrasonic gauging for wall thickness compensation.

(ii) Eddy Current Flaw Detection – This capability will complement the ultrasonic flaw detection for inside surface defects.

(iii) CCTV Video Visual Inspection Head – A dedicated inspection head containing an underwater television camera and associated lighting is being developed to interface with the CIGAR drive unit to provide visual inspection capability.

CIGAR is capable of inspecting an average of 2 fuel channels per day with approximately half the time being required for the fuel handling system to install inspection heads. Installation of the drive mechanism on the fuelling machine bridge and maintenance of equipment require minimal radiation exposure of personnel. At present, CIGAR is the primary delivery system for fuel channel inspection and monitoring.

3.5 CIGARette

The CIGARette system was developed by Ontario Hydro and AECL-SPEL in 1983 to meet the inspection needs following the rupture of a pressure tube in Pickering Unit 2. It uses a CIGAR inspection head and drive rods with a manually mounted and connected friction drive designed by AECL/27/.

Because a CIGAR inspection head is used and the system provides access to the whole channel, CIGARette is theoretically capable of doing any inspection that can be done by CIGAR. However, the rotational drive is much slower than CIGAR's and continuous rotation is not possible. Also, on inspections requiring many repeated rotations, slipping of the friction drive can lead to loss of position reference.

The CIGARette system has been used primarily for limited area ultrasonic examinations and "garter spring" spacer location scans. Because of the requirement of manual mounting and rod connection at the reactor face, its use is time consuming and results in radiation exposure to personnel. Its use has been superseded by CIGAR and it is kept for emergency use only.

3.6 PIPE

The PIPE (Packaged Inspection Probe) equipment was designed by Ontario Hydro in 1987 to rapidly perform ultrasonic inspection of pressure tube rolled joint regions to assure the absence of unacceptable manufacturing flaws or delayed hydrogen cracks/2/. Separate systems have been built for Bruce and Pickering. The Bruce system has been used to inspect a large number of rolled joint in Bruce Unit 2 achieving an inspection rate of 10 channels (20 rolled joints) per day. The Pickering system is in final stages of development testing.
The system is capable of performing ultrasonic flaw detection with sensitivity and coverage equivalent to that of the CIGAR system. The primary inspection is performed by scanning circumferential looking 45^{o} shear wave transducers on a circumferential 1 mm pitch. A normal beam and 2 axial looking 45^{o} shearwave transducers are also provided for flaw characterization.

The length of tube inspected is 100 mm extending approximately 50 mm on either side of the end of rolling transition.

PIPE performs a very specific, limited function but does it quickly and with very low radiation dose to operating personnel. The system, which uses modified fuelling machines to manipulate the inspection head, has demonstrated the feasibility of getting instrumentation cables through the fuelling machine pressure boundary and making underwater connections of signal cables. A concern about this concept is that the modification and use of the fuelling machines limits the ability of a shared fuel handling system, such as that at Bruce NGS A, to service other reactors. It also exposes the skilled mechanics who maintain and modify the machines to additional radiation dose.

3.7 BLIP

The BLIP (Blister and Spacer Location Inspection with PIPE) system for Pickering reactors was developed by Ontario Hydro in 1988 in anticipation of the need to be able to rapidly survey many fuel channels to find those with displaced spacers and to determine whether cracked blisters have formed.

Spacer location is performed using the same eddy current method used by CIGAR. Cracked blister location employs line focussed axial looking 45° shearwave ultrasonic transducers capable of inspecting the bottom 60° of the tube during axial movement of the inspection head. They are identical to those used on the SLAR system.

Like the PIPE system, BLIP utilizes the reactors' refuelling machines modified to provide greater travel and to allow instrument cables to penetrate the pressure boundary. The machines at both ends of the fuel channel must be modified if the whole length of the pressure tube is to be inspected.

BLIP has been designed to perform a very specific, limited function but to do it more quickly than other existing systems. However, conversion of the fuelling machines requires sufficient time and radiation exposure to skilled personnel that the system will only be used if the inspection of a very large number of fuel channels is required.

4.0 CONCLUSION

Ontario Hydro utilizes a wide variety of techniques and equipment to perform periodic and in-service inspection on the fuel channels of its CANDU nuclear reactors. Research and development is underway to extend these capabilities.

5.0 ACKNOWLEDGMENTS

The development and successful application of the inspection systems discussed in this paper are the result of the efforts of many groups of people in Ontario Hydro, AECL Engineering Company, AECL-CRNL and Canadian General Electric Nuclear Fuel Handling Division.

References

1. Dolbey, M.P. CIGAR – An Automated Inspection System for CANDU Reactor Fuel Channels. ASM 8th International Conference on NDE in the Nuclear Industry, Orlando, Florida, November 1986.

2. Mahil, K.S., G.N. Jarvis & D. Donnelly. Remotely Operated Inspection Equipment for the CANDU Fuel Channels. Remote techniques for inspection and refurbishment of nuclear plant. BNES, London 1988.

3. Benton, D.J. The SLAR System – An Overview. Proceedings of Canadian Nuclear Society 8th Annual Conference, St. John, NB, June 1987.

4. Chan, W.K. and M.P. Dolbey. Laser Sag Measurement Bruce NGS A Unit 2, Channels A14 and J11. Ontario Hydro Research Division (OHRD) Report No. 83-148-K, May 1983.

5. de Buda, E.G. Development of a Scanning Tool for Elongation Measurement for Pickering NGS B. OHRD Report No. 82-89-K, October 8, 1982.

6. Dolbey, M.P. Redesign of Yoke Nut Gap Tools for Pickering NGS A. OHRD Report No. 81-123-K, April 29, 1981.

7. Dolbey, M.P. Measurement of the Absolute Separation of Calandria Endshields on Unit #1, Pickering GS. OHRD Report No. 76-11-H, January 16, 1976.

8. Chan, W.K. and J.R. Boon. Spotface Measurement Tools for Pickering A Retube Operations. OHRD Report No. M85-85-K, August 28, 1985.

9. Chan, W.K. Design of a Fuel Channel Length Measurement Tool for Pickering NGS A. OHRD Report No. M84-165-K, January 22, 1985.

10. Chan, W.K. and M.P. Dolbey. A Scanning Tool for Elongation Measurement (STEM) for Bruce NGS. OHRD Report No. 84-145-K, June 4, 1984.

11. Chan, W.K. Design and Manufacture of STUD Measurement Tools for Bruce NGS B. OHRD Report No. M84-36-K, March 29, 1984.

12. Herring, J.A. M.T. Flaman and W.K. Chan. Measurement of Endshield Axial Displacement on Unit 3, Pickering GS A. OHRD Report No. 83-101-K, March 28, 1983.

13. Chan, W.K. and R.S. Algera. Design of Fuel Channel Acoustic Emission Leak Detection System for Bruce NGS A. OHRD Report No. M82-172-K.

14. Allen, A.L. and M.P. Dolbey. Development of an Ultrasonic Method of Detecting Water in Fuel Channel Pigtails. OHRD Report No. M83-2-K, January 18, 1983.

15. Sharp, F.L., J. Sedo, V.S. Cecco and H. Ghent. Eddy Current Detection of Garter Springs. Fuel Channel Technology Seminar, Oakville, Ontario, November 1985. Published by Atomic Energy of Canada Limited, CRNL, February 1987.

16. Chan, W.K. and J.R. Boon. Wet Channel Profilometry Module for CIGAR Applications. OHRD Report No. M87-102-K, December 10, 1987.

17. Moles, M.D.C. and D.W. Donnelly. Ultrasonic Fast-Scan Blister Detection System. Proceedings of Canadian Nuclear Society 8th Annual Conference, St. John, NB, June 1987.

18. DeVerno, M., H. Licht and W. Mayo. An Automated Inspection and Analysis System for SLAR. Proceedings of the Canadian Nuclear Society 8th Annual Conference, St. John, NB, June 1987.

19. Nelson, C.D. Gauging CANDU - PHW Reactor Pressure Tubes to Monitor Changes in Diameter, Sag and Length. Seminar on Creep and Growth of Zirconium Alloys, Atomic Energy of Canada Limited, Sheridan Park, May 18-19, 1977.

20. Baron, J.A. Acoustic Emission Leak Detection on CANDU Reactors. ASNT Non-Destructive Testing Handbook, Volume 5, Acoustic Emission Testing.

21. Harasym, T.L. Inaugural Inspection of Pickering NGS Unit 8 Pressure Tubes. Ontario Hydro Report No. CNS-IR-31110, 2-3, December 4, 1985.

22. O'Neill, J.A. and E.G. de Buda. An Annulus Gas "Sniffer" for Pressure Tube Leak Location. OHRD Report No. 83-135-K, June 15, 1983.

23. Kramer. S.M. and M.P. Dolbey. System for the High Frequency Ultrasonic Inspection of Pressure Tube Offcuts. OHRD Report No. M86-118-K, October 31, 1986.

24. Dolbey, M.P. and J.R. Boon. Design of Feeder Pipe Measurement Tools for Pickering NGS A. OHRD Report No. 81-130-K, April 23, 1981.

25. Fidleris, V., and A.R. Causey. Creep and Growth Tests on Calandria Tues. AECL/OH 2nd Fuel Channel Technology Seminar, Oakville, Ontario, November 12, 1985.

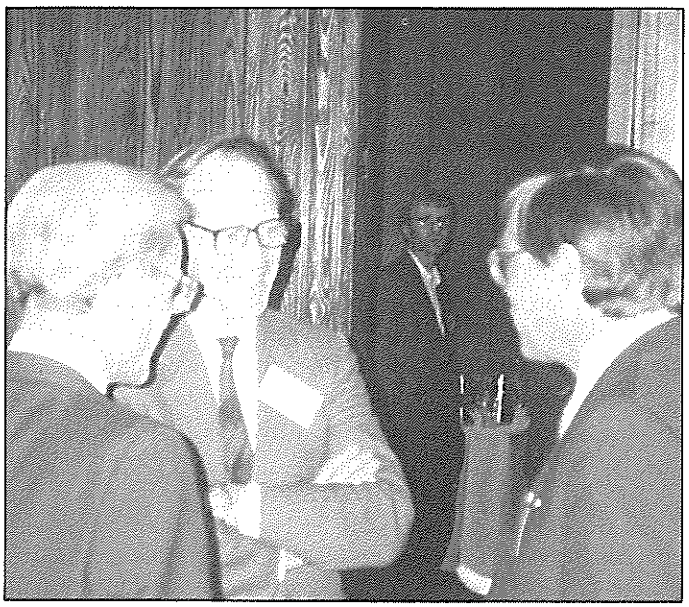
26. Kupcis, O.A. Ultrasonic Inspection of Defective Pressure Tube Rolled Joints from Unit 3, Pickering GS. OHRD Report No. 75-372-K, September 15, 1975.

27. Moles. M.D.C., M.P. Dolbey and K.S. Mahil. Wet Channel Inspection Systems for CANDU Nuclear Reactors - CIGAR and CIGARette. Proceedings of the Fifth Canadian Conference on NonDestructive Testing, Toronto, Ontario, October 28-31, 1984 (AECL-8707).

President moves on

In April Dr. Eva Rosinger, 1989-1990 President of the CNS, left Atomic Energy of Canada Limited to take on the new post of Director-General of the Canadian Council of Ministers of the Environment. This council was formed recently to encourage coordination of national political action and cooperation among governments and non-government organizations on matters related to protection of the environment. As Director-General, Dr. Rosinger will be responsible for creating and leading a secretariat to support the Council, which will be based in Winnipeg.

"It is an exciting and challenging task," Eva commented to the *Bulletin*, "but I will miss my friends and associates in the nuclear field." "I will definitely complete my term as the CNS President," she added.



Frank Stern, Terry Rogers and Herb Rosinger compare notes during a break at the International Conference on Simulation Methods in Nuclear Engineering held April 18-20 in Montreal.

Dr. Rosinger joined AECL in 1973 and has been associated with the waste management programme since 1976. In 1980 she became section head in the Environmental and Safety Assessment Branch at the Whiteshell Nuclear Research Establishment and later that year became assistant to the director of the Waste Management Division.

In 1984 she was appointed manager of her former branch which was involved in computer simulation, system assessment, and environmental impact analyses.

For a year and a half she served as executive assistant to the President of AECL Research Company at the head office in Ottawa. On her return to WNRE she took on the position of Director of Waste Management Concept Review with specific responsibility for AECL's participation in the review by the Federal Environmental Assessment and Review Office of AECL's nuclear fuel waste disposal concept.

Eva became President of the CNS in June 1989 after several years of active participation on the CNS Council. She is also a member of the Board on Radioactive Waste Management of the U.S. National Academy of Sciences.

At the time of writing her successor at WNRE had not been named.

Ottawa Branch

Expansion at the AECB

At the April meeting of the Ottawa Branch members heard the "whys and wherefores" of the recently announced expansion of the Atomic Energy Control Board.

Jim Harvie, Director of Research and Safeguards, noted that several reviews of the Canadian nuclear programme (such as the Ontario Nuclear Safety Review by Dr. Kenneth Hare) had recommended an increase of AECB staff. The size of the AECB, especially in the area of reactors, is smaller than all other nuclear regulatory bodies in relation to the size of the programme regulated, he said.

Harvie pointed out that the USA had 480 reactor-years experience at the time of the Three Mile Island accident and the USSR had 270 reactor-years when Chernobyl occurred. Canada has, now, something less than 200 reactor-years operating experience.

He reviewed a number of safety-related events at Canadian nuclear power plants, including, a failure of a trip because manual conditioning had not been carried out; blocking of a shutdown system, and incorrect wiring of a reactivity device. The controversy over the Darlington shutdown system software showed, he said, the AECB's need for more staff to be able to review such systems in detail.

The more than 4500 radioisotope licensees need more review and inspection than has been possible up to now, he added.

On the basis of outside comments and its own review the AECB had requested a doubling of its staff over five years. The government approved 93 new positions (on a base of 264) over two years, with a promise to review the need for additional resources at that time.

Harvie said the additional staff will be used: to increase the size of field offices; improve the review and assessment to safety analyses; institute a system of requalification of authorized reactor staff; increase inspection of radioisotope users and uranium mines; develop radiation protection standards and expand international participation.

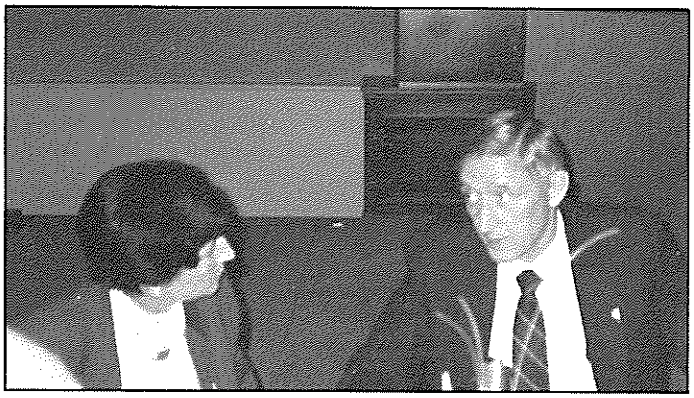
During discussion Harvie acknowledged that one factor leading to the government's approval for additional resources was the cost-recovery programme begun this year whereby licensees will be charged fees intended to cover the cost of the AECB's regulatory programmes.

Saskatchewan Branch formed

The CNS Council was on hand for the inaugural meeting of the newest branch of the CNS in January. Council had arranged to meet in Saskatoon to honour the occasion of the formation of the Saskatchewan Branch.

Over 50 members and guests attended the dinner meeting, to greet CNS President Eva Rosinger and hear Ed Hinchley speak about the innovative features, improvements and technological advances of the latest generation of the CANDU design - the CANDU 3.

An interim executive under chairman Ed Hinz, has been set up and committees are being formed to prepare for a full programme in the fall and to work with the CNA/CNS conference committee to plan for and organize the 1991 CNA/CNS conference which will be held in Saskatoon next June.



CNS President Eva Rosinger confers with Ed Hinz, chairman of the recently formed Saskatchewan Branch in Saskatoon.

Toronto Branch Activities

As a result of our Public Presentation Series, the Toronto Branch meets on a regular basis from September - May. The meetings, which are cosponsored by the University of Toronto Centre for Nuclear Engineering, feature a wide range of topics of interest to those in the nuclear industry.

On March 6, 1990, Mr. B. Ewing, Manager, Studies and Codification Division, Atomic Energy Control Board, gave a presentation entitled "The Atomic Energy Control Board's Project Officers - The Five W's". Mr. Ewing, having been a senior project officer for Point Lepreau G.S. for many years, discussed the unique approach to nuclear plant regulation which has resulted from the AECB practice of maintaining site-located staff representatives. The project officer philosophy is an interesting one, and differs from the regulatory approach of other countries which prefer a more "arms-length" stance. With the advent of the recent AECB reorganization, the commitment to sustain the present level of site-representation will surely continue, and perhaps increase, considering the current plan to increase the AECB staffing levels by 93 over the next 2½ years. Mr. Ewing's visit represented the first such presentation to the Toronto Branch by an AECB member in recent years.

At the recent April 3, 1990 meeting the topic was "Invasion of the Zebra Mussels" presented by Mr. P. M. Wiancko, Technical Superintendent - Environmental Protection Department, Ontario Hydro. This issue has become a growing concern, one not restricted only to the nuclear industry. The presentation generated a great deal of interest, as evidenced by the large public turnout and the appearance of a CBC film crew.

Since their 1985 introduction into Lake St. Clair from the ballast water of a European ship, the spread of zebra mussels throughout the Great Lakes system has been alarming. In August 1989 the mussels were discovered at the intake of the Ontario Hydro Nanticoke TGS, and are further expected to reach Lake Ontario by this summer. Effects of the mussel have been devastating, in terms of their abilities to clog external and internal water intake systems (i.e., filtration systems, piping, condensers, etc.). Ontario Hydro recently announced a $10 million program to investigate the problem. Mr. Wiancko discussed the details of this program, including the current plan to introduce chlorination systems designed to kill the free swimming zebra mussel larvae as they enter the station intake. He noted that because chlorine has not been officially sanctioned as a pesticide by Agriculture Canada, delays in these plans could result. Ontario Hydro is currently one of the only companies looking at the long term options of zebra mussel control.

Cold Fusion

Last fall the Toronto Branch opened its Public Presentation Series for the 1989/90 season with a talk on "Cold Fusion" by Dr. David P. Jackson of Chalk River Nuclear Laboratories. Dr. Jackson holds the title of Director, National Fusion Programme.

The first part of Dr. Jackson's talk dealt with the programme on conventional fusion. The R and D annual expenditure on fusion is 2 Billion dollars worldwide. The question is no longer whether fusion will work scientifically, but whether it can be successful from the engineering point of view and whether it will be economical. The public perception of fusion is a sympathetic one, and it is that fusion is inevitable, it is the ultimate energy source.

The Canadian National Fusion Program was formed in the 1970s. Its objectives are to gain access to international knowledge on fusion, to help maintain the fusion-power option in Canada, and to develop and market competitive Canadian industrial capability in fusion systems and components. The strategy is to exploit our special expertise to weld Canada firmly into the world fusion development. The components of the National Fusion Program are the Canadian Fusion Fuels Technology Project, the Tokamak de Varennes, industry, and universities. Canada has established many international links, both bilaterally and through the International Energy Agency, and has been accepted as a partner in ITER, the future International Thermonuclear Experimental Reactor.

Cold fusion hit the media like a bombshell with a televised announcement by Fleischmann and Pons on March 23, 1989, claiming to have achieved fusion at room temperature at the University of Utah. Their basic experiment consisted of an electrolytic cell of heavy water, with a cathode made of palladium and an anode made of a platinum-wise coil. The positive ions in the D_2O move to the cathode where they were claimed to be "forced together" and fuse, giving off helium and heat. Fleischmann and Pons claimed to have obtained a heat output 4 times the energy input.

Now fusion of deuterons would follow one of two paths, each with about 50% probability:

$$D + D \rightarrow T + p$$

$$\text{or } D + D \rightarrow He^{-3} + n$$

Thus, if there is fusion, one should observe heat, plus tritium, or Helium and (2.5 MeV) neutrons. At the~1 watt of heat reported, the neutron flux should be huge, in the order of 10^{12} n/s.

In summary, if you find both heat and neutrons, you have probably found fusion. However, neutron measurements, as well as calorimetry, are tricky to perform well. Therefore the experiment must be done with great care.

In the weeks and months following Pons and Fleischmann's announcement, many groups from around the world attempted to duplicate cold fusion. Included were several Canadian experiments. As of September 1989, there were only a very small number of confirmations worldwide, and most of these (e.g. Brigham Young University) report a fusion probability of less than 10^{-25} n s^{-1} per deuteron pair, as opposed to a probability greater than 10^{-12} n s^{-1} per deuteron pair calculated by Fleischmann and Pons. That is a difference of 37 orders of magnitude.

The picture is still somewhat cloudy. Although Fleischmann and Pons stand by their first results, a U.S. Department of Energy Review Panel has concluded that the experiments do not present convincing evidence by fusion. Thus in summary significant energy production from cold fusion seems improbable, but a much smaller probability of fusion as reported by Brigham Young University is possible.

Busy year for N.B. Branch

The active New Brunswick Branch, centred in Saint John, has had a full season, with the monthly meetings covering a wide range of topics.

September – Talk – Safety Critical Software, by Stephen Shaeffer, AECL

October – Visit to N.B. Power's energy control centre in Fredericton

November – Talk – Safety, A Perishable Asset, by Dr. Kenneth Hare

January – Presentation of a brief to the Premier's Round Table on the Environment and Economy (drafted by chairman Roger Steed and D.F. Weeks)

February – Talk – Canadian Concept for Spent Fuel Disposal by Dr. Bill Hancox, AECL

March – Talk – High Consequence Accidents, by Dr. David Mosey, O.H.

March – special dinner meeting with CNS Council and talk by Dr. Gil Phillips, AECL, on Canada's Fusion Programme

May – Talk – Magnetic Storms from the Sun, by B.K. Patterson, R.A. Gibb, and T.G. Anderson

CNS expresses sympathy over École Polytechnique tragedy

At its last meeting the Council of the Canadian Nuclear Society decided to convey formally the sympathy of CNS members to the staff, students and family members affected by the tragic shooting at L'école Polytechnique in Montreal last December.

The text of the letter sent by the CNS President is printed below.

The CNS Council also decided to donate $500 to the memorial fund that has been established in memory of the victims of the tragedy.

Cher Monsieur Doré,

C'est avec grande consternation que nous avons appris et suivi grâce aux médias électroniques, les terribles événements du 6 décembre 1989. En rencontrant plusieurs professeurs de génie nucléaire à la récente Conférence sur les Méthodes de Simulation en Génie Nucléaire à Montréal, nous avons constaté à quel point ils sont restés marqués par cette tuerie insensée qui s'est déroulée à quelques pas de leur lieu de travail.

L'École Polytechnique a toujours joué un rôle important au cours de l'histoire de la Société Nucléaire Canadienne, notamment en organisant plusieurs conférences et symposia (dont la Conférence étudiante à trois reprises), et en ayant plusieurs de ses professeurs comme membres actifs de comités et du Conseil de la SNC. De plus, un grand nombre de diplômés de l'École Polytechnique adhèrent à la Société Nucléaire Canadienne.

Le Conseil de la Société m'a mandatée pour vous faire part, au nom des membres de la SNC, de notre sympathie dans l'épreuve que vous traversez. Non seulement nous regrettons ardemment ces tristes événements, mais nous souhaitons de tout coeur qu'ils aient des conséquences positives sur les attitudes et les comportements de notre société si troublée.

Je vous demande, cher Monsieur Doré, de bien vouloir transmettre nos sentiments aux familles des jeunes femmes disparues, aux étudiants de l'École Polytechnique, aux professeurs et aux employés de l'École.

Veuillez bien agréer, cher Monsieur, l'expression de mes sentiments les meilleurs.

Eva L.J. Rosinger, Ph.D., P.Eng.
Présidente

Two successful conferences

The CNS sponsored or co-sponsored two successful conferences held within the last few weeks.

The 3rd International Conference on Simulation Methods in Nuclear Engineering was held April 18 to 20 at the Bonaventure Hotel in Montreal. There were 139 registrants of whom 40 were from outside Canada.

One of the features appreciated by all attendees was the complete set of proceedings available at the meeting. This facilitated discussion on the complex subjects presented.

Conference chairman Bill Midvidy commented that he and his committee were pleased with the success of the conference and promised to provide a summary for those who could not attend.

Just two weeks later the CNS held the Steam Generator and Heat Exchanger Conference in Toronto, from April 30 to May 2 with 165 registrants, including a number of world specialists in steam generator technology.

Jim Brown, the chairman of the Steam Generator conference reports that the proceedings will be published in about four months.

A New Image

Atomic Energy of Canada Limited believes it has an image problem. In any event the company has developed a new corporate look and colours, as announced recently by CEO Dr. Stanley R. Hatcher. The basic corporate colours will be blue, gold, and grey. The company will be known simply as AECL (ou EACL en français) but the existing logo – a gold "flying A" – will be retained.

11th Annual Conference

Royal York Hotel, Toronto, Ontario, Canada
June 3-6, 1990

Program

Conference Theme: "Nuclear Energy – Ready for the Challenges of the 90s"

Sunday, June 3 16:00-21:00
Registration

Sunday June 3 19:00-21:00
Reception

Monday June 4 08:30-08:50
Opening of the CNA/CNS Conference
R.W. Bartholomew, Sponsoring Director, Ontario Hydro

Monday June 4 08:50-12:00
CNA/CNS Session 1: Energy Needs and Challenges Facing the Nuclear Industry in the 90's
(see CNA program)

Monday June 4 14:00-17:00
CNS Session 1: Programs and Issues for the 90's
Chaired by: J.D. Harvie, AECB

1-1 CANDU 3 – Ready to Build
K.R. Hedges and E.M. Hinchley, AECL – CANDU Operations

1-2 Integrated Plant Design
G. Tolpa, AECL – CANDU Operations

1-3 Requirements for Advanced Reactor Designs
A. Natalizio and D.F. Rennick, CANTECH International

1-4 The Program to Develop and Demonstrate the CANFLEX Bundle, Its Additional Capabilities and Supporting Technologies
A.D. Lane, P.G. Boczar, T.J. Carter, D.C. Groeneveld, AECL – CRNL, and R. Sejnoha, AECL – CANDU Operations

1-5 Facility Requirements for an NRU Replacement
K.S. Kozier, H.E. Rosinger, and J.V. Donnelly, AECL – WNRE

1-6 Review of Canadian Contributions to the Design of ITER
R. Stasko, J. Blevins, and H. Brunnader, Canadian Fusion Fuels Technology Project

CNS Session 2: Thermohydraulics I
Chaired by: J. Hopwood, AECL – CANDU Operations

2-1 Transient Effects on Critical Heat Flux and Quenching in Directly Heated Tubes
S.C. Sutradhar, D.C. Groeneveld, and L.K.H. Leung, AECL – CRNL

2-2 Analysis of LOCA Experiments in the RD-12 Parallel-Channel Test Facility
N.K. Popov and G.R. McGee, AECL – WNRE

2-3 Tabular Approach to Predicting Critical Heat Flux
D.C. Groeneveld and L.K.H. Leung, AECL – CRNL

2-4 Commissioning the Two-Pump Mode of Operation at the Point Lepreau Generating Station
M. El-Hawary, P.D. Thompson, and D.F. Weeks, New Brunswick Power

2-5 Measurement of Enthalpy Migration in a Horizontal Test Assembly with Two Interconnected Subchannels
S.T. Yin and C.W. Snoek, AECL – CRNL

2-6 Bubble Migration in Horizontal Tubes and Rod-Bundle Geometries
S.I. Osamusali, University of Ottawa, D.C. Groeneveld, AECL – CRNL, and S.C. Cheng, University of Ottawa

CNS Session 3: Reactor Physics and Fuel Management
Chaired by: A.A. Pasanen, AECL – CANDU Operations

3-1 Application of Local-Parameter Lattice Properties to Fuel Management Simulations in Ontario Hydro Reactors
L. Wilk, Ontario Hydro, A.C. Mao and B. Rouben, AECL – CANDU Operations

3-2 Fuel Management Flexibility with Single-Ended Refuelling in CANDU-3
A.M. Manzer and H.C. Chow, AECL-CANDU Operations

3-3 Neutronic Decoupling and Coolant Void Reactivity in CANDU
V.K. Mohindra and A.R. Dastur, AECL – CANDU Operations

3-4 Fuel Management Simulation of CANDU 3 at Equilibrium Condition
M.H. Younis, AECL – CANDU Operations

3-5 SMOKIN – A Code for Time-Dependent Three-Dimensional Neutronics Calculations in CANDU-PHW Reactors Based on Modal Kinetics Theory – Application to Analysis of Loss of Coolant Accidents
M. Gold and J.C. Luxat, Ontario Hydro

3-6 The Influence of Lattice Structure and Composition on the Coolant Void Reactivity in CANDU
A.R. Dastur and D.B. Buss, AECL – CANDU Operations

Tuesday June 5 08:00-09:00
CNS Annual General Meeting

Tuesday June 5 09:00-12:00
CNA/CNS Session 3: Public Perception of the Nuclear Industry
(see CNA program)

Tuesday June 5 14:00-17:00
CNS Session 4: Nuclear Safety
Chaired by: P.D. Thompson, New Brunswick Power

4-1 Improving CANDU Safety with Organic Coolant
N.J. Spinks, AECL – CRNL

4-2 Catalytic and Spark Hydrogen Igniters
R. Heck, SIEMENS AG. UB KWU

4-3 Assessment of Pressure-Tube Response to Severe Conditions in CANDU Fuel Channels
P. Gulshani and E. Kohn, AECL – CANDU Operations, M.A. Wright, New Brunswick Power, and R. Hu, Hydro-Quebec

4-4 Development of Analytical Methods to Evaluate the Integrity of a Calandria Tube in the Case of Pressure Tube Rupture
Y. Morishita, I. Matsushita, and Y. Hayamizu, Power Reactor and Fuel Development Corporation

4-5 Chan-II (Mod 6) – Further Verification Against Single and Seven Element Experiments
M. Bayoumi, A.P. Muzumdar, F.B.P. Tran and K.E. Locke, Ontario Hydro

4-6 Gentilly-2 Secondary-Side Break Study
P. Lafreniere, Hydro-Quebec, and R. Shill, AECL – CANDU Operations

CNS Session 5: Small Reactors
Chaired by: D. Rozon, Ecole Polytechnique

5-1 Preliminary Design of the Advanced-MAPLE Research Reactor
J.V. Donnelly, N.P. Skulski, and K.S. Kozier, AECL – WNRE

5-2 Enhanced Boiling Heat Transfer for the SLOWPOKE Decay-Heat Rejection System
M.J. Brown and J.T. Rogers, Carleton University, and B.S. Larkin, National Research Council of Canada

5-3 Thermalhydraulic Modelling of MAPLE Research Reactor
S.Y. Shim, P.J. Mills and D.K. Baxter, AECL – WNRE

5-4 Full-Scale Thermohydraulic Tests of the AMPS Reactor System
T.C. Currie and J.C. Atkinson, ECS – Power Systems Inc.

5-5 Addition of a Gravity Separation Model to COBRA-IV for Use in AMPS Thermohydraulics Analysis
A. Tahir, ECS – Power Systems Inc.

CNS Session 6: Fuel Behaviour
Chaired by: P.J. Fehrenbach, AECL

6-1 Preparation and Applications of Simulated High-Burnup Nuclear Fuel
R.A. Verrall, P.G. Lucuta, AECL – CRNL, Hj. Matzke, Commission of the European Communities, Joint Research Centre, Institute for Transuranic Elements, and C.L. Brayman and I.J. Hastings, AECL – CRNL

6-2 Behaviour of Braze Heat-Affected Zone in CANDU Fuel Sheaths
N.A. Graham, Zircatec Precision Industries, J. Novak, Ontario Hydro, and R. Sejnoha, AECL – CANDU Operations

6-3 Influences of Load Following, Partial Dryout, and End-Flux Peaking on Temperature Distribution in CANDU Fuel
S. Girgis, N. Singhal, and M. Tayal, AECL – CANDU Operations

6-4 Characterization of Fuel Failures Resulting from the November 1988 Overpower Transient in Pickering NGS-A Unit 1
M.R. Floyd and R.L. daSilva, Ontario Hydro, M.J.F. Notley, Consultant to Ontario Hydro, R.J. Chenier and R.R. Elder, AECL – CRNL

6-5 CANDU Fuel: the Use of Zirconium Barrier Layer Cladding as an Alternative to CANLUB to Prevent PCI Failures
T.J. Carter, D.A. Leach, I.A. Lusk, J.R. Kelm, R.R. Elder, P.J. Valiant, R.F. O'Connor and J.P. Murphy, AECL – CRNL

6-6 A Preliminary Analysis of Fission Product Releases in the HEU-Fueled SLOWPOKE-2 Reactor
B.J. Lewis, D. Cole, and L.G.I. Bennett, Royal Military College of Canada, and R.G.V. Hancock, University of Toronto

Tuesday June 5 19:00-22:00
FUN NIGHT

Wednesday June 6 08:00-11:00

CNS Session 7: Energy Production and the Environment
Chaired by: W. Penn, Ontario Hydro

7-1 The Cooling of the Greenhouse and Nuclear Energy
D. Pendergast, AECL – CANDU Operations

7-2 New Environmental Initiatives by AECL
D. Wren, AECL – WNRE

7-3 Ontario Hydro's Planning for Energy Production and Environmental Protection
K. Talbot, Ontario Hydro

7-4 Development of Models for Estimating the Socio-Economic Impact of Severe Accidents
C.K. Scott, Atlantic Nuclear Services Ltd., M.J. Lewis, Electrowatt Consultant Engineers and Scientists Ltd., A. Omar and J.W. Beare, AECB

7-5 Nuclear Energy Production and Environmental Issues
J. Ryan, Ontario Hydro

CNS Session 8: Computer Applications
Chaired by: J. Popovic, AECL – CANDU Operations

8-1 An Integrated Pipe Stress Analysis Environment for the CANDU 3 Project
C.J. Barker, R.A. Judd, B. Remenda, AECL – CRNL, B.R. Ajmera, S.N. Sharma and H.M. Tolpa, AECL – CANDU Operations

8-2 Visualizing Information for the Nuclear Industry
H.E. Sillis, V.J. Langman, J.C. Amrouni, L.J. Watt, and D.B. Reeves, IDEA Research

8-3 Integrated Document Management for the CANDU 3
C.D. Sayles and D.W. Livingstone, AECL – CANDU Operations

8-4 The Application of Computers to Safety Systems in CANDU 3
D. Chan, AECL – CANDU Operations

8-5 An Interactive Computer-Based Training Aid for Nuclear Reactor Refuelling Operations
E.C. Davey, L.L. Anderson, and W.S. Simmons, AECL – CRNL

CNS Session 9: Nuclear Systems
Chaired by: J.A. Blasko, Ontario Hydro

9-1 Design and Installation of D20 Sampling System for Bruce 'B'
A.G. Norsworthy, S.M.P. Kashyap, J. Beaton, AECL – CANDU Operations, and G. Kozak, Ontario Hydro

9-2 A Review of the New Canadian Standard for the Support Power Systems of CANDU Nuclear Power Plants
B.A. Rolfe, Ontario Hydro, A. Josefowicz, and J.W. Vinnai, AECL – CANDU Operations

9-3 Pickering 'A' NGS – Calandria Vault Corrosion Control and Correction
A.N. Sangwine, AECL – CANDU Operations, and N.G. Brown, Ontario Hydro

9-4 The CANDU 3 Control Centre Design
R.F. Moore, J. Hinton, and R. Ashwell, AECL – CANDU Operations

9-5 A New Approach to Control and Monitor CANDU Fuel-Changing Operations Using 'On-Board' High-Temperature / Radiation-Hardened Electronics
B. Marshall and D. Arapakota, AECL – CANDU Operations

CNS Session 10: Fusion
Chaired by: D.P. Jackson, AECL – CRNL

10-1 The Use of Lithium-Based Ceramic Spheres in Fusion Breeder Blankets
J.D. Sullivan and B.J.F. Palmer, AECL – CRNL

10-2 Radiolysis of the Aqueous Lithium Salt Blanket
A.J. Elliott and M.P. Chenier, AECL – CRNL

10-3 Temperature Distribution and Stresses in the TF Coils During Long Pulse Operation on the Tokamak de Varennes
G. Le Clair, Les technologies MPB Inc., G.W. Pacher, IREQ, Institut de recherche d'Hydro-Quebec, H.D. Pacher, INRS-Energie, and R. Decoste, IREQ, Institut de recherche d'Hydro-Quebec

10-4 Applications of Tritium Technology to Fusion
J.M. Miller, R.E. Johnson, and L. Rodrigo, AECL – CRNL

10-5 Fusion Solid-Breeder Irradiation Experience at CRNL
R.A. Verrall and J.M. Miller, AECL – CRNL

Wednesday June 6 12:00
CNS Luncheon – Guest Speaker:
Dr. R.J.A. Levesque, President, Atomic Energy Control Board, "AECB Prepares for the Challenges of the 90's."

Wednesday June 6 14:00-17:00
CNS Session 11: Reactor Decommissioning, Irradiated Fuel and Materials Handling
Chaired by: F.P. Sargent, AECL – WNRE

11-1 Modelling the Release of Radionuclides from a Used Nuclear-Fuel Disposal Vault: Conservatism, Realism and Uncertainties
N.C. Garisto, AECL – WNRE

11-2 Container Storage of CANDU Fuel: Ontario Hydro's Dry Storage Demonstration Program
R.N. Sumar, P.J. Armstrong, J.D. Tulk, Ontario Hydro

11-3 Calculation of the Radioactive Inventory of the Decommissioned NPD Reactor
W.M. Smith, AECL – CANDU Operations

11-4 Environmental and Safety Assessment on the Conceptual Design of the Used Nuclear Fuel Disposal Centre – Occupational Safety Assessment and Preliminary Results
M. Zeya and D. Petras, Ontario Hydro

11-5 Tritium Gas Handling Using Tritide Forming Materials
W.T. Shmayda and A.G. Heics, Ontario Hydro

CNS Session 12: Thermohydraulics II
Chaired by: J.Y. Stambolich, Ontario Hydro

12-1 An Efficient Heat-Transfer Prediction Package Suitable for Steady-State and Accident Analysis
L.K.H. Leung and D.C. Groeneveld, AECL – CRNL

12-2 Development of a Model to Predict CHF Enhancement in Subchannels with Spacing Devices
K.F. Rudzinski and C.W. Snoek, AECL – CRNL

12-3 Turbulent Flow Structure in the Subchannels of a 37-Element Bundle
S.C. Sutradhar, AECL – CRNL

12-4 Thermalhydraulic Experiments in Support of the MAPLE Research Reactor
J.E. Kowalski, P.J. Mills, S.Y. Shim, and R.L. Hembroff, AECL – WNRE

12-5 CANDU 3 Directed Emergency Core Coolant Injection
S.D. Grant and D.N. Padhi, AECL – CANDU Operations

12-6 Two-Phase Pressure Drop and Wall-Temperature Measurements
L.K.H. Leung and D.C. Groeneveld, AECL – CRNL

CNS Session 13: Reactor Components
Chaired by: H. Lee, GE Canada

13-1 CANDU Fuel Channels – Overview of Pressure Tube Manufacturing Routes and Practices
J.F. Slavik and E.G. Price, AECL – CANDU Operations

13-2 Calandria Vessel Structural Integrity Under a Channel Flow Blockage / Loss of Coolant Accident Condition
S.S. Dua, AECL – CANDU Operations, W. Teper, Ontario Hydro, and T. Lee, AECL – CANDU Operations

13-3 Design and Development of a Mechanical Zone-Control Unit for the CANDU 3 Reactor
R.S. Porter and J.F. Cameron, AECL – CANDU Operations

13-4 CANDU 3 Fuel-Channel-Assemblies Rolled-Joint Development Program
I.M. Burnie, S. Venkatapathi, and C.A. Kittmer, AECL – CRNL

13-5 Use of a Thick Pressure Tube for the Improvements to the CANDU NPP Economics
S.S. Dua, A.R. Dastur, and C. Yao, AECL – CANDU Operations

13-6 Prospects for Stronger Calandria Tubes
C.E. Ells, C.E. Coleman, R.R. Hosbons, E.F. Ibrahim, and G.L. Doubt, AECL – CRNL

The Unfashionable Side

Early Morning Mamba

There was a half light everywhere. I was drifting. A fog horn was sounding right in my ear. I reached out and grabbed it, lifting it clear out of the water in my annoyance, and uttering an oath, as I did so, to St. Caligo, the patron saint of fog horns.

"Put your teeth in, please. I can't understand you."

The voice came to me out of nowhere.

We do have some odd dreams, I recall thinking to myself. Why can't we dream about that shapely brunette in the CNS office, instead of some querulous dental technician who fancies herself as a Maid of the Mist?

Another voice sounded suddenly in the fog. "My teeth are in."

Good, I thought. She was someone else's siren. I could drift off into the mist again and look for pirate treasure, damsels set adrift by crazed mutineers, or some such.

"You must come over immediately", she said with some urgency.

Now this was more like it, I thought. But suddenly I was panic-stricken. What about my teeth? I don't know where my teeth are! How can I rescue someone with no teeth?

"You don't have dentures, you twit". This from yet another voice which had sounded somewhere nearby.

I never have liked crowds, and this was becoming tiresome. Fortunately, other things were happening which overshadowed my developing ennui. The fog seemed to be lifting now, and with the improved visibility I realized that my teeth were fixed firmly in my gums. All but one of the voices had gone silent as well. Looking out over the gunwales of the boat, some of the objects around me had started to become recognizable. There was a bookcase, inexplicably, and sitting next to a book, which seemed curiously to be floating on the water, there was a cat looking at me from a few...

The clock said 4:15 a.m., and the fog horn I was holding had turned into a telephone. Within a few seconds, things were sorted out. At the other end of the line was the librarian from Ontario Hydro. "Please, you must help. Someone has blockaded themself in the library at Head Office. If we don't do something they say they'll randomize the catalogue." She was obviously a bit disturbed, and it's hard to think straight when you're disturbed. Perhaps if I asked her over to my place for a drink.... ("I'm too old for etchings, but perhaps you'd like to come up anyway", is a line I've been tempted with.) Did she know anything about this bibliophobe, this latter day "Name of the Rose" type, I managed to ask casually?

The answer brought me awake fast.

It was Mamba Wildfang.

It's frightening the damage that can be done by parents with a malicious sense of humour. Nowhere was this more

Short Course on Environmental Radiation Protection Aspects of Nuclear Safety

The Nuclear Science and Engineering Division of the CNS is planning to hold a two-day course on radiation protection aspects of nuclear safety in November, 1990. The course will focus on issues relating to the consequences of radioactivity releases from nuclear plants to the public during normal operation and as a consequence of an accident. Subject matter to be covered includes:

1. consequences of releases of radioactive materials
2. radiation measurements and calculations of public dose
3. biological effects
4. regulations.

The course will be held in the Toronto area. Details will be provided in the next issue of the *Bulletin*. Anyone interested in attending the course or seeking further information should contact:

A.C.D. Wright
AECL-CANDU Operations
Sheridan Park, Mississauga,
Ontario, Canada
K0J 1J0
Telephone: (416) 823-9040

vividly demonstrated than in the case of Mamba Wildfang. With a triple first in physics and mathematics, and great promise for cutting through the seething mass of thermalhydraulics codes with which the nuclear industry has slowly strangled itself over thirty years, Wildfang had suddenly changed tack upon graduation, deciding to seek her revenge on the world for years of mockery. ("Serpentina" and "Anna Konda" had been scribbled in her notebooks as jibes all through school, but they now became IOUs with immediate and full payment demanded.) The threat was doubly menacing because of something else. Mamba was strikingly beautiful and she could use that quality with devastating effect and deadly precision.

The librarian had begun chirping excitedly again so I promised to come down right away. Throwing on black slacks and roll neck sweater, and grabbing gloves and flashlight, I was soon out in the false dawn blasting down Bay Street in the Lagonda. I had momentarily thought of rousing Worthing, but had quickly decided against it. He's not at his best in the early hours, and besides, the thought of all those brandy bottles clinking about in his swag made me feel a bit squeamish.

The crystal palace, home of the perpetually pupating Ontario Hydro, loomed ahead like a great obese ice cube. I roared through the university campus (which was asleep but for a fun-loving band of 200 engineers who were demolishing a chemical toilet in front of the medical building), crossed College Street and eventually parked on McCaul behind the beached cube.

The time and money Worthing and I had spent entertaining Ambrosia, the sly (but not sly enough) second in command to the plodding Rosco in security, paid off once again. My special pass opened the rear door to the bloated berg without alerting the building's computer. The main security desk in the lobby was no threat; the guard on duty had enlisted the combined talents of the Sony Corporation and Rod Stewart to help him perforate his eardrums. Reaching the mezzanine was simple. A dim light glowed somewhere in the library and I slipped in quietly, crouching low behind the information desk. The sign devised by Worthing which had so tickled the head of Information Services, "Lepers and MBAs please identify yourselves!", was still in place.

There was a clear view into the stacks and nobody was there. She must be down in the reference section or waiting among the journals. My pass key let me into the public reference centre and thence through various offices to the rear of an area occupied by shelved journals. I soon found her. She was standing perfectly still, looking toward the main door, away from where I stood, in the reference section just between the OED and Chambers Technical Dictionary. (One row further over would have given her a better view but would have placed her amid the unspeakable vulgarity of Books in Print.) I like a cracksman with proper pedagogical respect, and I had to smile.

A few soundless paces and I was in the next row, looking

at her profile just over Ulrich's Periodical Index, and the fifteen volume "In Hot Water: The Story of Thermalhydraulics". With her long black hair and one piece grey cat suit, she looked like something out of Rider Haggard. It was time to get the show on the road.

"Alors, ma petite vipere. Je vois que tu m'attends."

She swung around in one fluid movement, but then softly exclaimed "Merde!" as a burst from my flashlight struck her eyes, destroying her night vision.

"We meet again, Mamba. Got tired of Hillsdale, did you?"

About a year earlier, Worthing and I had hatched this devious plan to tout Mamba to the ANS as the greatest and most proficient nuclear critic ever. If they took her on as critic-in-residence, we argued, they would never have trouble with regulators again, because all the arguments would already have been tried. If the ANS found it interesting, Mamba leaped at it like a hungry Doberman, realizing that this was the ideal chance to hone her talents. (Worthing and I demurred before accepting a nominal payment, of course.) Now she was back. Apparently American thermalhydraulicists don't like being proved irrecoverably wrong any more than Canadian ones do.

"Whatever your plan is, it won't work this time", she said truculently. Her night vision was recovering and she glanced apprehensively to either side of me.

"He's not here", I assured her, and she relaxed noticeably. Mamba is somewhat ambivalent about Worthing. She hates Shakespeare but she loves brandy (and, of course, Worthing lays both on fairly thick whenever she's nearby). "And I have no plan", I continued. "It's you who called me, remember?"

"I didn't...."

"I know. I'm here to rescue the library, right? The librarian wouldn't have known to call me unless someone told her. You've been onto Andy Quinn again, haven't you?"

Andrew Throckmorton de Quincey-Buick (i.e. Andy Quinn, unless you have the lungs of a Wagnerian female lead or a pearl diver) is the consummate corporate politician, a true managerial McCavity. A lifer in the Hydro establishment, he's had me in his sights ever since Worthing and I cleaned out the executive bar and fingered him for it. Wildfang knew about that little episode (it had been her idea to have a brandy party, after all), and she obviously had called Quinn about the present caper, knowing that he would try to set me up and create a nice diversion for her.

She just stood there in feline silence.

"Well, since we only have about another twenty minutes before Quinn brings in the hounds, maybe you should tell me what it's all about and how I can help". She thought about this for a second and then said there were certain things she had picked up in the U.S. that she wanted the right people in Ontario to grasp. At her feet was a black bag full of books which would be found to have been "newly acquired" by the library tomorrow. She pointed toward a notice board where announcements of the "acquisitions" beamed out their messages.

"You know how the library works", she said. "I want you to help me doctor the paperwork so even the library staff will think that these are really new acquisitions".

It wasn't difficult, but you had to know where to look. First there were the purchase requests, then the orders, then the annotations in the mail book that the goods had actually arrived. The invoices didn't matter. The library staff would write off to the publishers after they hadn't received any demands for payment, begging said publishers to help relieve them of the burden of all that spare gelt. An argument would ensue, as is always the case with publishers (once they realize that you think you owe them, they try to charge you twice as much as you have offered to pay). But by then it wouldn't matter; the information would already be in the hands of the target users.

It all sounded a bit flakey, but positively Wildfangian, so I didn't say anything and Mamba and I worked silently. I did rescue a small crumpled piece of paper which was the only occupant of the waste basket next to the photocopier. On it were written the call numbers of about ten reports, all in the area of thermalhydraulics. Good.

We finished and snaked out. The stars had all fled the bowl of night, and a great pink swath of cloud was smeared across the sky like a large approving tick mark. As I unlocked the Lagonda, two doors slammed somewhere to the lee of the somnolent iceberg. Quinn's goons come to catch me in the act. Next time, boys.

"Where can I drop you?", I asked Mamba. She did a sphinx and said nothing, so I didn't drop her anywhere.

When I awoke much later, the sun was high in the sky, and Mamba's side of the bed was empty. There was only one thing left to do, and after a fast shower and shave I was soon out in the Lagonda again, heading back to the great electric eye. There was a throng of people outside the library, and the staff were running ragged. Well, it was understandable, since publication notices for nuclear texts don't usually carry full size posters of Bo Derek. But I had some reports to borrow. In fact, they were the reports Mamba had added to the shelves but not told me about. That was the real information she wanted to get into the library, of course: information that would invalidate all the two-fluid models, strike their mooring bowlines and send them drifting off in flames to that great (and rapidly over-crowding) Fortran Valhalla. The Bo Derek posters were just good fun.

I found the shelf locations quickly, using the call numbers she had not too carefully disposed of. It was dynamite stuff and would raise merry hell among the themalhydraulics types. Did Mamba actually intend me to be implicated? Who knows. Better Quinn than me anyway, and I made certain by borrow-

ing all of the rogue reports. The desk looked and sounded like the floor of the stock exchange, so it was easy to sign them all out in Quinn's name, bundle them up, and send them off to the Grand Conjuror himself, the head of the thermalhydraulics research unit.

Of course, as a result of all this manoeuvring Quinn swung (metaphorically) for a time, but Wildfang's plan didn't really work. Being proven totally and irretrievably wrong is only a minor, and momentary, setback to a thermalhydraulicist. They recover quickly, like a hydra. But Mamba regards the crusade as necessary, and in my weak moments, i.e. most of the time, I tend to agree. The common or garden thermalhydraulicist would, after all, claim that the world is actually composed of eight basic elements: earth, air, fire, water, steam, slip, drift, and bullshit.

George Bauer

Open Houses Scheduled to Explain Review Process and Concept for Nuclear Fuel Waste Management

The Environmental Assessment Panel established by the federal Environmental Assessment Review Office to review the Nuclear Fuel Waste Management and Disposal Concept has scheduled open houses for May and June in New Brunswick, Quebec, Ontario, Manitoba and Saskatchewan. Secretariat members will be available to discuss the review process, the Panel's terms of reference, anticipated review activities and participant funding while Atomic Energy of Canada Limited staff will have displays and literature available on nuclear fuel waste management.

This is the first time a federal environmental assessment panel has scheduled open houses to inform potential review participants of review activities. Open houses will be held in the following centres:

May 22	Fredericton	Lord Beaverbrook Hotel	2:00 – 5:00	7:00 – 9:00
May 23	Saint John	Holiday Inn	2:00 – 5:00	7:00 – 9:00
May 24	Moncton	Rodd Park House Inn	2:00 – 5:00	7:00 – 9:00
May 28	Quebec City	Loew's Le Concorde	2:00 – 5:00	7:00 – 9:00
May 29	Trois Rivieres	Hotel des Gouverneurs	2:00 – 5:00	7:00 – 9:00
May 30	Montreal	Le Centre Sheraton	2:00 – 5:00	7:00 – 9:00
May 31	Montreal	Le Centre Sheraton	9:00 – 12:00	
June 4	Toronto	Park Plaza	2:00 – 5:00	7:00 – 9:00
June 5	Toronto	Park Plaza	9:00 – 12:00	2:00 – 5:00
June 6	Oshawa	Oshawa Civic Aud.	2:00 – 5:00	7:00 – 9:00
June 7	London	Ramada Hotel Downtown	7:00 – 9:00	
June 8	London	Ramada Hotel Downtown	9:00 – 12:00	
June 11	Sudbury	President Hotel	2:00 – 5:00	7:00 – 9:00
June 12	Timmins	Senator Hotel	7:00 – 9:00	
June 13	Timmins	Senator Hotel	9:00 – 12:00	
June 14	Thunder Bay	Red Oak Inn	2:00 – 5:00	7:00 – 9:00
June 18	Winnipeg	Winnipeg Conv. Centre	2:00 – 5:00	7:00 – 9:00
June 19	Regina	Regina Inn	2:00 – 5:00	7:00 – 9:00
June 20	Saskatoon	Sheraton Cavalier	2:00 – 5:00	7:00 – 9:00
June 26	Ottawa	Venture Inn	2:00 – 5:00	7:00 – 9:00

For further information contact Bob Greyell at (819) 953-3374.

CANADIAN NUCLEAR SOCIETY

Events Calendar
Calendrier des Activités

This program lists events which are sponsored, co-sponsored or considered to be of interest to the members of the Canadian Nuclear Society

Les événements de cette liste sont organisés ou commandité par la Société Nucléaire Canadienne, ou sont considérés d'intérêt pour ses membres

Chairman-Program Committee / Président, Comité du Programme: Hugues W. Bonin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

1990

30 APRIL - 2 MAY 1990
Steam Generators and Heat Exchangers Seminar
Toronto, Ontario
Co-sponsored by ANS

CONTACT:
E.G. Price (AECL-CANDU OPS)
Atomic Energy of Canada Limited
CANDU Operations
Sheridan Park Research Community
Mississauga, Ontario, Canada
L5K 1B2 416-823-9040

3-6 JUNE 1990
CNA/CNS Annual Conference
Toronto, Ontario

CONTACTS:
B. Rouben (AECL-CANDU Ops.)
Atomic Energy of Canada Limited
CANDU Operations
Sheridan Park Research Community
Mississauga, Ontario, Canada
L5K 1B2 416-823-9040

N. Yousef (OH)
Ontario Hydro
700 University Avenue
Toronto, Ontario, Canada
M5G 1X6 416-592-5211

10-14 JUNE 1990
ANS Annual Meeting
Nashville, Tennessee

CONTACT:
Paul Haas
Concord Associates
10615 Alameda Drive
Knoxville, TN, U.S.A.
37922

24-28 JUNE 1990
Canadian Conference on Engineering Education & American Society for Engineering Education Conference
Toronto, Ontario

CONTACT:
Ken Talbot (OH)
Ontario Hydro
700 University Avenue
Toronto, Ontario, Canada
M5G 1X6 416-592-2962

28-30 JUNE 1990
CNS First International Topical Conference on Neutron Radiography System Design and Characterization
Pembroke, Ontario
Co-sponsorship by ANS sought

CONTACT:
A.D. Lane (AECL-CRNL)
Atomic Energy of Canada Limited
Chalk River Nuclear Research Laboratories
Chalk River, Ontario, Canada
K0J 1J0 613-584-3311

30 SEPTEMBER - 4 OCTOBER 1990
International Topical Meeting
"The Safety, Status, & Future of Non-Commercial Reactors and Irradiation Facilities"
Boise, Idaho, U.S.A.
Main sponsor: ANS

CONTACT:
D. Croucher (EG&G)
EG&G Idaho
Idaho Falls, Idaho, U.S.A.
83403-1218 208-526-9804

30 SEPTEMBER - 3 OCTOBER 1990
International Conference on Handling Hazardous Materials: Social Aspects of Facility Planning & Management
Toronto, Ontario

CONTACT:
G.D. Leitch (AECL/WNRE)
Atomic Energy of Canada Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba, Canada
R0E 1L0 204-753-2311

14-17 OCTOBER 1990
Second International Conference on Containment Design and Operation
Toronto, Ontario
Co-sponsored by ANS, ENS, JNS

CONTACT:
P. Burroughs (OH)
Ontario Hydro
700 University Avenue
Toronto, Ontario, Canada
M5G 1X6 416-592-5210

LATE 1990
Fuel Handling Symposium
Location TBA

CONTACT:
A.D. Lane (AECL-CRNL)
Atomic Energy of Canada Limited
Chalk River Nuclear Research Laboratories
Chalk River, Ontario, Canada
K0J 1J0 613-584-3311

LATE 1990
Course on
"Radiation Protection"
Toronto, Ontario

CONTACT:
D. Wright (AECL-CANDU Ops.)
Atomic Energy of Canada Limited
CANDU Operations
Sheridan Park Research Community
Mississauga, Ontario, Canada
L5K 1B2 416-823-9040

11-16 NOVEMBER 1990
Winter Meeting of ANS
Washington, D.C., U.S.A.

CONTACT:
Meetings Dept., ANS
555 No. Kensington Avenue
La Grange Park, IL, U.S.A.
60525 312-352-6611

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1991

22-23 MARCH 1991
CNA/CNS Student Conference
Kingston, Ontario
(to be confirmed)
Major Sponsor: CNA

CONTACT:
H.W. Bonin (RMC)
Royal Military College of Canada
Dept. Chemistry & Chemical Engineering
Kingston, Ontario, Canada
K7K 5L0 613-541-6613

21-27 APRIL 1991
Second International Conference on Methods and Applications of Radioanalytical Chemistry
Kona, Hawaii, U.S.A.
Main Sponsor: ANS

CONTACT:
Dr. R.E. Jervis
SLOWPOKE Reactor Facility
University of Toronto
Toronto, Ontario, Canada
M5S 1A4 416-978-7129

28 APRIL - 1 MAY 1991
International Topical Meeting of American Nuclear Society on Mathematics Computations and Reactor Physics
Pittsburgh, Pennsylvania, U.S.A.
Main Sponsor: ANS

CONTACT:
M.S. Milgram (AECL-CRNL)
Atomic Energy of Canada Limited
Chalk River Nuclear Research Laboratories
Chalk River, Ontario, Canada
K0J 1J0 613-584-3311

2-6 JUNE 1991
ANS Annual Meeting
Orlando, Florida, U.S.A.

CONTACT:
Meetings Dept., ANS
555 No. Kensington Avenue
La Grange Park, IL, U.S.A.
60525 312-352-6611

9-12 JUNE 1991
CNA/CNS Annual Conference
Saskatoon, Saskatchewan

CONTACT:
Canadian Nuclear Society
111 Elizabeth Street, 11th Floor
Toronto, Ontario, Canada
M5G 1P7 416-977-7620

17-21 JUNE 1991
Sixth International Conference on Emerging Nuclear Energy Systems
Monterey, California, U.S.A.
Main Sponsor: Lawrence Livermore National Laboratory

CONTACT:
Dr. A.A. Harms
Dept. of Engineering Physics
McMaster University
Hamilton, Ontario, Canada
L8S 4M1 416-525-9140 ext. 4545

21-25 JULY 1991
International Safety of Thermal Reactor Topical Meeting
Portland, Oregon, U.S.A.

CONTACT:
W. Munn
Westinghouse Hanford Co.
P.O. Box 1970, L5-59
Richland, WA, U.S.A.
99352 509-376-4953

10-15 NOVEMBER 1991
ANS Winter Meeting
San Francisco, California

CONTACT:
Meetings Dept., ANS
555 No. Kensington Avenue
La Grange Park, IL, U.S.A.
60525 312-352-6611

1992

SPRING 1992
Radiation Processing Conference
Toronto, Ontario

CONTACT:
S.L. Iverson (AECL-WNRE)
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba, Canada
R0E 1L0 204-753-2311

17-22 MAY 1992
Eighth World Congress of the International Radiation Protection Association
Montreal, Quebec
Organized by: International Radiation Protection Association

CONTACT:
Jean-Pierre Gauvin
2155 Rue Guy,
Bureau 820
Montreal, Quebec, Canada
H3H 2L9 514-932-9552

25-29 MAY 1992
Workshop on Radiation Safety in Uranium Mining
Saskatoon, Saskatchewan
Main Sponsor: Govt. of Saskatchewan

CONTACT:
L.D. Brown (Sask. Govt.)
Saskatchewan Human Resources,
Labour and Employment
1870 Albert Street
Regina, Saskatchewan, Canada
S4P 3V7 306-787-4486

31 MAY - 3 JUNE 1992
CNA/CNS Annual Conference
Montreal, Quebec

CONTACT:
Canadian Nuclear Society
111 Elizabeth Street, 11th Floor
Toronto, Ontario, Canada
M5G 1P7 416-977-7620

1993

4-8 OCTOBER 1993
Proposed World Conference on Nuclear Energy and the Environment
Toronto, Ontario
Wide international co-sponsorship being sought

CONTACT:
J. Weller (CNA/CNS)
Canadian Nuclear Society
111 Elizabeth Street, 11th Floor
Toronto, Ontario, Canada
M5G 1P7 416-977-7620

Requests for information:
Pour des plus amples renseignements:

CANADIAN NUCLEAR SOCIETY
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111 ELIZABETH STREET, 11TH FLOOR
TORONTO, ONTARIO, CANADA
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1989-1990

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  Al Lane (613) 584-3311

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1989-1990

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