CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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Guest Editorial

St-Basile: Firestorm of Change

The PCB warehouse fire at St-Basile-Le-Grand, Quebec on 23 August became, to use Alvin Toffler's words, the "firestorm of change" for the PCB industry, or whatever is left of it, after the chemical was banned in the 1970s. The fire, whose toxic cloud of smoke forced the evacuation of 3300 residents – citoyens contaminés ("contaminated citizens") as they were dubbed – forced Canada's environment ministers to phase out PCBs by 1993, whipped the governments into action to accelerate PCB incineration Canada wide, woke up the bureaucracies to cataloguing PCBs across the country and the unglamorous industries to the task of better storage and disposal. Within three weeks, the residents returned to their homes, after the Government gave the word that it was safe to return. Although the fire subsided within hours, one hopes the "firestorm of change" will not, until all PCBs are totally eliminated.

Are there some immutable laws of techno-political evolution that the St-Basile accident uncovered? Are there any lessons for the beleagured nuclear industry saddled with the problem of disposal of nuclear wastes? Is it an aberration or does it illustrate a more fundamental characteristic of the society that we need to recognize?

Let me discuss these under three heads: evolution, environment, and economics.

Evolution

The public usually castigates governments for lack of political will, foot-dragging and finally for messing up their lives, as in St-Basile. The public at large does not understand the technology – PCBs, BCPs, CCPs, PCPs or what? Nor should it be expected to. Governments are expected to fill this gap, however. Part of the responsibility of Government in society is to search for truth, evaluate solutions, finance technologies and finally make decisions. Until the truth emerges and the right technology evolves, there can be no permanent solution, only promises as in the disposal of high-level nuclear wastes. In the St-Basile case, the technology was in the wings: it is a matter of acquiring it. Government whipped itself into action. Fear, sparked sometimes by accidents unfortunate as they are, helps in rallying people behind their governments for quick action. Perhaps people will now see siting of the incinerator at Senneterre as Quebec's permanent solution to the PCB conundrum. If there is a lesson to learn, a part to play for the nuclear industry, it is: *Let us do all that is needed in getting our technologies in still a better shape. Let the CANDUs be still safer. Let not nuclear waste disposal be a pie in the sky. Good technology is the key. Public and governments will naturally follow.*

Environment

Like radioactivity, toxins are omnipresent. We evolved with them since the dawn of life. Whether they are bad or worse, is a matter of dose. Technological civilization – nuclear and chemical industries in particular – without proper measures can add to our natural exposure. We may accept it sometimes, as we accept X-rays and drugs, balancing the good against the bad. Where we cannot accept, the contamination has to be fought against. With environmental toxins and ecological disasters such as Chernobyl and Bhopal, rightly, our societies in the words of Professor Rea, are "allergic to the twentieth century" and will remain so, into the third millenium until the operant for the allergy disappears with fuller environmental consciousness on the part of technology.

Economics

Economics is the stray horse. If we cannot afford protection of life from technology, we shouldn't be affording the technology. Technologies should be adopted only after evaluating their full impact, including their effect on the environment and its genetic wealth. We may argue that we always do. If we consciously believe that this in fact is the case there should be nothing we cannot afford.

Mohan Rao

Editorials

Who transports the container?

In the late summer, with politicians reacting to the pheremones of a possible federal election, Mr. Ed Broadbent visited Toronto, made a boat tour of that city's harbour, and then proceeded to make a speech about pollution. He was against it. In addition to voicing this relatively uncontentious sentiment, he suggested (as far as we understand it) that the responsible executives of corporations that pollute should be held individually responsible and tried in the courts.

While unusual, it is not completely unknown for politicians (of any stripe) to sometimes say something sensible. This is one of those times. There seems little doubt that if a senior company executive faced the prospect of being hoicked from the boardroom to the dock and thence, possibly, to the hoosegow his (or her) mind might focus on the issues of meeting environmental performance standards with rather more precision and promptitude than has hitherto been the case. After all, using the company's money to pay a fine levied against the company is one thing. A spot of porridge is quite another.

But is this fair? we hear you cry. Should these undoubted pillars of the community be snatched from their families' bosoms and tossed in the clink like common felons just because Johnson down in plant maintenance has fouled up again? Why not? The executive is the person with the authority, therefore must take the responsibility. In testimony before the US Joint Committee on Atomic Energy in 1961, Admiral Rickover had this to say on the subject of responsibility:

Responsibility is a unique concept: it can only reside and inhere in a single individual. You may share it with others, but your portion is not diminished. You may delegate it, but it is still with you. You may disclaim it, but you cannot divest yourself of it. Even if you do not recognize it or admit its presence, you cannot escape it. If the responsibility is rightfully yours, no evasion, or ignorance or passing the blame can shift the burden to someone else. Unless you can point your finger to the man who is responsible when something goes wrong, then you have never had anyone really responsible.

Naturally we would not suggest that only the executive officers of private corporations should be subject to such sanctions – those who run publicly owned corporations and government ministries should by no means be above the law. The tradition of "ministerial responsibility" is long overdue for revivification.

As a prerequisite to adopting this sort of approach it would be necessary to establish quite clearly on a scientific basis which materials are deemed to be damaging and what limits should be placed on their emission to the environment. The limits would have to be unequivocally specified since, like the current blood-alcohol limits for motor car drivers, they would establish a legal boundary. The important thing here is that a firm starting point would be established, and how corporations (private or public) related their environmental performance to that point or standard would be available for examination. The principle of the "reasonable man" (in a non-gender sense) would come into operation and, history shows us, this is not the worst basis for major decisions.

The prospect of putting people in prison is not funny. Neither is the prospect of a steadily more toxic environment. Fines, bad publicity, public enquiry – even wireless interviews with aggressive reporters are, at worst, temporary embarrassments to those who treat the environment as a free garbage disposal service. And have been proved to be ineffectual. It is time to start pinning responsibility to individuals and showing those individuals in the least equivocal manner available that the air and the water are not free resources.

Return to sender

We like getting letters. All kinds of people write to us. Usually, it is true, our correspondents have an ulterior motive, to wit they want money. But our momentary irritation at such importunity is largely extinguished by our admiration of the literary abilities of our creditors, the pertinacity of their efforts and the truly astounding degree of arithmetical *leger-de-main* exhibited. We have been known to be held in rapt contemplation for periods as long as 5 milliseconds by such missives before, with regret, we consign them to their appropriate destination.

More rarely we receive letters for publication. It would be pleasant to report that such letters are scrutinized carefully and edited rigorously to ensure that in both form and content they conform to the high standards of this Organ and that only the really outstanding contributions stand a chance of being published. It would be pleasant so to report, but alas, it would be untrue. We are not so inundated with contributions that our greatest task every other month is to select those few for which we can make space. Quite the contrary.

It was, therefore, with eager anticipation we saw a letter on our desk which did not appear to contain a threatening demand for money or other similar appeal to our better nature, cupidity or desire for respectability and creditworthiness. The envelope was emblazoned with the escutcheon of the American Society of Mechanical Engineers. What, we wondered excitedly, could it contain? An invitation to the editors to attend some prestigious gathering of technical experts? An announcement of a new Standard for technical publications? A limited time cut-price offer of membership in the Code-of-the-Month-Club?

With trembling fingers we ripped the envelope open to find . . . nothing.

That's right: not a sausage.

We were somewhat nonplussed at this. Had we missed something, we wondered. It was possible, we reasoned, that ASME might have turned to transmitting written information via microdot. However all the full-stops, commas and other likely typographical camouflage resisted firmly all attempts to separate them from the envelope. Further investigations involving neutron activation analysis, gas chromatography and the next-door neighbour's scanning electron microscope have been fruitless. One of our number claims that his examination of the envelope reveals that it was sealed by a tall, left-handed man who wears eyeglasses and smokes Trincomalee cigars, but further than that he is unwilling to go without more data.

An interesting little printed note on the top right-hand corner of the envelope requests its return to some Scandinavian address in the event of "non delivery". This puts us in something of a quandary for while it is indisputable that the envelope has been delivered it is equally unarguable that nothing else has. Except a mystery.

But we're not letting things rest. Already we have formed ourselves into an investigative task group and arranged an impressive series of meetings at a nearby place of refreshment. We shall probe the matter to its bottom.

In the meantime, if anyone out there has any ideas, please let us know. By phone.

Interested in Contributing to the CNS Bulletin?

To submit original articles, letters, FYI items, reviews, calls for papers, etc., contact one of the following:

- J. Nathwani, Editor, *CNS Bulletin*, c/o Ontario Hydro, 700 University Avenue, Toronto, Ontario, M5G 1X6.
- The *CNS Bulletin*, c/o the CNS office.
- Your branch or division representative.

CNS Bulletin **Issue:**	**Editorial Deadline:**
January/February	January 1
March/April	March 1
May/June	May 1
July/August	July 1
September/October	September 1
November/December	November 1

From the Gallery

Quite a summer for the nuclear debate, when you add up all the statements and reports issued over the past few months. We've had three major statements out of Ottawa since June, all supportive; and although not nuclear-centred, there has also been a lot of action on the provincial scene that includes nuclear references.

First there was Energy Mines & Resources' response to *The Eleventh Hour*, in which the government rejected a parliamentary committee's call for a moratorium on nuclear projects pending agreement on an acceptable means of storing spent fuel. Instead, EM&R will hold public hearings on the burial concept (but not on sites).

Next, Tom Kierans and his Energy Options Study panel, reporting to EM&R minister Marcel Masse, declared that the nuclear option "should be sustained as a component of Canada's energy mix." And finally, in late August, another parliamentary committee issued its *Nuclear Energy: Unmasking the Mystery*, the most supportive of the three.

If you're wondering how two parliamentary committees came to such different conclusions, you are entering a realm where things are not always exactly as they appear. The Commons' Standing Order 96(2) allows committees to study whatever they choose, so long as it is arguably within the terms of their mandates. The Standing Committee on Environment and Forestry chose nuclear waste, and made its recommendations last February in *The Eleventh Hour*. The Standing Committee on Energy Mines & Resources chose the economics of nuclear energy (Ontario Hydro appeared before the latter, but not the former).

The really interesting question is how much sanction these committees had before the government, because that would tell how much store the feds are likely to put by each. The EM&R committee was within its mandate in that nuclear energy is specifically an EM&R responsibility; Environment & Forestry was within the rules, but has no mandate to review nuclear matters.

Meanwhile, at Queen's Park, we've seen the reports of the Technical Advisory Panel and the International Review, on Ontario Hydro's Demand Supply Planning Strategy, and the initial Ontario Hydro presentations to the Select Committee on Energy. One of TAP's concerns was "the validity of nuclear generation costs". It recommended independent review, and it seems there will be one sometime this fall.

Other events we can soon look forward to include federal environmental review of the burial concept; the Sparrow committee's review of Mr. Kierans' report; hearings of a federal task force seeking potential sites for low-level radwaste; and perhaps early in the new year, the findings of the provincial Select Committee on Energy. So there was a lot of action this summer, but it appears there's even more to come.

Richard Furness

"When the fog lifts..."

As if there hasn't already been enough research on water properties, there is yet another cloudy issue: water aerosol behaviour. Water aerosols are droplets of water suspended in air. They occur under a variety of situations, such as mist over wet highways with heavy traffic, water falls, air pollution, cooling of humid air, the making of tea and in reactor containments under accident conditions. This short note describes an analytical challenge in reactor accident analysis, and the approach being taken to solve that problem.

There are only two ways in which water aerosols can form: condensation of vapour or fragmentation of liquid. Both these processes are relevant to reactor accident conditions. The former is usually referred to as "volume condensation" since the vapour condenses in suspension rather than on a surface. Droplets formed by volume condensation are small, of the order of one micron diameter. Liquid fragmentation produces aerosols when a force acting on the liquid exceeds the surface tension, causing breakup. Thermal flashing of reactor coolant, hydrodynamic drag force and impaction (splashing) are examples of processes that would occur under reactor accident conditions, and which could result in liquid fragmentation. These processes produce larger droplets in the range from one to 100 micron diameter.

Water aerosols are important for reactor safety evaluations because they are carriers of soluble fission products, including the radiologically significant iodine. During a LOCA, the water in the core would dissolve any iodine forming the ionic non-volatile iodide. As this water discharges from the break, it flashes to a steam and liquid mixture, accelerating to near sonic velocity in the process. But just as ordinary salt (sodium and chloride ions) remains dissolved in liquid as it boils to steam, the iodide remains in the liquid phase of the reactor coolant as the water discharges from the core and flashes to a liquid and steam mixture[1]. However, by forces of thermal flashing, hydrodynamic drag and impaction with structures, the liquid, with its cargo of dissolved radioiodine, fragments into a water aerosol. Thus, any leakage of iodine to the environment would depend on the extent of aerosol "carry-over" or leakage transported by the escaping steam. There is considerable interest now in quantifying water aerosol leakage under accident conditions.

After a short review of the physical processes affecting aerosol behaviour, one soon realizes that they all depend on the droplet size. For example, gravity is important for large droplets whereas diffusion is important for small droplets. One may argue, therefore, that one must develop the ability to predict the droplet size distribution in a flashing jet, in order to be able to predict water aerosol carry-over. This would require a detailed understanding of flashing jets and the fragmentation processes. An experimental validation would be extremely difficult, because: (a) any instrumentation to measure droplet sizes in a flashing jet needs to be developed; and (b) the measurements would be difficult to interpret because a large fraction of "fines" would be formed by steam condensation. These fines are not of interest to radioiodine release because they are "clean", condensed from vapour, whereas the radioiodine remains in the unflashed water. Thus, in more than a metaphorical sense, the fog gets thicker.

One area of current debate regarding droplet size distribution in flashing jets is the relative importance of thermal flashing force vs. hydrodynamic drag force in liquid fragmentation. It is likely that the initial fragmentation is caused by flashing as nucleated vapour bubbles rapidly expand. As sonic velocities are approached, hydrodynamic drag forces become more important. When the ratio of drag force to surface tension, defined as the Weber Number, reaches a critical value, probably 12,[2] then the liquid drop will fragment to smaller droplets. For high superheats, thermal flashing may initially fragment the unflashed liquid to the extent that the droplets are so fine as to be unaffected by drag force. The sizes would then be a function of superheat. On the other hand, whether thermal flashing is dominant or not, the high turbulence combined with high droplet density would result in rapid agglomeration until the coagulated droplets reach the maximum size limited by the critical Weber Number. The droplet size distribution would then depend, not so much on the superheat, but on the jet velocity. The fog thickens further.

But there is evidence of light at the end of the tunnel – which may not be an oncoming steam locomotive throwing even more aerosols into the air. There is evidence of a strong depletion mechanism driven by the very flashing jet that is the source of the fog. An experiment performed at KWU in West Germany, a full scale simulation of a small break in an auxiliary room, resulted in an unflashed water aerosol carry-over of about 0.3%[3]. Mathematical simulations to reproduce the results were unsuccessful. If one were to assume that gravity sedimentation was the most important mechanism, then one could derive the necessary droplet terminal velocity and work out the corresponding size of the droplets. This exercise revealed that a 1 cm globlet (the size of a gumball) would have the necessary terminal velocity. But, using the critical Weber number, the maximum stable droplet size in free fall is limited to about 1 mm at about 5 m/s (assuming water in steam at 100°C). Larger droplets would break up and therefore have slower terminal velocities. In short, there is no way that gravity was an important factor in these tests.

A new model, called the Jet Scrubbing model[4], assumes that aerosols are removed by entrainment into the jet followed by impingement onto a surface. It gives good agreement with the KWU data. However, good agreement does not prove the theory. It was argued that the results may have been much different if jet impingement occurred at close range, where splashing and high velocity may have generated more fines and increased the carry-over. The antithesis was that fine droplets are created during the flashing process, and so when an impingement surface is encountered, the droplets are already small such that coalescence at the surface was a more likely scenario, which would result in larger, not smaller droplets. (Just when you thought the fog was lifting!) A series of small scale tests was commissioned to test the effect of jet impingement at close range, with encouraging results. It was found that an impingement plate at close range does not enhance the droplet carry-over, but rather it tends to attenuate the carry-over.

There is a need to validate the dominant mechanisms assumed in the Jet Scrubbing model in order to realize its benefit in reactor safety evaluations. To solve this problem, an empirical approach was selected for the following three reasons. First, it would provide quick confirmation as to the dominant mechanisms to ensure that the analytical development is on the right track and that water aerosol research is properly focussed. Second, it would provide the necessary data to develop an empirical correlation for the Jet Scrubbing model. Third, at the very least, it would provide a large scale demonstration that water aerosol leakage from an impaired containment is very small compared to safety analysis assumptions. A fundamental approach would have longer term benefits because it would provide a more mechanistic data base for development of more precise physical models. But, because the topic is highly complex, such an approach would be costly, could lead to many areas of research that can not be readily applied and the benefit would not be realized in the near future. (I had another statement about "fogging" the issue but the editor suggested that I delete it.)

A programme of large scale tests was commissioned with sufficient care to control various parameters, and appropriate instrumentation to discriminate and discern the water aerosol behaviour. The tests are being conducted at Stern Laboratories Inc. in Hamilton, Ontario (formerly Westinghouse Canada Inc., Nuclear Products Division) with assistance from Ontario Hydro Research Division. The programme is called the Water Aerosol Leakage Experiments (WALE) and is about half complete. Some conclusions to date are as follows:

(a) The carry-over fractions are small, consistent with the KWU experiment.

(b) Impingement plate proximity and orientation relative to the flashing jet have an influence on the carry-over.

(c) The Jet Scrubbing model with basic assumptions is in good agreement with the data for most cases, the exception being when an impingement plate is at close range.

(d) The data support a jet scrubbing mechanism where entrainment and impingement are dominant.

The programme is expected to be completed in 1990. Further separate effects tests may be warranted at that time in order to develop means to quantify more precisely the important mechanisms confirmed in the WALE programme.

It would appear that the fog is lifting!

R.J. Fluke

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The CANDU Owners Group – history and current status

Owners' Groups, as such, are a relativly new phenomenon in the nuclear industry. In the United States several came into being at the time of TMI-2 to address issues of mutual interest to the utilities operating nuclear plants. At that time the need was to address regulatory issues and the lessons learned from the accident.

As a result of the success of the owners' groups several other such owner groups were organized. Following is a representative selection of such groups in the US and Canada at the present time:

- BWROG (boiling water reactors)
- HCOG (hydrogen control)
- WOG (Westinghouse)
- SNUG (snubber utility group)
- CEOG (Combustion Engineering)
- COG (CANDU)

The role of the groups has changed significantly since their first inception when their main focus was a reactive one with particular emphasis on licensing problems. Recent years have seen a change to a more proactive role – groups of utilities with similar problems have begun to exploit the advantages of uniquely focused organizational structures for the resolution of their common problems.

The BWROG objectives are fairly typical of all the owners groups. They are to:

- perform work to assure plant safety, achieve higher plant availability and reduce costs

- allow BMR owners to control, minimize and share costs to resolve generic BWR issues
- provide a forum to discuss common issues and operating experience
- exchange information between BWROG, NUMARC, INPO and EPRI
- ensure regulatory activities accurately represent BWR plant safety

The primary objective is to achieve mutual benefit, both technical and financial, through joint engineering, licensing and plant operation enhancement programmes.

In terms of membership the BWROG has 23 US members and 13 international members. The WOG has 27 domestic members and 8 international members. In WOG there is a total of 32 "shares", international utilities have ½ share with no vote, Westinghouse has 3 shares also with no vote while the domestic members have a full share with a full vote.

In Canada an owners' group has, in effect, existed since the early days of the commercial nuclear power programme. However the group consisted of only two members, AECL and Ontario Hydro and was deeply involved in the design and construction of Pickering "A". In the early 70's some of the generic R&D work came under the title of "Common Development" (Figure 1), work which both the members needed equally and were willing to fund on a 50/50 basis. The funding levels were quite low but one significant programme, resulting from the rolled joint failures in the Pickering 3/4 rolled joints, was the development of the zero clearance rolled joint which subsequently became the standard in all reactors.

The "Common Development" programme increased slightly in size with time, but in general AECL were responsible for the CANDU development and in parallel Ontario Hydro were busy building several plants.

This programme developed into the "CANDU Development" programme (CANDEV) in the early 80's and became more formalized with several Working Parties guiding and defining the work to be done. Funding levels were generally limited by Ontario Hydro budgets. The Reactor Mechanical Working Party, for example, generally had a budget of about $1M/year and identified needed common work in the reactor area. As expected, much of this work was in the fuel channel area. Other working parties covered areas such as: Process Mechanical Working Party ($240K) and Fuel Normal Operation Conditions Working Party ($500K).

During this period AECL sold CANDU reactors to other utilities, CNEA (Argentina), KEPCO (Korea), Hydro Quebec and New Brunswick Electric Power Commission. In 1984, with all the plants running, it was felt appropriate to form an owners' group for the CANDU installations along similar lines to the American groups. Appropriately it was called the "CANDU Owners Group" (COG) and was established by an Agreement signed on August 1, 1984 by the four founding members, OH, AECL, NBEPC and HQ.

The fundamental objective of the agreement was to establish a "framework for cooperation, mutual assistance and exchange of information as may be found necessary or desirable from time to time for the successful operation and maintenance of CANDU nuclear electric generating stations."

The organization which was established to meet this objective is illustrated in Figure 2.

The Directing Committee, comprising a senior executive from each of the founding members, is responsible for overall direction of the CANDU Owners Group and for approval of policies, programmes and associated funding.

COG Operations staff are responsible to the Directing Committee for administration and coordination of authorized activities.

In the first two years following its inception COG Operations evolved into the structure illustrated in Figure 3. Activities were divided into four major areas: Projects, Operational Services, Information Exchange and R&D programs. Two Advisory Committees were established to ensure exchange of information in specific areas of common interest and to recommend programmes or projects as required for share funding.

The organization of COG is continually changing as needs are identified. An early need was an information exchange programme which was set up to encompass electronic messaging (CANNET & NETWORK), computerized data base management, production of newsletters and distribution of reports.

CANNET

The electronic messaging service, CANNET, was developed with the operating stations to:

- notify members of information available through COG
- exchange solutions to operating problems
- keep abreast of current activities

Data Base Management

COG Operations developed four computerized data bases containing abstracts of information relevant to the CANDU programme. These are:

1. REPEX – contains member operating, design, construction and research reports available through COG. (4000 entries)
2. INPO – contains external reports available through COG, screened for relevance to the CANDU programme. (398 entries)
3. PCN – contains changes made to operating stations by station staff to improve plant safety and operation. (7173 entries)
4. SEREX – contains significant events that have occurred at member station. (5310 entries)

The data bases can be searched by a variety of methods including: keyword, station name, subject index (USI/BSI), report number, report type and date of report.

Newsletters

The COG newsletter on CANDU Station Performance was established towards the end of 1984, and gives highlights of CANDU station performance and comparisons between stations.

Report Distribution

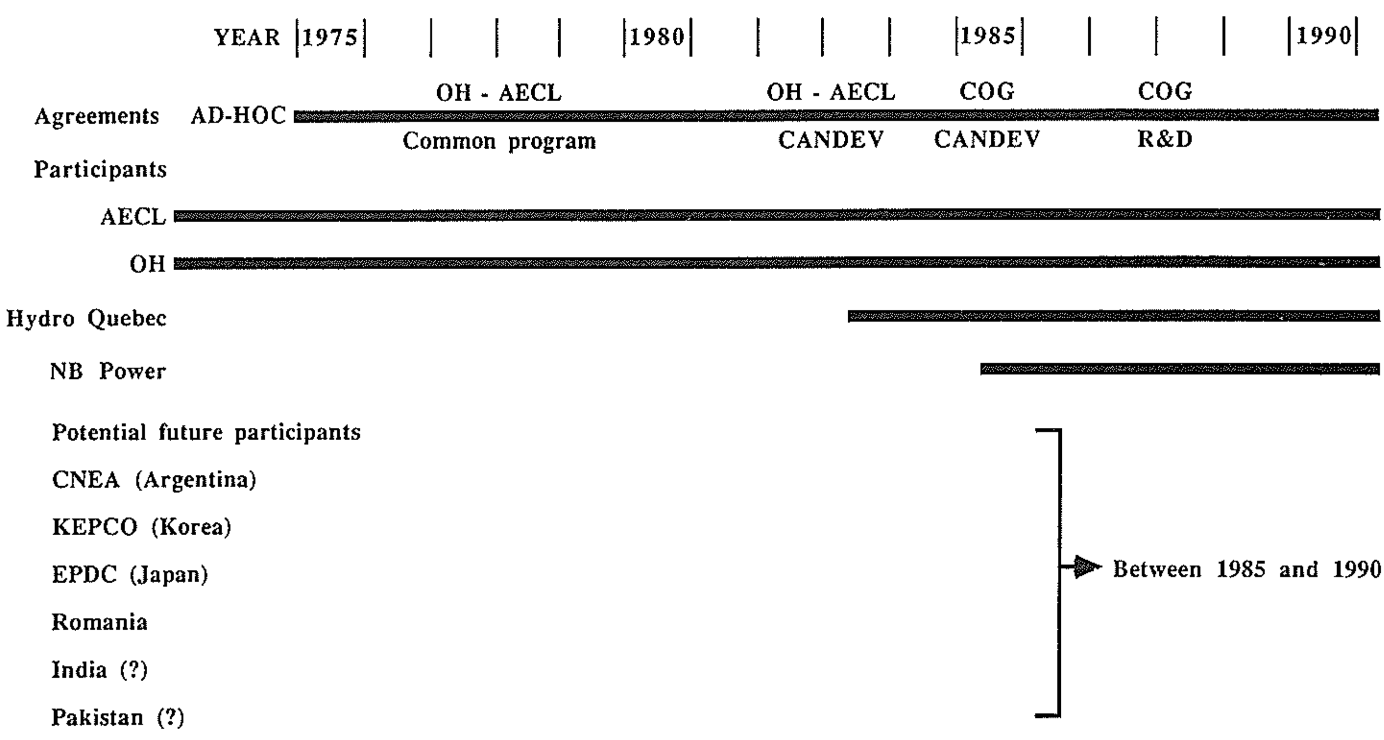
A significant number of reports are acquired by COG, covering operations, design, construction and research. The majority of the reports were donated to COG by its members. Some were donated by external organizations and a few were purchased.

In 1985 the COG R&D programme was established to supersede the two party CANDEV agreement and take over the 11 working parties existing at the time. The current R&D organization is shown in Figure 3 and consists of 27 working parties with an overall budget of 92 M$. The development of the funding levels since 1972 is shown in Figure 4 and covers both "Common Development", CANDEV and COG operations.

The dramatic increase in the funding levels in the last few years has been the result of a number of factors. The major factor was the realization, following the rupture of the pressure tube G16 in Pickering 2 in August 1983, that pressure tube performance was not sufficiently understood to give confidence in long term tube behaviour. The utility funding of fuel channel R&D was increased. Another major factor was the decision made by the Federal Government in 1985 to reduce funding to AECL RC by 50% over the following 5 year period. Much of the reduction was absorbed by AECL RC in improved efficiency and elimination of facilities, etc. However a significant proportion, particularly in the areas where the utilities needed R&D work, was picked up by increased utility funding through the COG R&D programme.

The COG organization continues to change and work is underway in several areas to better serve the needs of the members. The area of "spare parts" is a good example. Because orders for CANDU reactors have been lacking in recent years many manufacturers have closed their shops and thus replacement parts are no longer available. COG is being instrumental in developing new manufacturers or means to acquire spare parts for the members. The most recent example is the closing of the Bristol Aerospace plant in Winnipeg. Items such as liquid zone control assemblies, made only by Bristol, are no longer available. In addition to services, the other members of the CANDU "family", are requesting membership in more of the activities of COG. In particular CNEA and KEPCO are keenly interested in joining the COG R&D programme to ensure that they understand the ongoing R&D work and how it is applicable to their reactors. As one member of the COG Directing Committee pointed out, unlike the US where owners groups have tens of members, the CANDU Owners Group has a limited number of members; only five utilities in the world own operating CANDU reactors, and they should all be part of the COG organization.

George Field



HISTORY OF CANDEV

Figure 1

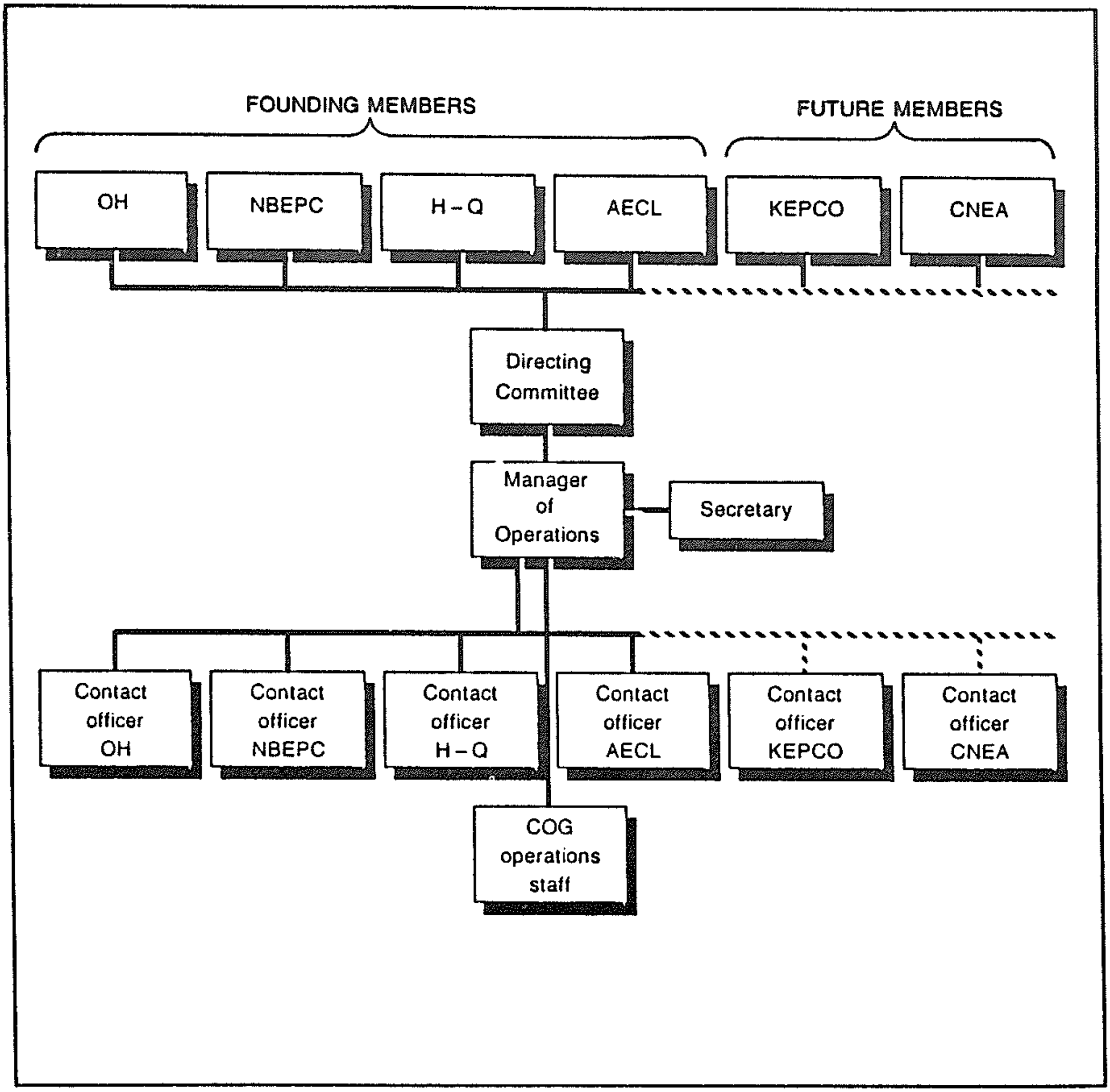
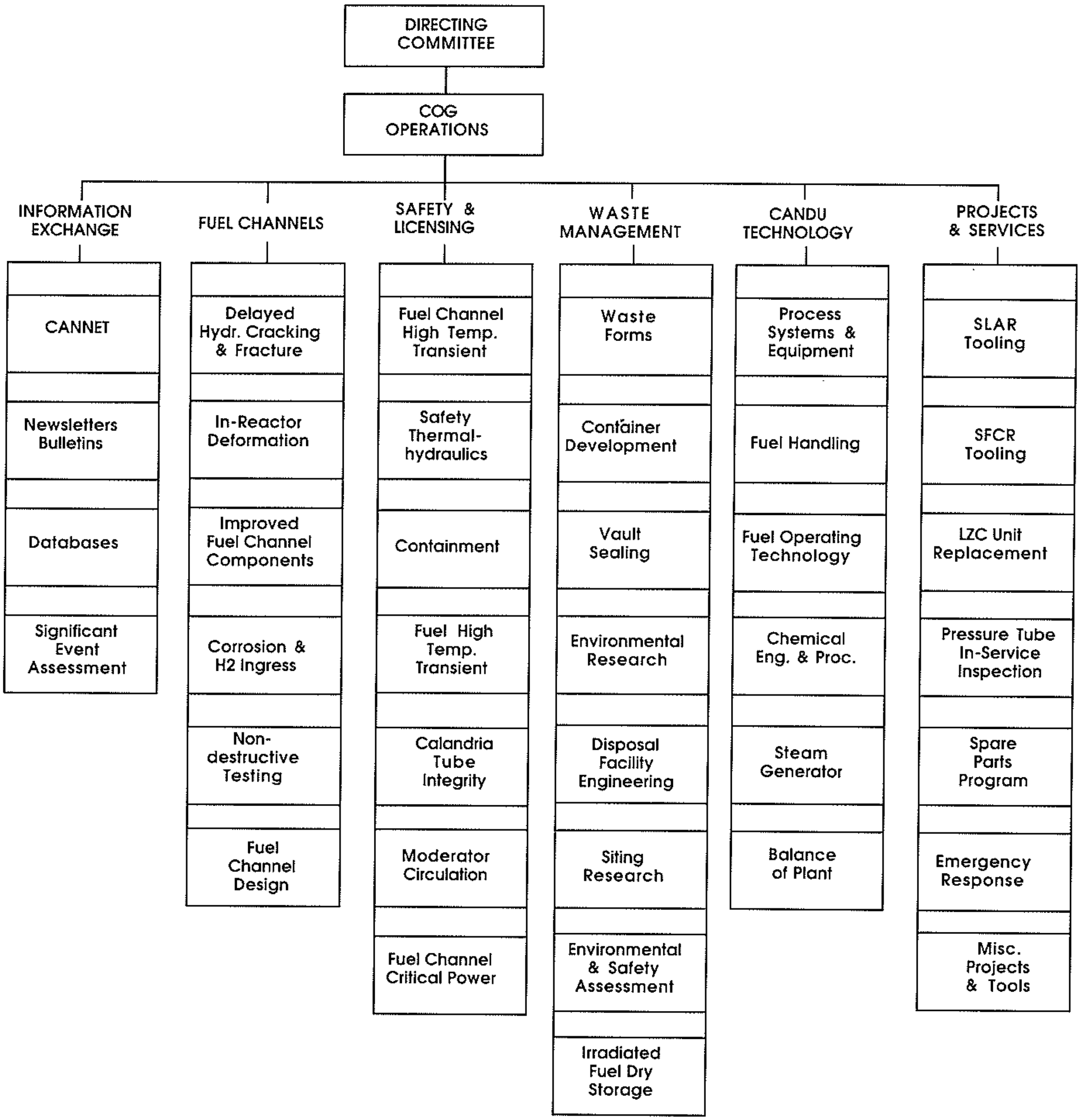


Figure 2 **COG Organization**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COG OPERATIONS
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CANDU TECHNOLOGY
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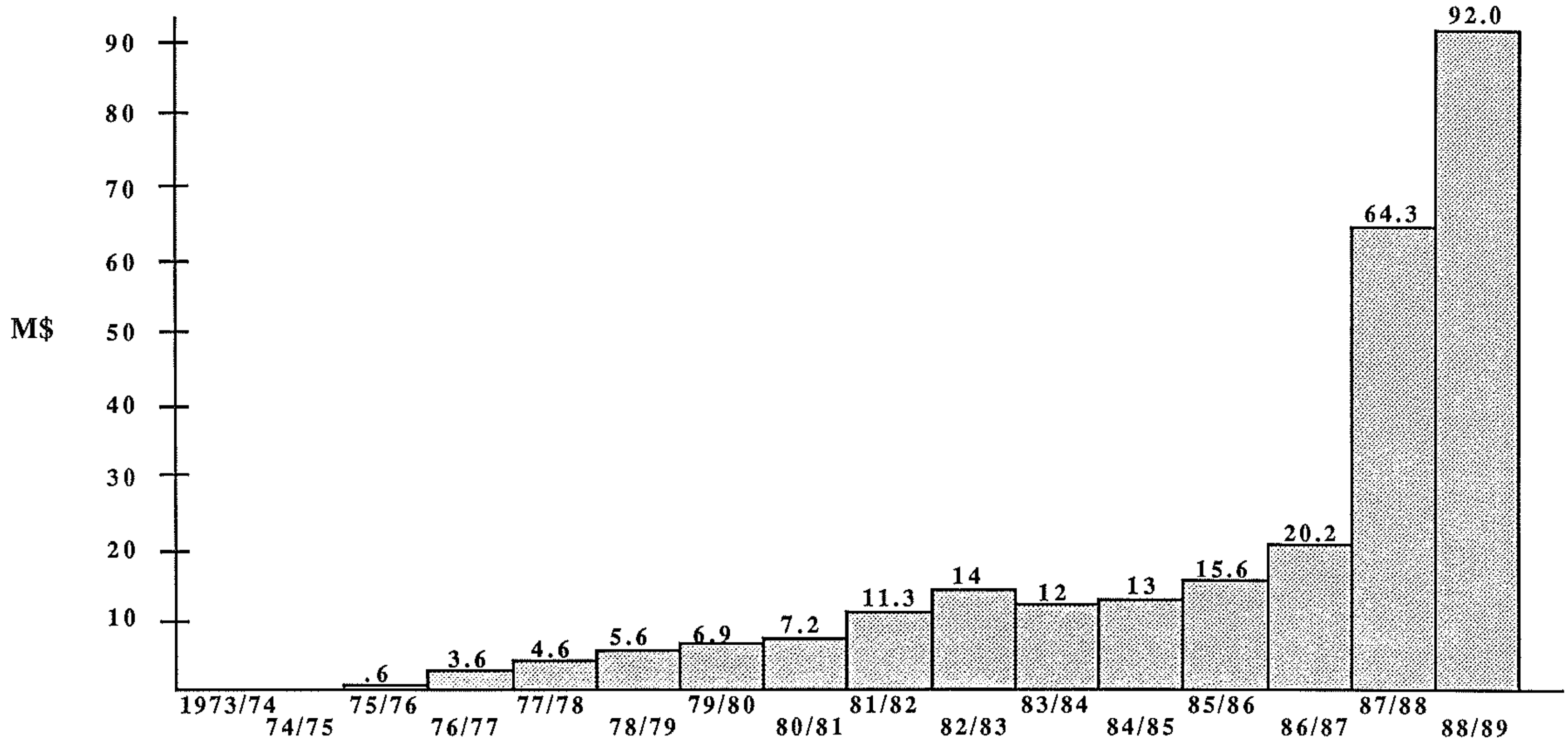
Improved Fuel Channel Components
Corrosion & H2 Ingress
Non-destructive Testing
Fuel Channel Design
Fuel Channel High Temp. Transient
Safety Thermal-hydraulics
Containment
Fuel High Temp. Transient
Calandria Tube Integrity
Moderator Circulation
Fuel Channel Critical Power
Waste Forms
Container Development
Vault Sealing
Environmental Research
Disposal Facility Engineering
Siting Research
Environmental & Safety Assessment
Irradiated Fuel Dry Storage
Process Systems & Equipment
Fuel Handling
Fuel Operating Technology
Chemical Eng. & Proc.
Steam Generator
Balance of Plant
SLAR Tooling
SFCR Tooling
LZC Unit Replacement
Pressure Tube In-Service Inspection
Spare Parts Program
Emergency Response
Misc. Projects & Tools

Figure 3



HISTORY OF CANDEV/COG R&D PROGRAM

Figure 4

Special Report – CNS submits brief to Select Committee

On September 6, the Canadian Nuclear Society submitted a short brief to the Ontario Legislature's Select Committee on Energy. At the time of writing, it was not known whether the CNS would be asked to make a formal presentation in support of its submission. Below we reproduce the text of the submission.

Brief to the Ontario Select Committee on Energy Regarding the Ontario Hydro Draft Demand/Supply Planning Strategy

Introduction

The Canadian Nuclear Society is an organization of individuals with a common professional interest in nuclear science and engineering and with a desire to promote the understanding and use of Canadian nuclear expertise in national and international fora. We do not necessarily represent a commercial or industrial point of view. Rather, we voice the collective opinion of Canadian nuclear scientists, engineers and technologists.

Membership in the Society includes individuals with expertise in all areas of nuclear science and engineering, including fission, fusion, production and handling of isotopes, health and safety, environmental protection, research and education. In the more restricted field of nuclear fission, the expertise of the Society's membership encompasses the entire fuel cycle, from mining and refining, through reactor design and operations to waste disposal.

Society members have worked with nuclear technology for many years and we feel that, based on this expertise and understanding, we have a unique contribution to make in discussions of future energy supply strategies. We are convinced that nuclear power can and should continue to be relied upon to meet Ontario's electrical energy needs in the future.

In what follows, we will summarize the demand and supply situation as we perceive it. We will then comment more particularly on questions within our own field of expertise, namely the nuclear option. In the process, we will indicate why we believe that nuclear power is a logical, advantageous and correct choice for Ontario.

Meeting Electricity Demand

Recent Ontario Hydro studies predicted a most probable increase in electricity demand of 2.4% per year. This prediction was the best judgement at the time it was made, but in fact the demand has been nearly double this figure for five years running.

If this trend were to continue into the future, it would necessitate a large programme to add generating capacity to the power system. As a result, Ontario Hydro has undertaken a programme of demand management. This is something that nobody could fail to endorse. But while this is a positive step, it is important to see demand management for what it is: applied correctly, it is the more efficient use of electricity in those cases where the incremental cost of the efficiency improvements is less than the cost of adding additional generating capacity. It is not an increase in the supply.

Demand management can exert considerable influence over the average demand and it can save large amounts of energy, but it may be quite powerless in the face of peak demands (e.g. the recent heat wave in July and August) that can arise suddenly as a result of a number of factors which are hard to predict and difficult or impossible to control.

The point of all this is that predicting electricity demand is an art and the predictions have some uncertainty attached. Demand management is a necessary and desirable component of an energy strategy but in all cases the situation to be avoided is that of not being able to meet the demand. The only way to do this is through the timely provision of an assured supply.

Electrical Supply Options

Apart from limited contributions from hydro-electricity and co-generation, Ontario can look to only two sources for significant blocks of electrical generation: coal and nuclear.

We cannot comment on the details of how much hydraulic, coal-fired and co-generation capacity could be provided and on what time scale. However it is a readily verifiable fact that Ontario's resources in fossil fuels are essentially non-existent and that with the exception of capacity additions at Niagara Falls, any large blocks of hydraulic capacity must come from remote northern rivers with subsequent high transmission losses/costs. The total amounts of hydraulic capacity available are not large, and compared to the additions that are expected to be needed by the year 2010, they are small and inadequate.

Ontario Hydro has several large coal-fired power stations in its system and others could be added.

Nuclear power stations now provide about 50% of the province's electricity and more of them could also be built.

For large scale additions to the grid, therefore, the options are basically nuclear and coal-fired stations. In approaching this choice, we are convinced that the important factors to be taken into account are environmental considerations, supply security and economic issues, in that order. We will now concentrate on those points, indicating those aspects of the nuclear option which we feel are important.

The Nuclear Option: Its Characteristics and Advantages

In characterizing nuclear power plants, it is inevitable that comparisons will be made to coal-fired stations, since they constitute the alternative.

At the outset, we can make the statement that nuclear power stations are clean, safe and provide electricity at favourable rates.

Nuclear power stations are clean environmentally. They emit no acid gases, no fly ash, and no smoke. Releases of radioactive material from Ontario's CANDU stations are kept consistently below 1% of the federal regulatory limits. In common with coal-fired power stations, they do need to discharge waste heat into the environment through cooling water.

The waste produced by nuclear power stations is small in volume. The total amount of such waste generated in Canada since the first CANDU reactor began operating in 1962 could be contained in one Olympic size swimming pool. This material is contained within the stations and is managed responsibly. Public perceptions may be otherwise, but in fact the nuclear industry has developed complete, extensive and well-researched plans for managing its wastes and minimizing its impact on the environment. Few or none of the alternative options for power production can make that claim.

Storage of fuel by the method presently used (i.e. in the form of intact fuel bundles in water-filled pools) is safe and reliable for at least 50 years[1]. The ultimate disposition of this waste in a safe manner is a topic of general concern and interest. It is impossible to give a complete and authoritative rundown of all the activities related to nuclear waste management in a short space. The Committee should be aware, however, that there have been and are ongoing national and international research and demonstration programmes which are designed to demonstrate the scientific and engineering components of a long term disposal plan. The elements of such a plan are summarized in the attached overview paper by Hancox[2]. Canada, with its experimental underground research laboratory, is leading the field in this area. In plain terms, we are nearing the time when we will be able to demonstrate to all reasonable people that nuclear wastes can be immobilized and stored safely in deep rock disposal vaults. To illustrate that this general conclusion is not restricted to the technical community, we quote from the recent report of the House of Commons Standing Committee on Energy, Mines and Resources: "The technical problems of radioactive waste management are not insurmountable: the Committee concludes that these wastes can be safely handled, stored, transported and disposed of providing the political will is there."[3] In summary, we believe that the major questions have been answered or that workable answers are in sight.

Nuclear power stations are safe, both as regards the public and the staff who operate them. Although health records for workers over the years have demonstrated this safety, and studies have been carried out to look for health effects among the general population (with no such effects found), the entire question has been aired once again by the recent inquiry headed by Prof. Kenneth Hare (the Ontario Nuclear Safety Review). While he made suggestions for improvements and changes, his major conclusion was that Ontario's reactors are being operated safely and at high standards of technical performance and that the risk to the public is very remote.

Nuclear power stations are economically competitive. Over the lifetime of the plant, the per kilowatt-hour cost of nuclear electricity is less than that from coal-fired stations. This conclusion was stated by Ontario Hydro in its planning documents and studies. We expect that the Minister's independent review currently being carried out on the cost of nuclear energy will confirm this conclusion.

A very significant advantage of nuclear power stations in Ontario relates to economics and availability of resources.

Nuclear energy is a home-grown Ontario resource. Canada is the world's largest uranium producer and a large proportion of the country's uranium reserves are in Ontario. Uranium mining, refining and fuel bundle manufacture all take place in Ontario. Most of the major suppliers of equipment needed to build a nuclear station are located in Ontario. Much of the research and virtually all of the design capability is found in Ontario. These activities provide high quality jobs in centres across the province, such as Port Hope, Elliot Lake, Blind River, Peterborough, Cambridge, Chalk River, Hamilton, Arnprior and Toronto. Sixteen of the 18 power reactors operating in Canada are in Ontario. And of the 260 large power reactors in the world, six of Ontario's reactors were among the ten best performing units internationally in 1987. In short, we have the tools, the people, the resources and the experience to build the finest nuclear stations in the world – right here in Ontario.

The "Canadian content" of an Ontario Hydro nuclear station is about 75% and of this 75%, about nine-tenths is "Ontario content". The significance of the construction and operation of a nuclear station for Ontario can be illustrated by referring to the existing overall programme. Over the period 1970-1983, a "no nuclear" scenario would have resulted in a cumulative reduction in balance of trade of $4 billion (due to coal imports) and a cumulative reduction in real Ontario GDP of $9 billion (due to reduced construction activity and lower demand for uranium). For the 1990s, the higher electricity prices implied by a "no nuclear" scenario would result in a GDP reduction of $1 billion per year and a trade balance of $1.5 billion per year.[4] Therefore, apart from its environmental advantages, the nuclear industry has a very substantial (and beneficial) economic impact.

Constraints

Although the choice for Ontario would seem to come down to some combination of coal and nuclear for a longer term strategy, there are also several very real and important constraints that will figure in any responsible decision.

The first is acid rain. Apart from the accounted and unaccounted costs of acid rain which could be factored into the economics, consideration has to be given to the long term environmental, amenity and aesthetic effects of increased acid gas emissions to the atmosphere. These are only a consideration with coal-fired stations, and they can be countered to some extent at a cost of an increased economic burden and a greater waste management problem.

The second is the question of climate warming through the emission of so-called greenhouse gases. As with the case of acid gas emission, the effects are long term and not well known. However, enough information is available for environmental scientists to conclude that humanity, in effect, "is conducting an unintended, uncontrolled, globally pervasive experiment", with the earth's atmosphere "being changed at an unprecedented rate by pollutants resulting from human activities, inefficient and wasteful fossil fuel use and the effects of

TECHNICAL SUPPLEMENT

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APPLICATION OF FISSION PRODUCT RELEASE STUDIES TO FUEL FAILURE MONITORING

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ABSTRACT

An in-reactor research program with single defective nuclear fuel elements has provided a fundamental understanding of the physical processes of fission product release from defective fuel. As a result of this study, a methodology is established whereby release from surface uranium contamination can be distinguished from that of fuel pin failure. Application of this work to power reactors is discussed.

INTRODUCTION

An experimental program with defective CANDU-type (Canada Deuterium Uranium) UO_2 fuel elements was carried out at Chalk River Nuclear Laboratories (CRNL) from 1975 to 1983. Failed elements with various degrees of sheath damage were irradiated in separate tests in an experimental loop of the NRX reactor. In this program, the irradiation history of the elements and the characteristics of the failures were well known. The experiments were designed to provide a large data base for assessing the characteristics of fission product release and post-defect behaviour under a variety of irradiation conditions.

In this paper, results of the fission product release studies are reviewed. The application of this work to fuel failure monitoring in the power reactor is also discussed.

TABLE I Fuel Element Design

	Fuel Element Classification*	
	Class I	Class II
Fuel description		
Sintered UO_2 density (Mg/m^3)	10.7	10.7
Enrichment (wt% U-235 in uranium)	4.5	5.0
Pellet diameter (mm)	13.7	12.1
Pellet length (mm)	18.0	16.5
Pellet end dishing	one end	both ends
Land width (mm)	0.56	0.46
Depth (mm)	0.64	0.23
Fuel stack length (mm)**	179	477
Sheath description		
Material	Zircaloy-4	Zircaloy-4
Outside diameter (mm)	15.2	13.1
Wall thickness (mm)	0.71	0.43
Clearances		
Diametral (mm)	0.10	0.10
Axial (mm)	1.0	2.2

* Class I elements include: RPL, LFZ, RPP, RPR and NSZ. Class II elements include: A3M, A3N, A7E, A7A and A2F.

** Elements LFZ and NSZ had fuel stack lengths of 168 mm. Element A3N had a fuel stack length of 470 mm.

EXPERIMENTAL DETAILS

Experiment Description

The fuel element design is detailed in Table 1. A brief summary of the fuel-operating parameters for each experiment is given in Table 2. The experiments involved fuel elements which were either artificially or naturally defective. Several elements were defected prior to irradiation with artificially drilled holes or machined slits in the fuel sheathing. In other experiments, however, the elements were characteristic of failures found in power reactors. These latter failures arose naturally in the reactor as a result of small manufacturing flaws during fuel fabrication, or by stress-corrosion-induced cracking of the fuel sheathing after a power ramp. The naturally-failed fuel elements were particularly susceptible to the phenomenon of sheath hydriding, with the hydriding process leading to further deterioration of the sheath.

TABLE 2

Summary of Experiments With Single Defective Fuel Elements at Chalk River

1.1 Artificially-Defective Fuel

Experiment (Element)	Test Description	Defect Description	Defect Size (mm^2) Initial	Defect Size (mm^2) Final	Linear Power (kW/m)	Burnup (MW.h/kg U) Initial	Burnup (MW.h/kg U) Final	Defect Residence Time (Effective Full Power Days)	Irradiation Date
FDO-681									
Phase 1 (RPL)	Irradiation of elements with drilled hole(s)	Single hole (1.3 mm)*	1.3	1.3	49	140**	158	15	1975 July 24-Aug. 10
Phase 2 (LFZ)		Single hole (1.2 mm)*	1.1	1.1	48	0	20	24	1975 Aug. 10-Sept. 23
Phase 3 (RPP)		Two holes (1.3 & 0.4 mm)*	1.5	1.5	47	140**	173	35	1975 Oct. 8-Nov. 16
FDO-687									
Phase 1 (RPR)	Irradiation of elements with drilled hole(s) or single slit	Single hole (2.0 mm)*	3.1	3.1	55	43**	85	40	1976 Mar. 13-Apr. 25
Phase 2 (NSZ)		Slit (10 mm x 0.6 mm)*	6.0	6.0	58	0	28	26	1976 Apr. 30-May 26
Phase 3 (RPR)		Three holes†	7.2	7.2	54	85	90	4	1976 June 10-June 14
FFO-101 (A3H)	Irradiation of an element with a drilled hole	Single hole (1.0 mm)*	0.8	0.8	39	0	45	47	1979 Jan. 3-Mar. 5
FFO-103 (A3N)	Irradiation of an element with 23 slits	Twenty-three slits in a helical pattern along sheath (each slit 36 mm x 0.3 mm)	272	1490††	48	0	18	15	1981 May 30-June 14

* Located at element mid-length.
** Irradiated intact to this burnup.
† Two additional 1.6 mm holes were drilled, one at each end of the element.
†† Slits enlarged during irradiation due to fuel expansion from UO_2 oxidation. Defect size estimated from post-irradiation examination.

1.2 Naturally-Defective Fuel

Experiment (Element)	Test Description	Post-Test Defect Description	Defect Size (mm^2) Initial	Defect Size (mm^2) Final	Linear Power (kW/m)	Burnup (MW.h/kg U) Initial	Burnup (MW.h/kg U) Final	Defect Residence Time (Effective Full Power Days)	Irradiation Date
FFO-102-2 (A7E)	Re-irradiation of an element with through-wall hydriding at high power	Cracked hydride blisters at one end of element	11	300†	67	37	67	19	1981 Mar. 17-Apr. 5
FFO-102-3 (A7A)	Re-irradiation of an element with incipient sheath hydriding at low power	Six randomly located, small hydride cracks	-*	-	23	68	130	110	1981 July 30-1982 Nov. 5
FFO-104 (A2F)	Power ramp failure by stress corrosion cracking	Nine randomly located, small hydride cracks	0.0**	45†	58	255	278	16	1981 May 6-May 24
FFO-110 and FFO-109 (A7A)	Power-cycling of an element with through-wall hydriding	Six randomly located, small hydride cracks	- -	- ≤1†	14-26 22-38	130 140	140 155	18 19	1983 Mar. 23-Apr. 10 1983 Apr. 27-May 10

* Element A7A initially had a porous end plug fabrication flaw.
** Element A2F was initially intact, but failed in-reactor following a power ramp.
† Defect sizes estimated from post-irradiation examinations.

Facility Description

A schematic diagram of the defect loop facility is shown in Fig. 1. This loop is capable of operating at the coolant conditions specified for the CANDU pressurized heavy water reactor. Details of the loop operational parameters are given in Table 3. This facility is designed to cope with high activity levels as a result of fission product release and fuel loss through large defects. The full-flow graphite filters prevent significant UO_2 fuel recirculation. Separate side-stream circuits for the ion-exchange mixed-bed resin columns, and degassing system, provide an optional coolant-cleanup capability for both radioiodine and noble gas.

Activity releases in the coolant were monitored continuously with on-line gamma-ray spectrometry. The design of the spectrometer system has been described in Ref. 1. Fission product concentrations of the dissolved and gaseous species were calculated from the count rate data at the spectrometer located at the inlet of the test section (monitoring zone M1). The data processing algorithms also provided a calculation of the fission product release rate as a function of time (at the fuel location) with the expression (2):

$$R(t) = V e^{\lambda T} \left[C_m + \frac{1}{\lambda} \frac{dC_m}{dt} \right] \qquad (1)$$

where
- C_m = measured activity concentration in the coolant
- V = volume of the loop
- λ = radioactive decay constant
- T = transport time from the fuel location to the measuring station.

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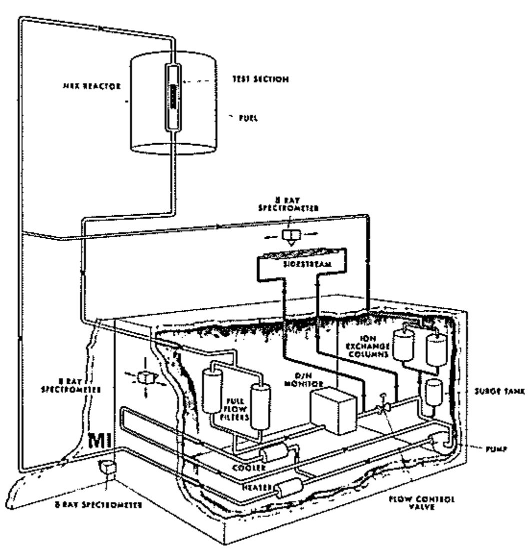

FIGURE 1 The X-2 defect loop facility.

TABLE 3 Loop Operational Parameters

Thermal flux (axially-averaged)	5.5×10^{13} n/cm^2.s
Temperature	240 - 260°C
Pressurized water	7.7 - 10.5 MPa
Flow rate	0.6 - 1.1 kg/s
Recirculation time	105 s
Coolant pH (LiOH controlled)	10 - 11
Hydrogen content	5 - 20 mL/kg
Graphite filters	6 μm
Effective volume of loop	0.15 m^3

FISSION PRODUCT RELEASE STUDIES

Steady-State Analysis

Experimental Results. The dependence of the release-to-birth rate ratio, R/B, on the decay constant, λ, for both the iodine and noble gas species, has been obtained for the various defect experiments in Fig. 2. The ratio R/B, is used to normalize the effect of different yield or birth rate for each of the fission product isotopes.

Inspection of Fig. 2 reveals release dependencies between $\lambda^{-\frac{1}{2}}$ and $\lambda^{-3/2}$. Early theoretical considerations by Booth (3) predicted an R/B proportional to $\lambda^{-\frac{1}{2}}$ for purely diffusive release from the bulk UO_2. This latter dependence has been confirmed in recent sweep gas experiments with intact fuel at CRNL at high linear powers (40 to 62 kW/m) (4), and Halden at low linear power (23 kW/m) (5). A similar dependence was also found for experiment FFO-103. In this experiment (see Table 2), the element was machined with many slits along its sheath to minimize the holdup of fission products in the fuel-to-sheath gap. Therefore, any delay in release from elements with defects of a smaller size can be attributed to additional trapping in the gap as fission products migrate toward the defect site. The steeper slope for iodine also indicates a greater holdup and chemical retention of this species in the gap. Based on these experimental observations, a steady-state release model has been developed.

Model Description. Fission products like iodine, xenon and krypton generated in the UO_2 fuel matrix are partially released into the fuel-to-sheath gap. With defective fuel, these products migrate toward the defect site, and eventually into the primary coolant. In the development of the model, transport mechanisms in the UO_2 fuel and in the gap were considered separately.

i) Release from UO_2 Pellets

Above about 1000°C, fission products migrate primarily by diffusion in the bulk UO_2. The release-to-birth rate ratio can be described by (6)

$$R_{dif}/B = 3 \, (D'/\lambda)^{\frac{1}{2}} \, H' \qquad (2)$$

where
- D' = empirical diffusion coefficient in the UO_2 fuel (s^{-1})
- λ = radioactive decay constant (s^{-1})
- H' = factor to account for the effect of precursors on the diffusional release of fission products in the fuel matrix.

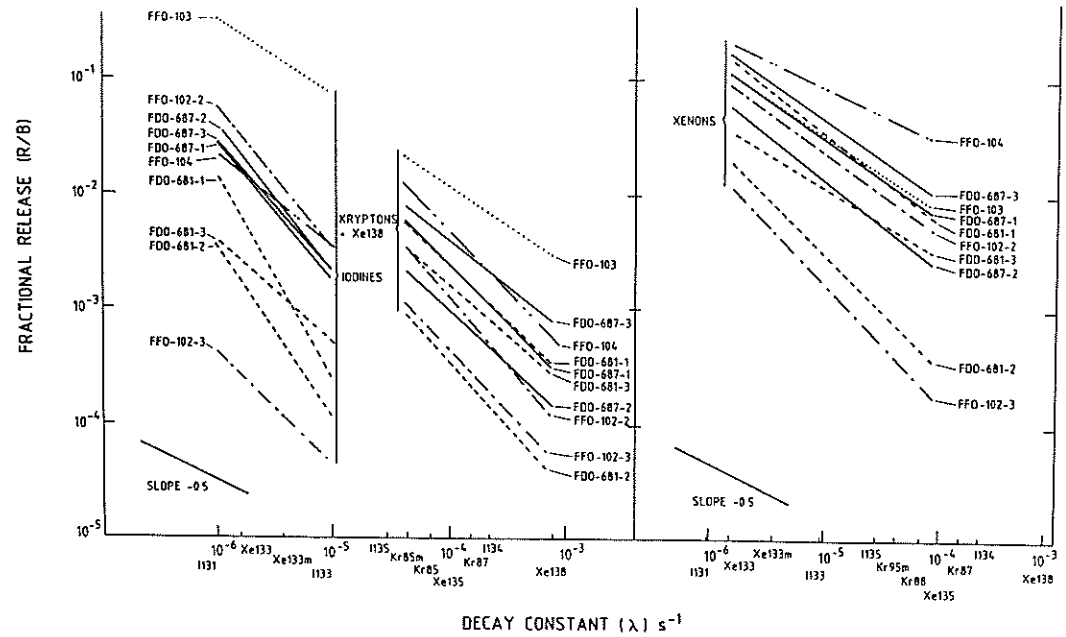

FIGURE 2: Steady-state R/B versus decay constant plot for noble gas and iodine for various defect experiments at Chalk River.

Below 1000°C, fission gas in the matrix of the UO_2 solid is relatively immobile. Only the gas formed at the external surface of the pellet is capable of escape. Release to the steam-filled gap of a defective element can occur by direct recoil when a high-energy fission fragment is produced within a surface layer equal to its range in the solid (7):

$$R_{rec}/B = \frac{1}{4}\,\eta\left(\frac{S_g}{V}\right)\mu_f \qquad (3)$$

where

μ_f = average range of fission fragment in the UO_2 (~10 μm)

S_g/V = ratio of the geometric surface area to volume of the solid.

The recoil fragments have sufficient kinetic energy (~80 MeV) to embed themselves in the fuel sheathing. The efficiency for such particles to stop in the steam-filled interspace is therefore given by

$$\eta = 2\,t_g/\mu_g \quad \text{for } t_g << \mu_g, \qquad (4)$$

where

t_g = thickness of the radial fuel-to-sheath gap

μ_g = maximum range of fission fragment in the gap (μm) [= $23.6/\rho_g$ for a steam density in the gap of ρ_g (g/cm^3)].

In Eq. (3), the cumulative birth rate is used to account for the decay of the precursor products which are also emitted into the gap. A second temperature-independent process of release is knock-out when either a primary fragment, or energetic particle created in a collision cascade, interacts elastically with a fission product atom. The release fraction for this low-energy process is (7)

$$R_{ko}/B = \left(\frac{S_t}{V}\right)\mu_U^{ko}\,I(H), \qquad (5)$$

where

μ_U^{ko} = range of higher-order knock-on of uranium atoms in UO_2 (~ 50 Å)

S_t/V = ratio of total surface area to volume of the solid.

$I(H)$ = knockout integral (see Ref. 7).

In contrast to the recoil process, the initial kinetic energy of the knock-on is sufficiently low (~200 eV) that these particles can be easily stopped within small cracks in the fuel as well as in the fuel-to-sheath gap.

ii) Transport in the Fuel-to-Sheath Gap

Release of fission products from the gap into the coolant can occur by first-order kinetics. Here, the observed release to the coolant (R_c) is proportional to the available inventory in the gap, N_g:

$$R_c = \nu N_g. \qquad (6)$$

In this case, the observed release fraction is (6):

$$(R/B)_c = \left\{ \frac{\nu_i}{\nu_i + \lambda} \right\} (R_t/B)_f \qquad (7)$$

$$\nu_I = \nu_N/(1 + K_{eq}^{-1}) \qquad (8)$$

where i = Iodine or Noble gas species
ν_i = escape-rate constant in the gap (s^{-1})
K_{eq} = equilibrium reaction constant for iodine in the gap
R_t = total release from fuel matrix
= $R_{dif} + R_{rec} + R_{ko}$
[given by Eqs. (2) to (5)].

Alternatively, transport of fission products in the steam-filled gap can be considered to be a diffusion phenomenon. Thus, the rate of release into the primary coolant can be evaluated from the Fick's law of diffusion

$$R_c = - \mathcal{D} \left. \frac{\partial N_g}{\partial x} \right|_{\text{defect site}} \qquad (9)$$

where N_g = concentration distribution of fission product (per unit length)
$\mathcal{D}$ = diffusivity of fission product in the gap (cm^2/s).

For an element of length ℓ, with n defect sites located symmetrically along the sheath, the R/B behaviour is given by (6)

$$(R/B)_c = \left\{ \frac{2nL}{\ell} \tanh \left(\frac{\ell}{2nL}\right) \right\} (R_t/B)_f . \qquad (10)$$

Here L is the so-called "diffusion length" as defined by $(\mathcal{D}_i/\lambda)^{\frac{1}{2}}$ where

$$\mathcal{D}_I = \mathcal{D}_N/(1 + K_{eq}^{-1}). \qquad (11)$$

In Eqs. (7) and (10), those terms enclosed in curly brackets describe the holdup of fission products in the gap during their transport toward the defect opening.

Comparison With Experiment. Assuming that diffusion is the dominant release mechanism from the fuel, the kinetic model [Eq. (7)] yields a release dependence on the decay constant of $\lambda^{-\frac{1}{2}}$ to $\lambda^{-3/2}$; the diffusion model [Eq. (10)] yields a behaviour of $\lambda^{-\frac{1}{2}}$ to λ^{-1}. These dependencies are in excellent agreement with the observed results (Fig. 2). This agreement therefore implies that there is negligible release from the surface-fission processes. For example Fig. 3 shows that for a low power rating of 23 kW/m, releases predicted for the recoil and knockout mechanisms were considerably less than the measured releases of noble gas in experiment FFO-102-3, particularly after correcting for decay of the short-lived fission products during transport in the gap.

It is also important to note the significant effect that fuel oxidation has on the diffusion rates of fission gas in the fuel matrix. Using the gap-transport models, empirical diffusivities (D') can be calculated from measured releases for defective rods, and compared to sweep gas values

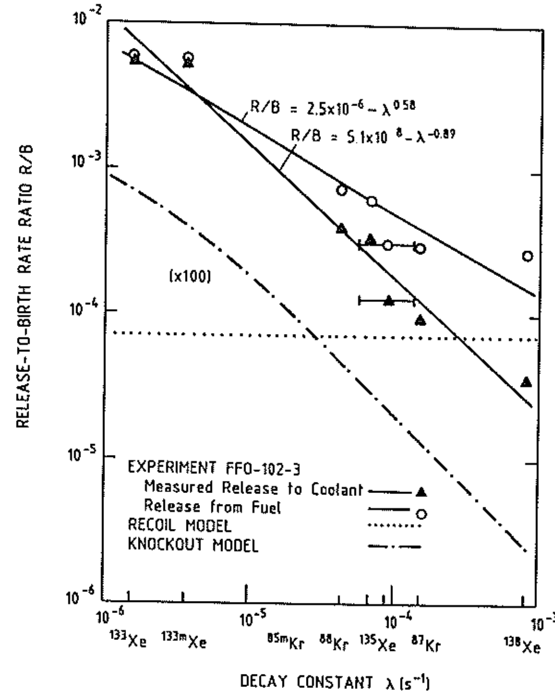

FIGURE 3: Comparison of the recoil and knockout release estimates with measured data for experiment FFO-102-3. [Note: The knockout releases are actually a factor of 100 less than that shown above.] (Data provided by M.R. Floyd, 1984.)

where the fuel is essentially stoichiometric UO_2 (unoxidized). As seen in Fig. 4, the effective diffusivities are enhanced by several orders of magnitude with fuel oxidation. This is due both to an enhanced gas mobility in the hyper-stoichiometric UO_2 (9), and to a decrease in the UO_2 thermal conductivity, resulting in an average temperature increase in the fuel (see discussion below). Moreover, the diffusion coefficient in experiment

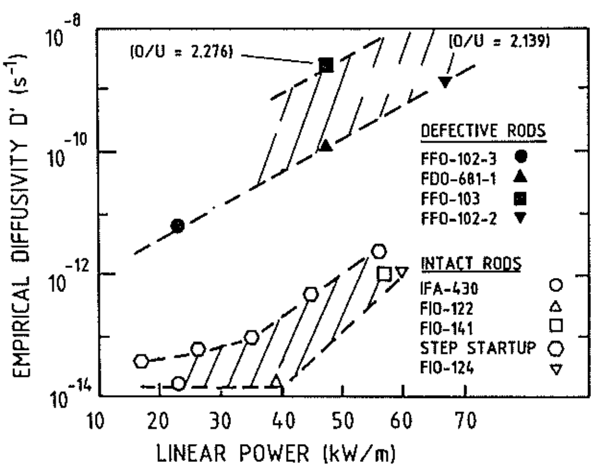

FIGURE 4: Correlation of empirical diffusion coefficients (for noble gas in UO_2) versus linear power for intact rods (4,8) and defective rods (6).

FFO-103 is greater than that in the higher-powered test, FFO-102-2, consistent with an increased oxygen-to-uranium ratio. In fact, in FFO-103, the higher-oxide phase U_3O_8 was observed in cracks near the periphery of the fuel pellets in accord with equilibrium thermodynamics for the oxidation of UO_2 in high-pressure steam (10). However, the limited extent of the U_3O_8 phase implies that the kinetics of this reaction are relatively slow at fuel surface temperatures.

The enhanced diffusion rates in Fig. 4 can be interpreted theoretically using the analysis of Turnbull (11). In this treatment, the diffusion coefficient is represented as a composite expression with components for intrinsic diffusion at high temperature, irradiation enhanced vacancy production at intermediate temperature, and irradiation enhanced (athermal) diffusion at low temperature:

$$D(m^2/s) = 7.6 \times 10^{-10} \exp(-7 \times 10^4/RT)$$

$$+ s^2 j_v (V + V_u) + 2 \times 10^{-40} \dot{F}. \qquad (12)$$

Here $\dot{F}$ is the fission rate (fission/m^3/s) and V is the irradiation-induced vacancy concentration (12)

$$V = \left(\frac{\alpha_s s^2 + Z V_u}{2 Z} \right) \times$$

$$\left\{ \left[1 + \frac{4 K Z}{j_v (\alpha_s s^2 + Z V_u)^2} \right]^{\frac{1}{2}} - 1 \right\}, \qquad (13)$$

where α_s is the fixed sink strength 10^{15} m^{-2}, s is the atomic jump distance (~3 x 10^{-10} m^2), Z is the number of sites around a point defect from which recombination is inevitable (100), $j_v \simeq 10^{13} \exp(-5.52 \times 10^4/RT)$ s^{-1} is the cation vacancy jump rate and K is the rate of defect production per atom (~2 x 10^{-4} defects/s/atom). The uranium vacancy concentration V_u as a function of the deviation from stoichiometry x is given by (13)

$$V_u = \left(S x^2/F_o^2 \right) \left[\frac{1}{2} + (F_o/x^2) + \frac{1}{2} \left(1 + 4 F_o^2/x^2 \right)^{\frac{1}{2}} \right] \qquad (14)$$

$$F_o = \exp(-Q_F/RT)$$
$$S = \exp(-Q_S/RT),$$

where Q_S is the Schottky energy (147.2 kcal/mole) and Q_F is the Frenkel energy for the oxygen lattice (71.3 kcal/mole). Assuming that the ratio of the empirical diffusivities (for defective-to-intact fuel) is proportional to that of the composite diffusion coefficients, an enhancement factor in Fig. 4 can be estimated with Eq. (12) as illustrated in Table 4. An average oxygen-to-uranium ratio of 2.1 was assumed for the failed fuel calculation. Temperature profiles were provided with the ELESIM fuel performance code (14) in order to determine a radially-averaged diffusivity for a given fuel rating* (see Table 4). For example, at 30 kW/m, the diffusion rate increased by a factor of ~ 7 due to an overall increase in the fuel temperature; however, an enhancement factor of ~ 170 resulted from a direct stoichiometric change. The combination of both effects thus yielded an increase in the diffusion rate of 3 orders of magnitude in reasonable agreement with that observed in Fig. 4. The over-prediction of 40 kW/m (Table 4) occurred because the calculation did not account for enhanced grain growth in the defective rod.

Iodine Release Following Reactor Shutdown

Model Description. As seen in Fig. 2, the release fractions for iodine are consistently less than that for noble gas for most experiments indicating that only a relatively small fraction of the fission-product iodine in a defective pin is released into the coolant while the reactor is operating at constant power. Most of the iodine available for release is present as a liquid-water soluble deposit (such as cesium iodide) on the UO_2 fuel surface or inner surface of the Zircaloy sheath. If the temperature in the fuel-to-sheath gap drops below that of coolant saturation, as during reactor shutdown, the water which has entered the element remains in the liquid phase and leaches these deposits. The dissolved iodine then migrates by diffusion along the water-filled gap to the defect site, resulting in an increased release to the primary coolant according to the expression (16)

$$N_c(t) = \left\{ N_{co} + \sum_{j=1,3...} N_{jo} \left(\frac{\nu}{j^2\nu - L} \right) \times \left[1 - \exp\{-(j^2\nu - L)t\} \right] \right\} \exp\{-(\lambda + L)t\} \qquad (15)$$

where

- $N_c(t)$ = inventory of iodine in the coolant at time t
- N_{co} = initial inventory of iodine in the coolant at the time of shutdown
- N_{jo} = series fitting parameters
- N_{go} = initial inventory of iodine in the gap (available for release) at the time of shutdown [= $\Sigma N_{jo}/j^2$, where j=1,3..]
- ν = escape-rate coefficient [$\propto n^2\mathcal{D}/\ell^2$ where $\mathcal{D}$ is the effective diffusion coefficient for iodine in the gap on shutdown, and n is the number of defect sites]
- L = loss-rate constant for coolant leakage and ion-exchange purification in the primary coolant system.

This equation is based on Fickian diffusion into the coolant. Since the higher-order terms in the series expansion (j>1) die out rapidly, the

* For the defective fuel calculation, the heat transfer coefficient in ELESIM was modified to account for the presence of steam in the fuel-to-sheath gap, and the MATPRO.11 correlation (15) was used to model the effect of a reduced thermal conductivity in the hyperstoichiometric UO_2.

TABLE 4 Enhancement Factor for Rare Gas Diffusivity in UO_{2+x}

Fuel Rod Rating (kW/m)	Fission Rate $\dot{F}$ ($f/m^3/s$)	Intact Rods: Fuel Temperature (K) T_{centre}	$T_{surface}$	Intact Rods: Diffusion Coefficient* $\bar{D}$ (m^2/s) $x \le 0.0001$	Defective Rods: Fuel Temperature (K) T_{centre}	$T_{surface}$	Defective Rods: Diffusion Coefficient* $\bar{D}$ (m^2/s) $x \le 0.0001$	$x = 0.1$	Enhancement Factor $\bar{D}^{x=0.1}_{defect} / \bar{D}^{x \le 0.0001}_{intact}$
20	5.8×10^{18}	923	604	1.2×10^{-21}	1165	791	1.9×10^{-21}	1.2×10^{-20}	10
30	8.7×10^{18}	1155	629	2.2×10^{-21}	1485	843	1.6×10^{-20}	2.6×10^{-18}	1.2×10^{3}
40	1.2×10^{19}	1410	643	8.1×10^{-21}	1867	894	8.4×10^{-19}	1.7×10^{-16}	2.1×10^{4}

* Calculated using a 3-point Simpson rule approximation: $\bar{D} = \frac{1}{6}[D(T_c) + 4\,D(T_m) + D(T_s)]$ where $T_m = (T_c + T_s)/2$. The diffusion coefficient D(T) is evaluated with Eq. (12).

release behaviour can therefore be approximated by the first-order expansion. Moreover, this simple expression is also identical to that derived by first-order kinetics.

Based on this simple model, the time at which the iodine inventory in the coolant reaches a maximum is given by

$$t_{max} = \frac{1}{L-\nu} \ln \left\{ \left[\frac{N_{co}}{N_{go}} \left(\frac{\nu-L}{\nu}\right) + 1 \right] \times \left(\frac{\lambda+L}{\lambda+\nu}\right) \right\} . \qquad (16)$$

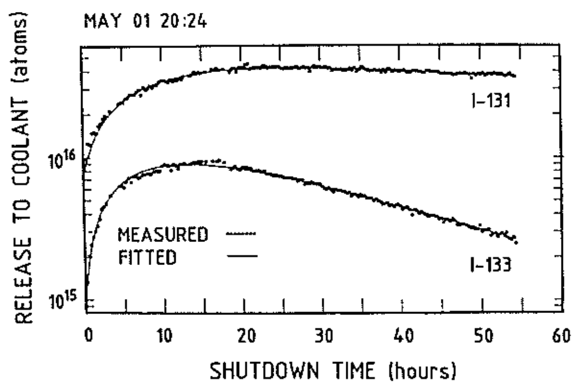

Fig. 5 Fitting of iodine release model [Eq. (15)] to isotopic data from experiment FFO-109. (Data provided by R. da Silva and N. Macici, 1984.)

Comparison with Experimental Data. Defect test FFO-109 was designed to investigate the performance of defective CANDU fuel during transient conditions. The defective fuel element was typical of failures discharged from the power reactor, i.e. the element initially contained a manufacturing flaw which had led to the development of localized hydriding and cracked blisters on the Zircaloy sheath.

A non-linear least-squares fit of the iodine release model using only the first term in the series expansion in Eq. (15) to the experimental data for the isotopes I-131 and I-133 is shown in Fig. 5. The excellent fit of the theoretical expression to experimental data suggests that the diffusion model may be used to describe the release process.

It is important to note that the model in Eq. (15) can be used to describe the "iodine-spiking" behaviour in Light Water Reactors (LWR's) as well. For instance, a fitting of the model to data from the Oconee 1 Pressurized Water Reactor (PWR) (17) is shown in Fig. 6. This model is also compared to an empirical model developed by EPRI (Fig. 6), and is better suited for evaluations in the power plants since it is physically based.

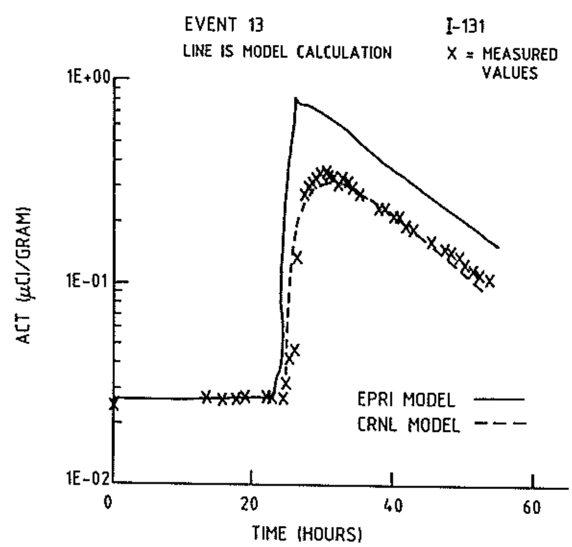

FIGURE 6: Fitting of iodine release model [Eq. (15)] to EPRI data for LWR spiking event (17).

Fission Product Release From Uranium Contamination

In a reactor, traces of uranium compounds may be found on the surfaces of the heat-transport system. This contamination is the result of a previous loss from defective fuel and from the original uranium traces deposited on fuel pin external surfaces during fuel fabrication, and is in the form of very fine particles. Experiments at Chalk River have shown that fuel is lost from defective pins after individual grains of fuel are loosened by oxidation along their boundaries.

For small particles of fuel at low temperature, fission product release may occur by such low-temperature mechanisms as direct recoil and knockout. However, since the range of the fission fragment ($\mu_f \simeq 10$ μm) is comparable to the size of the UO_2 fuel particle itself, each fragment will leave the individual particle of the fissioning uranium-atom, and knockout does not occur. Knockout is also negligible, compared to that of recoil, for fuel with dimensions much greater than the recoil range (Fig. 3.) For instance, experimental ratios of release rates of Kr-88 to Xe-138 were between 0.4 and 0.7 in a pressurized-water loop containing fuel debris on the piping surface (18). These measured ratios are in excellent agreement with the theory of recoil: Here the release expression for a small particle of fuel of diameter D, deposited onto a solid surface, is (7)

$$R/B = \frac{1}{2}\left\{\frac{1}{\alpha^3} + \frac{3\,\mu_f}{2\,D}\left(1 - \frac{1}{\alpha^2}\right)\right\}, \quad (17)$$

and $\alpha = 1$ or D/μ_f whichever is greater. Since B is proportional to the fission yield y, and the right hand side of Eq. (17) is a constant, a release ratio of $R_{88}/R_{138} = y_{88}/y_{138} = 0.55$ is calculated which is in excellent agreement with the observed measurement data. In this calculation, the cumulative yield has been used to account for the decay of the precursor products also emitted into the recirculating coolant.

POWER REACTOR APPLICATIONS

Steady-State Analysis

For fuel failure monitoring in the power plant it is important to distinguish the activity release originating from uranium contamination on the in-core surfaces from direct fuel failure. This can be achieved as the two sources have distinctly different release processes.

With defective fuel, fission products migrate through the UO_2 matrix and then along the fuel-to-sheath gap to the defect site. For fuel ratings greater than about 20 kW/m (see Fig. 3), diffusion is the primary mode of release from the UO_2 fuel [with fuel pin failures, diffusion is enhanced because of fuel oxidation by steam (Fig. 4)]. Therefore, using Eqs. (2), (7) and (10), the release rate when normalized by the fission yield can be described generally by:

$$R/y = a\,\lambda^b\,H'. \quad (18)$$

The parameter H' is a dimensionless factor which takes into account precursor effects. Except for I-132 (where $H' \simeq 12$ because of the relatively long half-life of its tellurium precursor), this factor is the order of unity and can be ignored. The constants a and b are dependent on the chemical nature of the species. The constant b (for both iodine and noble gas) is strongly influenced by the size, number and distribution of defects in the sheath. When there is little holdup of fission products in the gap, as with many defects located along the length of an element, b = -0.5 corresponding to a high "UO_2 exposure" (Table 5). For defects of smaller size, diffusion of fission products in the gap becomes important, and b = -1.0. However, with the small failure there is an additional chemical holdup of iodine in the gap, controlled by iodine dissolution from fuel and sheath surfaces, where b = -1.5. On the other hand, for uranium contamination, Eq. (17) shows that the R/y is independent of λ:

$$R/y = c \simeq \frac{1}{2}\dot{F}\,V. \quad (19)$$

Equation (19) implicitly assumes that the range of the fission fragment is comparable to the diameter of the fuel particle itself. Using Eqs. (18) and (19), the different sources of release in the power reactor can be mathematically separated with the general relation

$$R/y = a\,\lambda^b + c. \quad (20)$$

TABLE 5 Summary of Slopes From Log R/B Versus Log λ Plots

Defect Size	UO_2 Exposure* (mm^2)	Dependence** Iodine	Noble Gas
Large	300 - 1500	-0.5	-0.5
Moderate	11 - 200	-1.0	-1.0
Small	1	-1.5	-1.0

* Range of defect size investigated (Fig. 2).
** Exponential dependence of R/B on λ.

CANDU Reactor System. As a typical example of the use of Eq. (20), consider fission product release data for the Point Lepreau CANDU reactor (see Fig. 7). Here R is calculated from the steady-state coolant activity concentration for the various isotopes of iodine. This release is normalized by the fission yield y, and then plotted against the decay constant. The fission yield has been corrected to include fissioning of the Pu-239 formed by U-238 capture.

The release curve in Fig. 7 indicates the presence of both defective fuel and uranium contamination in the reactor. There is a superposition of the two release processes, e.g. the release curve is sloped for the longer-lived isotopes, but is independent of decay constant at $\lambda > 2 \times 10^{-5}\ s^{-1}$. For the defective fuel contribution, a value of b = -1.3 indicates a small defect with a UO_2 exposure between ~1 and 11 mm^2 (see Table 5). Since the release of I-131 is due mainly to fuel failure, its release rate can be used to estimate the number of in-core failures. Normalizing the measured I-131 release by a single element value* of

* This value is based on previous cases in the Douglas Point and Pickering reactors, where the number of failures were known (19).

6×10^{11} atoms/s, a single failure is predicted. This prediction is consistent with on-line gaseous fission product (GFP) monitoring. A step increase in the Xe-133 coolant activity levels was observed prior to the sample period in Fig. 7. These levels began to decrease at a natural rate of decay after an individual fuel channel was refuelled. A single failure was later confirmed by wet sipping techniques and visual inspection.

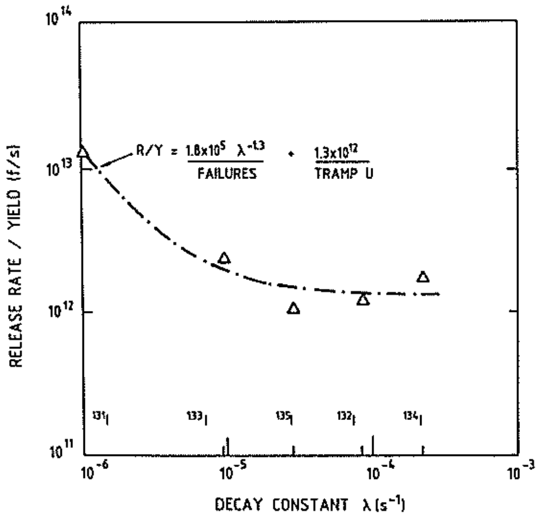

FIGURE 7: Fitting of fission product release model in Eq. (20) to release data for the Point Lepreau reactor. (The release data have been corrected for Pu-239 production, assuming a burnup of 100 MW.h/kg U.) (Data provided by R.W. Sancton of New Brunswick Electric Power Corporation.)

Finally, the amount of fuel debris in the core can be estimated from the fitted parameter $c \simeq \frac{1}{2} \dot{F} V$ ($\sim 1.3 \times 10^{12}$ fissions/s). The fission density can be derived from the average thermal fission cross section $\bar{\sigma}_f$ and volumetrically-averaged thermal neutron flux $\langle \phi_T \rangle$ ($\sim 8.0 \times 10^{13}$ $n/cm^2.s$):

$$\dot{F} = N_f \, \bar{\sigma}_f \, \langle \phi_T \rangle \tag{21}$$

$$\bar{\sigma}_f = \frac{\sqrt{\pi}}{2} \, g_f(T) \left(\frac{T_o}{T}\right)^{\frac{1}{2}} \sigma_f(E_o) \tag{22}$$

where

- N_f = atom density of fissionable material = $m_f N_o/AV$) [m_f = mass of fissionable material; N_o = Avogadro's number; A = atomic mass of fissionable isotope),
- g_f = non-1/v fission factor (= 0.9374 for U-235 and 1.3316 for Pu-239 at T = 509 K),
- T = neutron temperature = 509 K (600 MW standard CANDU),
- T_o = temperature constant = 293.6 K,
- $\sigma_f(E_o)$ = 580 b for U-235 and 742 b for Pu-239.

The mass of in-core tramp uranium is therefore given by

$$m_U = \frac{c}{\psi \, N_o \langle \phi_T \rangle} \, . \tag{23}$$

with

$$\psi = \frac{\sqrt{\pi}}{4} \left(\frac{T_o}{T}\right)^{\frac{1}{2}} \sum_i \left[w \, \sigma_f(E_o) \, g_f/A\right]_i \tag{24}$$

where i = U-235, Pu-239 and w is the weight fraction of fissile material (= 3.75 g/kg natural U for U-235 and 2.13 g/kg natural U for Pu-239, at a fuel burnup of 100 MW.h/kg U). Using Eqs. (23) and (24), approximately 4 g of uranium are estimated to be deposited on the in-core surfaces. This value is in excellent agreement with that determined by delayed neutron monitoring techniques (20).

LWR Reactor System. The previous analysis can also be applied to the Light Water Reactor (LWR) system. For example, Eq. (20) has been applied to the BWR off-gas data (21) of the HATCH-1 plant. When no fuel failures are present, a plot of the normalized coolant activity data versus decay constant (Figure 8) shows a release behaviour independent of λ, indicative of a recoil release from uranium contamination. Following the occurrence of a failure, a cumulative release curve of the form of Eq. (20) is observed (see Figure 8). When the background source of off-gas is subtracted, a slope of b = -0.94 is obtained in accordance with diffusion control in the gap.

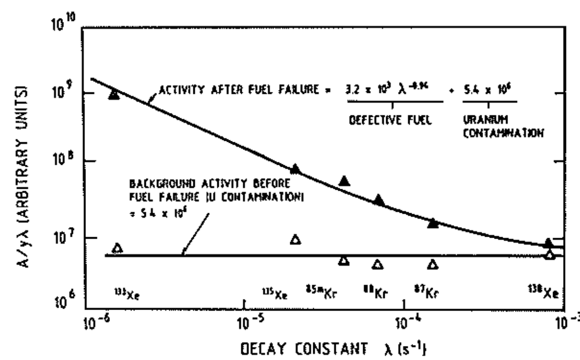

FIGURE 8: Application of defect model [Eq. (20)] to BWR off-gas data for the HATCH-1 plant (21).

Transient Analysis

CANDU Reactor System. The size of the "iodine spike" on reactor shutdown can also provide information on the number of fuel failures.

In the experimental loop, t_{max} is seen to occur in about a day for the isotope I-131 (see Figure 5). However, in the power reactor, this peak occurs at an earlier time because of the continual operation of the coolant cleanup system. For instance, with a purification constant of L = 6×10^{-5} s^{-1}, a peak is predicted to occur in just six hours (using the fitting value of ν in

Figure 5 and Eq. (16)). This prediction is in reasonable agreement with that observed in the power reactor suggesting that Eq. (15) can be used to predict the number of fuel failures, i.e. for a single defective element in the power reactor, $N_c(t_{max}) \simeq 39$ Ci*. Normalizing the observed value of 765 Ci in the Pickering Unit 3 reactor to the single element value, a defect rate of 0.016% is predicted. This value is in good agreement with the estimated value of 0.022% (19), as calculated from steady-state I-131 activity measurements. This period of unusually high coolant activity in 1973 was a result of power ramp defects prior to the introduction of a graphite interlayer coating (CANLUB) on the inner surface of the Zircaloy cladding, and better fuel management.

CONCLUSIONS

(1) A model has been developed to describe the release of fission products from defective fuel into the primary coolant. Analytic expressions are given for the release of iodine and noble gases during constant reactor operation, and for the release of iodine on reactor shutdown. The theoretical models are in excellent agreement with measured data from in-reactor loop experiments. These models can also be applied to the LWR fuel data.

(2) Recoil is the dominant mechanism of fission product release from fuel debris found on in-core reactor surfaces. This source of activity release in the primary heat-transport system can be distinguished easily from that of fuel pin failure, allowing for a more accurate assessment of the core condition.

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* In this calculation, it is assumed that $N_{co} << N_{go}$ where $N_{go} \simeq 160$ Ci for a power ramp failure; this number is based on a previous case for the Pickering reactor where the number of failures was known from post-irradiation examination.

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TECHNICAL SUPPLEMENT

CNS Bulletin September/October 1988 Canadian Nuclear Society

CUTTING ONTARIO HYDRO CANDU COSTS WITH ADVANCED IN-CORE FUEL MANAGEMENT TECHNIQUES

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ABSTRACT - The last decade has marked a period of innovation and excellence for increasing fuel utilization in CANDU reactors at Ontario Hydro. Advanced in-core fuel management techniques developed and implemented by Ontario Hydro have resulted in savings of several millions of dollars in fuel and irradiated fuel management costs. These were achieved through the flexibility of on-power fuelling of the CANDU system, improved fuel performance and fuel handling capacity, and especially through the combined efforts and growing experience of Station Operations staff and a centralized technical support group (Fuel and Physics staff - Central Nuclear Services).

In early 1980, a fuel burnup improvement program for equilibrium core conditions was started for the Bruce NGS-A reactors. However, with a series of new reactors coming on line at Pickering NGS-B, Bruce NGS-B, and Darlington NGS-A there was incentive to extend the program to the preequilibrium period such that fuel savings could be maximized as early as possible in the life of a reactor.

The study and implementation of more advanced in-core fuel management techniques will continue to play a major role in reducing fuel usage. Ontario Hydro is currently concentrating its efforts on low neutron leakage schemes. In addition, since reactor uprating is a viable option, the challenge lies in devising the optimum strategy for the more stringent operating conditions.

This report describes all in-core fuel management techniques leading to fuel burnup improvement at Ontario Hydro. It is intended primarily as a reference document for fuelling engineers and physicists.

1.0 INTRODUCTION

Fuel burnup improvement strategies developed and implemented by Ontario Hydro have resulted in savings of several millions of dollars in fuel and irradiated fuel management costs. Except for increasing heavy water moderator purity (99.76 to 99.94 D_2O Mass %) and fuel density (10.6 to 10.7 Mg/m^3) no major changes were made to the current design, materials used or to the control and safety systems.

The objectives of the fuel scheduling program are:

(a) to avoid fuel defects since these can lead to unnecessary radiation exposure, deratings or shutdowns and lower burnups;

(b) to minimize flux peaking since this can lead to deratings and use of costly replacement energy sources (eg, coal);

(c) to achieve a high fuel burnup, and therefore a low fuelling unit energy cost, and

(d) to make the most efficient use of the available fuel handling capacity.

In other words, the overall objective is to maximize burnup within the existing constraints. Initially, the greatest emphasis was placed on objective (a). However, with the introduction of Canlub fuel (graphite coatings) in 1974, the fuel defect rate has been less than 0.1%. Subsequently, with the start up of Bruce NGS-A reactors, emphasis shifted to objective (b). This objective also was soon satisfied and flux peaking was significantly reduced with the introduction of the 4/8-bundle shifting scheme. Finally, the last two objectives have been the major focus over the last 10 years.

As the capability of the fuel handling system increased and as more experience with the reactor regulating system was acquired, it was possible to improve burnup through use of advanced in-core fuel management techniques. A 3-phase burnup improvement program started in early 1980 on Bruce NGS-A reactors which were operating in the vicinity of equilibrium core conditions (after ~ 1 full power year). However, with a series of new reactors coming on line at Pickering NGS-B, Bruce NGS-B, and Darlington NGS-A* there was incentive to extend the program to preequilibrium such that fuel savings could be maximized as early as possible in the reactor life. This initiated the second phase in mid 1983 for Bruce NGS-B reactors. Several methods of improving burnup were identified and resulted in the recycling of first charge fuel at preequilibrium of Bruce NGS-B Unit 7.[1]

A third phase of the program has just started, and is concentrating on low neutron leakage schemes. In addition, since reactor uprating is a viable option, the challenge lies in devising the optimum strategy for the more stringent operating conditions.

Before proceeding to the description of all identified in-core fuel management techniques leading to burnup improvement an understanding of the effects of fuelling on flux peaking and the calibrated settings of the neutron overpower system detectors is necessary.

2.0 MEASUREMENT OF FLUX PEAKING

Flux peaking for Ontario Hydro CANDUs is characterized by the differences between the actual channel power distribution and a so called reference channel power distribution. The reference channel power distribution is used as the basis for Neutron Over Power trip (NOP) safety analysis and it is, therefore, necessary to measure and protect for deviations from this nominal power distribution. The measure used is the Channel Power Peaking Factor (CPPF) which is defined as follows:

$$CPPF = \max_{i,j} \left\{ \frac{CP\ (i,j,t)}{\overline{CP}\ (i,j)} \right\}$$

Where the channels (i,j) are taken over the High Power Region, and

$CP\ (i,j,t)$ = Instantaneous Channel Power

$\overline{CP}\ (i,j)$ = Reference Channel Power

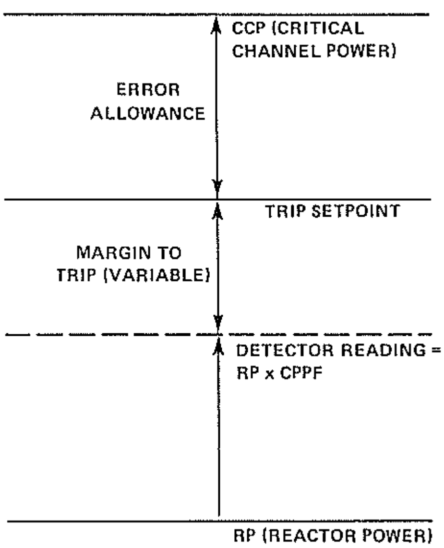

Figure 1
NOP DETECTOR CALIBRATION METHOD
BRUCE–A

* A list of Ontario Hydro Nuclear Generating Stations and a summary of reactor data is given in Tables 1 and 2, respectively.

TABLE 1: ONTARIO HYDRO NUCLEAR GENERATING CAPACITY

Stations	Number of Units		Net Capacity (MWe)		In-Service Dates First Unit
	In-Service	Under Construction or Commissioning	In-Service	Under Construction or Commissioning	
NPD (S/D)	(1)		(22)		1962
Douglas Point (S/D)	(1)		(206)		1966
Pickering	8		4 124		1971
Bruce	8		6 987		1977
Darlington		4		3 524	1988
TOTALS	16	4	11 111	3 524	

TABLE 2: ONTARIO HYDRO NUCLEAR REACTOR DATA

	PICKERING		BRUCE		DARLINGTON
	PNGS-A	PNGS-B	BNGS-A	BNGS-B	(Under Construction)
Power/Unit					
Fission (MW @ 100% FP)	1 744	1 744	2 832	2 832	2 774
Gross Thermal (MWth)	1 655	1 661	2 707	2 706	2 651
Gross Electrical (MWe)	542	540	825 (815)(1)	915	935
Net Electrical (MWe)	515	516	769 (759)(1)	837	881
Reactor Physics					
Number of Channels	390	380	480		480
Lattice Pitch (m)	0.2858		0.2858		0.2858
Core Diameter (m)	6.370		7.068		7.064
Core Length (m)	5.944		5.944		5.944
Average Reflector Thickness at Midpoint (m)	0.696		0.70		0.70
Uranium Mass In-Core (Mg)	94.5	92.1	119.8		119.8
Moderator and Reflector D_2O (Mg)	241	247	313	312	309
Heat Transport System D_2O (Mg)	190	190	270	318	218
Fueling Scheme	4/8 (10/8)(2)	4/8	2/4/8	4/8	4/8
Poison Override Reactivity Control Unit	Withdrawal of Adjuster Rods(3)		Insertion of Booster Rods (No Adjusters)	Withdrawal of Adjuster Rods(3)	Withdrawal of Adjuster Rods(3)
Fuel					
Number of Bundles per Channel	12		13		13
Number of Elements per Bundle	28		37		37
Bundle Length (mm)	495		495		495
Bundle Maximum Diameter (mm)	102.4		102.4		102.4
Element Outer Diameter (mm)	14.8		13.1		13.1
Uranium Mass/Bundle (kg)	20.2		19.2		19.2
Burnup (MWh/kgU)(4)	208	180	206	185	
Licence Limits					
Maximum Bundle Power (kW)	750 (705)(2)	750	1 035	1 035	1 035
Maximum Channel Power	6 100	6 100	6 900 (inner flow region) 6 400 (outer flow region)	7 200 6 700	7 500
Trip Setpoints (%): SDS1	110	127.0	124.0	121.5	127.0
SDS2		127.0	118.0	121.5	127.0

(1) Units 1, 2, 4 (Unit 3)
(2) Units 1, 2 (Units 3, 4)
(3) Adjuster Rods are also used for Neutron Flux Flattening
(4) 1 MWh/kgU = 41.67 MWd/MgU

The SORO[2][3] fuel scheduling computer program is used to calculate values of CPPF.

The NOP system is comprised of a number of in-core neutron detectors which varies between 50 and 105 depending on the station in consideration. These detectors are frequently recalibrated to reflect the difference between the actual channel powers and the reference channel powers.

The calibration method can be understood by reference to Figure 1. As can be seen, the larger the CPPF, the larger the calibrated detector setting and the smaller the available margin to trip. High values of CPPF, ie, typically greater than 1.15, indicate undesirable flux peaking and narrow operating margins. A major objective of the fuel scheduling program is, therefore, to maintain an acceptable operating margin in order to avoid reactor trips.

3.0 BURNUP IMPROVEMENT PROGRAM

For the sake of simplicity, the burnup improvement program taking place at Ontario Hydro can be divided into three phases. Several of the in-core fuel management techniques identified have already proven to be very successful in reducing the unit energy cost and they will be discussed in the following sections of this report.

3.1 Phase I

The major thrust to Phase I of the burnup improvement program began in early 1980 on Bruce NGS-A reactors which were operating in the vicinity of equilibrium core conditions. Significant improvements were made by:

(a) development of the 4/8-bundle shift scheme (this scheme was actually introduced in the mid-1970s),

(b) expansion of the 4/8-boundary,

(c) development of the fifth bundle burnup criterion for fuel scheduling,

(d) decreased differential burnup, and

(e) reduction of the boron concentration in the moderator (used for shim).

3.1.1 Development of the 4/8-Bundle Shift Scheme

Each of the 480 Bruce NGS channels contains 13 fuel bundles. Darlington NGS reactors also have 13-bundle channels, while all Pickering NGS reactors and other CANDU 600's are designed with channels containing 12 bundles. A fuel scheduling program is based on replacing a certain number of these bundles at each fuelling machine visit to a channel. For example, an 8-bundle shift fuel scheduling scheme is based on removing 8 irradiated bundles from a channel while at the same time adding 8 new fuel bundles to the same channel.

Initial fuelling studies for Bruce NGS-A, using 8-bundle shifting, indicated that it would be difficult to limit CPPF values to below 1.14. It would have been extremely difficult to consistently achieve full electrical power output with CPPF values of this magnitude. Other alternatives had to be considered. A fuelling scheme based on mixed 4/8-bundle shifts showed the most promise in satisfying the fuel scheduling objectives. A central reactor region containing 57% of the channels was eventually chosen for 4-bundle shifting, while the remaining channels in the outer region were dedicated for 8-bundle shifting.

Eight-bundle shifting in the inner region is undesirable because of the large channel power changes associated with this scheme. As a result, high flux peaking and CPPF are to be expected. Four-bundle shifting on the other hand, produces moderate power changes which lead to lower CPPFs.

Four-bundle shifting in the outer region produces small reactivity gains. On this basis, 4-bundle shifting in the outer region was rejected as this would place fuelling demand in excess of the fuel handling system capacity.

The only remaining concern to be addressed was if the fuel could withstand the higher power ramps associated with 4-bundle shifting. Theoretical studies, based on the 4/8 fuelling program, demonstrated very low defect probabilities with higher performing Canlub fuel. Actual experience has confirmed this.

The above considerations formed the basis for adopting the mixed 4/8-bundle shifting scheme as the most appropriate scheme for Bruce NGS-A. However, with time, 4/8-bundle shifting has spread to other stations and is now the accepted practice in most of Ontario Hydro CANDU reactors.

With experience, control of flux peaking improved. Consequently, more flexibility and additional optimization of fuel scheduling was possible. These additional improvements are described below.

3.1.2 Expansion of the 4/8 Boundary

As the fuelling machine capability increased, the 4/8 boundary was expanded by converting a number of 8-bundle shift channels to 4-bundle shifts.

The number of 4-bundle shift channels gradually increased from 57% to 71% of all channels at Bruce NGS-A so that more channels could take advantage of smaller changes in channel power upon refuelling to improve on burnup.

3.1.3 Development of the Fifth Bundle Burnup Criterion For Fuel Scheduling

During the early part of 1980 Units 2, 3, and 4 at Bruce NGS-A were observed to have significantly lower average discharge burnups than Unit 1. This initiated a review of the fuelling selection process and procedures.

It was realized that there was a larger spread in the values of average discharge burnup in the 4-bundle region of the operational data than that in the in-core fuel management study. The objective was therefore to determine a method of reducing this spread. It was noticed that strong correlations existed between:

(a) discharge burnup and the ninth bundle burnup in the 4-bundle region, and

(b) discharge burnup and the fifth bundle burnup in the 8-bundle region

Therefore, by scheduling channels for fuelling when established targets of ninth bundle burnup in the 4-bundle region and fifth bundle burnup in the 8-bundle region are met it is possible to control the average discharge burnup. For finer control, 4 targets were established, one for each of the 4 annular regions in which the core was divided (inner and outer regions of the 4 and 8-bundle zones).

Fuelling guidelines were therefore revised to use the ninth bundle burnup in the 4-bundle region (the fifth bundle burnup in the 8-bundle region) and changes were made to the SORO program to highlight channels surpassing the limits. Note that the ninth bundle in the 4-bundle region and the fifth bundle in the 8-bundle region are destined to position 13 by applying the assigned shifts. The objective was to maximize the burnup of these bundles before shifting them into Position 13. Once in this position of significantly low neutron flux negligible additional burnup can be accumulated.

After implementation of the new fuelling ground rules, the average discharge burnup from all units increased by ~ 10 MWh/kg-U from 190 to 200 MWh/kg-U and the Channel Power Peaking Factor also decreased by ~ 3% thus producing a power distribution closer to the reference and an increased operating margin.

As experience with the revised guidelines grew, it became apparent that in some instances the ninth bundle guideline created some problems in maintaining an ideal irradiation profile along a channel. Based on past fuelling experience, it was concluded that a fifth bundle burnup guideline (in the 4-bundle region) would eliminate this problem. By developing a combined fifth and ninth bundle burnup guideline, it is possible to control, and maximize the burnup of bundles destined for Position 13 in each channel. As a result, the average discharge burnup improved as each channel approached an ideal irradiation profile.

In summary then, discharge burnup cannot be maximized on the basis of control of the discharge burnup alone. It is necessary to control burnup as soon as fuel is introduced into a channel and ensure that it is shifted into subsequent positions based on the control of selected parameters to fall within an identified band of variation. Parameters giving the highest resolution, such as the burnup of individual bundles (rather than averages of more bundles), should be selected as the control parameters since higher resolution allows for a tighter control on variability.

Variability can exist with in-core fuel management and this can be due to:

(a) localized flux variations caused by

(i) reactivity device movement
(ii) changing operating conditions
(iii) abnormal fuelling (eg, 8- to 12-bundle shifts for defect bundle removal)

(b) experience of the fuelling engineer

The acceptable limits on variation that maximize burnup with the allowable operating constraints are determined through in-core fuel management studies and operational experience.

Control on variability is, therefore, very important and computer programs using the burnups and neutron fluxes produced by the SORO code have been developed for channel selection. These programs help identify and correct the variation and ensure that the "process" operates in a desired state of statistical control with only random inherent variation.

3.1.4 Decreased Differential Burnup

As the 4/8 boundary expanded to incorporate more channels into the 4-bundle region at Bruce NGS-A, the need for more than two 4-bundle burnup regions became apparent. Figure 2 shows these regions and the corresponding fifth bundle burnup targets. It can be seen that the target decreases with the distance from the centre of the core. The result of differential burnup between regions is flattening of the radial power distribution. At all other stations, radial flux flattening is partly accomplished with the presence of neutron absorbing cobalt adjuster rods located in the core and therefore less differential burnup between regions is required than at Bruce NGS-A.

Some radial flux flattening is required to ensure adequate margin to NOP trip and licence channel power limits (thermal margin). However, overflattening should be avoided because it results in increased neutron leakage at the core periphery and hence a reduction in the discharge burnup.

Reduced differential burnup, in conjunction with 4-bundle shifting (or smaller bundle shifts) provides the maximum burnup with acceptable thermal margin.

Typical axial burnup distributions per region are illustrated in Figure 3. Note the difference in shape and magnitude between 4-bundle shifts (characterized by 3 axial regions) and the 8-bundle shifts (characterized by 2 axial regions). As discussed earlier, the fuel burnup typically increases:

FIFTH BUNDLE BURNUP TARGETS

4 - BUNDLE SHIFT REGION: INNER = 120 MWh/kg-U; MIDDLE = 110 MWh/kgU; OUTER = 90 MWh/kgU

8 - BUNDLE SHIFT REGION: INNER = 120 MWh/kgU; OUTER = 110 MWh/kgU

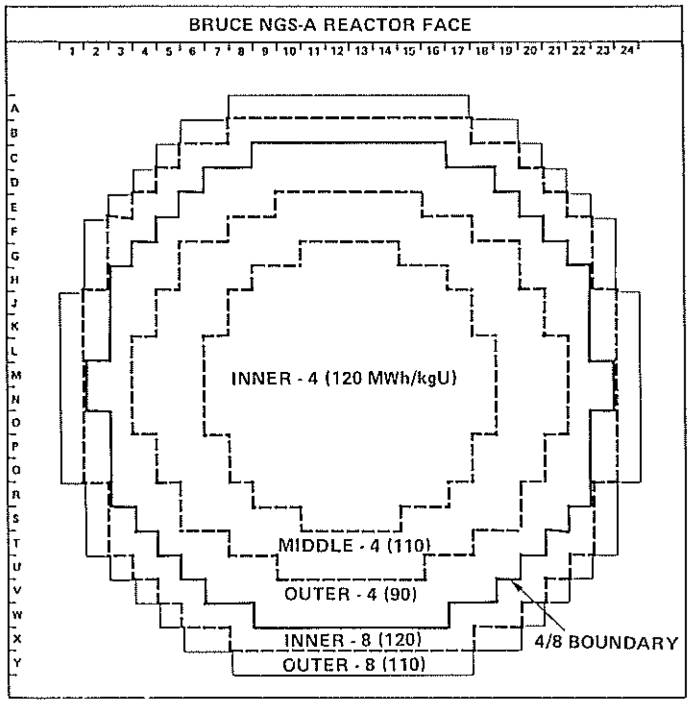

Figure 2

FUELING REGIONS AND TARGET 5th BUNDLE BURNUPS
BNGS–A

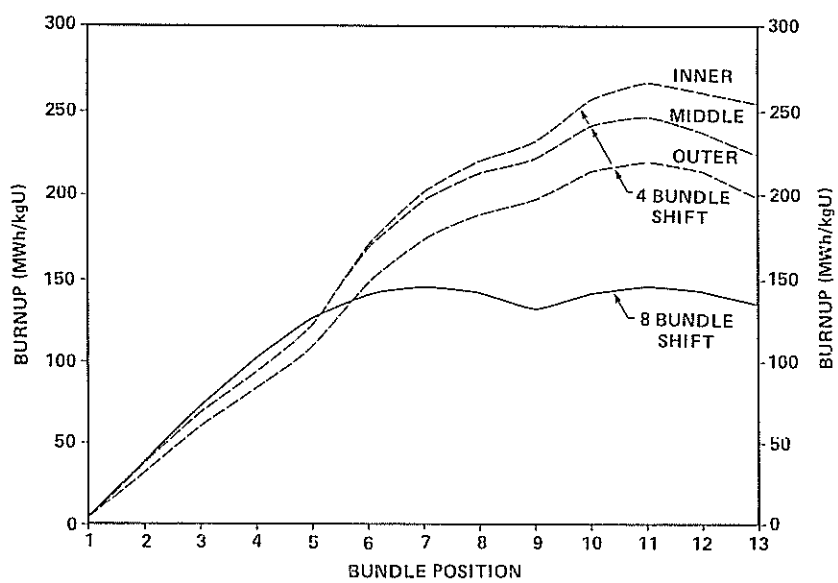

Figure 3
AXIAL BURNUP PROFILES
BNGS–A

(a) from core periphery to core centre (radially)

(b) from fuel inlet end to discharge end (axially) and the difference in discharge burnup between channels can be as large as 100 MWh/kgU (see Figure 3).

3.1.5 Reduction of the Boron Concentration in the Bruce NGS-A Moderator

The reason for holding boron in the moderator is to provide a reactivity shim which can be drawn on in the event of a fuel handling system outage. In such an event, reactivity losses due to burnup can be compensated for by removal of boron from the moderator and thereby allow several days for fuelling machine repair without loss of power. It would not be desirable to use booster rods for this purpose since this would lead to unnecessary and expensive burnup of the booster fuel and potential derating. (Boosters were designed for Xenon override purposes).

In determining the optimum amount of boron to carry, a balance has to be struck. Increasing the boron load will decrease the fuel burnup (2.8 MWh/kgU/mk) and increase fuel costs. Decreasing the boron load will lead to longer and therefore more expensive deratings following fuel handling system outages. As the capability of the fuel handling system increased throughout the years, the optimum boron load has decreased from 4 mk to 1 mk. A 3 mk reduction in boron load is equivalent to an increase in burnup of 8.4 MWh/kgU.

This method of increasing burnup is only applicable to Bruce NGS-A. In all other Ontario Hydro owned reactors no boron is held in the moderator since reactivity shim is accomplished through removal of adjuster rods.

BURNUP IMPROVEMENT PROGRAM

3.2 Phase II

With a series of new reactors coming on line at Pickering NGS-B, Bruce NGS-B, and Darlington NGS-A there was incentive to extend the burnup improvement program to preequilibrium such that fuel savings could be maximized as early as possible in the reactor life. Burnup was improved in this phase by:

(a) delaying the onset of fuelling

(b) reducing the quantity of depleted fuel in the first fuel charge

(c) recycling the first fuel charge

(d) delaying the onset of fuelling in the 8-bundle shift region (core periphery)

(e) reducing the fuelling frequency in the 8-bundle shift region (core periphery)

By combining these advanced in-core fuel management techniques with those in the previous phase it is possible to maximize burnup at all times, from preequilibrium to equilibrium.

3.2.1 Delay of the Onset of Fuelling

The cores of new units consist of entirely fresh fuel. This has two effects:

(a) There is no contribution to radial flattening from differential burnup between burnup regions.

(b) The core has a large amount of excess reactivity (~ 30 mk).

To compensate for the lack of sufficient radial flattening, additional flattening is provided by including bundles of depleted fuel in the core, but this will be discussed in the following section. The remaining excess reactivity is compensated for by including soluble boron poison in the moderator. As the core burnup increases, the excess reactivity (and maximum bundle and channel powers) starts increasing due to buildup of fissile Pu-239, peaks around 30 to 50 days, then drops off as neutron poisons accumulate in the fuel and the fissile uranium content decreases. At the same time boron is being removed for reactivity compensation purposes. When all boron is removed fuelling must commence to compensate for the daily reactivity losses and thus maintain criticality. However, if fuelling is delayed until all boron is removed from the core then the required fuelling rate could exceed the fuel handling system capability and adjuster rods would eventually withdraw. To avoid withdrawal of adjusters it is necessary to start fuelling earlier. Although not necessary, it is desirable to avoid adjuster rod removal because it could lead to potential deratings caused by the induced flux shape perturbations.

In the past, the standard procedure was to commence fuelling at 6 mk of excess reactivity. However there are advantages in delaying fuelling beyond this point, namely:

(a) burnup of the first bundles discharged increases, and

(b) reactivity gain upon refuellings increases.

On the other hand, the longer that fuelling is delayed then the higher the fuelling rate at the onset of fuelling. In fact, the rate at which the core loses reactivity increases with the fission product inventory. Therefore, an excess reactivity of 3 mk was finally selected as a good compromise. This delays the onset of fuelling by about one week and requires an initial fuelling rate approximately 40% higher than the equilibrium value.

3.2.2 Reduction of Depleted Fuel in the First Fuel Charge

All cores of new units starting up for the first time are loaded with fresh fuel. Initially, with the absence of fuelling, there is no contribution to radial flattening from differential burnup. It would therefore be necessary to derate the reactor to reduce the maximum channel power and maximum bundle power below their respective licence values as well as to limit CPPF to values producing acceptable margins to trip (at least 8%). However, to avoid costly deratings, additional flattening is provided by including depleted fuel bundles in the high flux region of the core. (Depleted fuel usually contains 0.4 (or 0.5) weight percent U-235. Natural fuel contains 0.7 weight percent U-235). Depending on the number and location of depleted fuel bundles more or less flattening is achieved (overflattening should be avoided). The additional effect of the presence of less reactive depleted fuel is to reduce the overall core excess reactivity causing fuelling to commence earlier.

The first unit to start up at Bruce NGS-B had 208 depleted fuel bundles located in the radial centre of the reactor in axial Position 8 of 208 channels. Subsequent reactors used fewer depleted bundles in the high flux region: 32 depleted bundles in axial Positions 8 and 9 of 16 channels. See Figure 4.

Although the number of depleted bundles has been reduced significantly, sufficient flux flattening is still provided. However, the increased excess reactivity delays the onset of fuelling by about 11 days.

UNIT	NUMBER OF DEPLETED UO_2 BUNDLES PER POSITION POS. 8	POS. 9	POS. 13	TOTAL NUMBER OF DEPLETED UO_2 BUNDLES
6	208	0	480	688
5	16	16	480	512
7	16	16	0	32

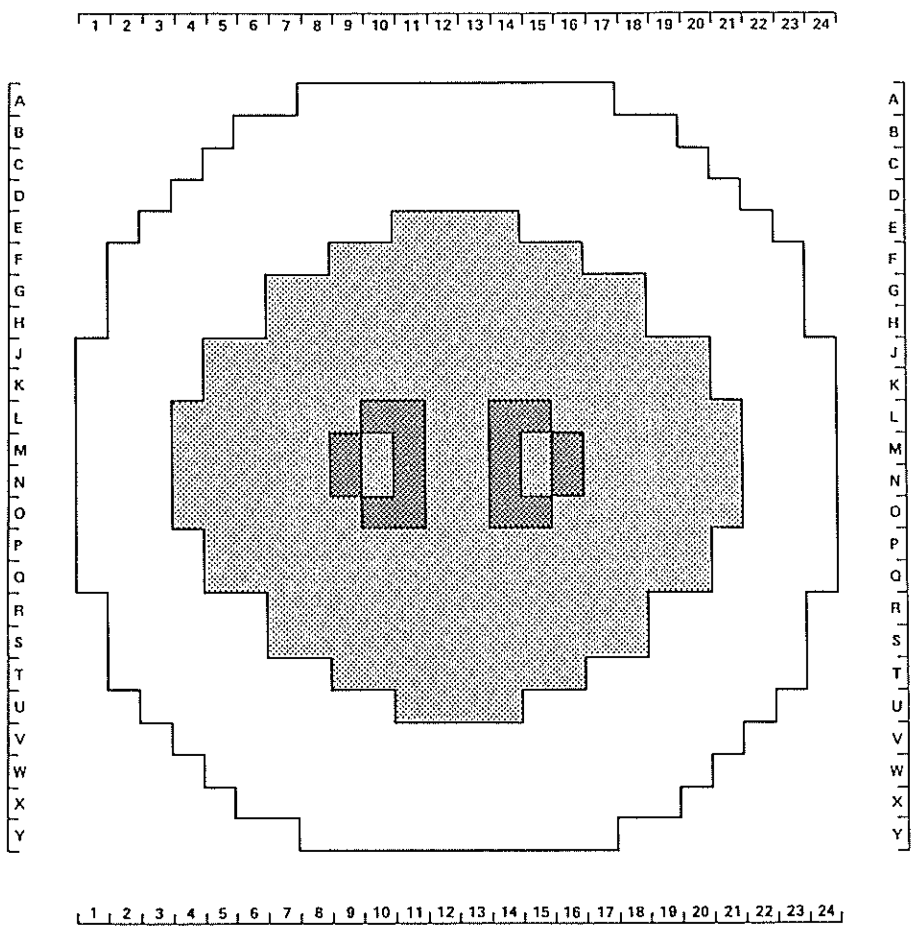

Figure 4
INITIAL FUEL CHARGES
BNGS–B

3.2.3 Recycling of the First Fuel Charge

At the onset of fuelling the first bundles discharged achieve relatively low burnup compared to the equilibrium discharge burnup. The equilibrium burnup distribution along a channel increases from fuelling end to discharge end. For a fresh core the burnup distribution is symmetric about the centre with the end bundles having low burnup. When normal once-through fuelling is initiated (at 3 mk) the first 4 bundles discharged to the irradiated fuel bay will have accumulated very little burnup. In particular, the bundle in the last position (Position 12 at Pickering NGS and Position 13 at Bruce NGS) will have received negligible irradiation. Therefore, as a cost saving measure, each channel in the reactor can be loaded with a depleted fuel bundle in the last position instead of natural fuel. This cost saving measure was applied for the first time in a Pickering NGS-B reactor. The cost of a depleted fuel bundle is about 67% of the cost of a natural fuel bundle. At Bruce NGS-B this is equivalent to a savings of 160 natural fuel bundles if a depleted fuel bundle replaces a natural fuel bundle in Position 13 of all 480 channels. This exchange has minimal effect on reactivity, less than 0.5 mk.

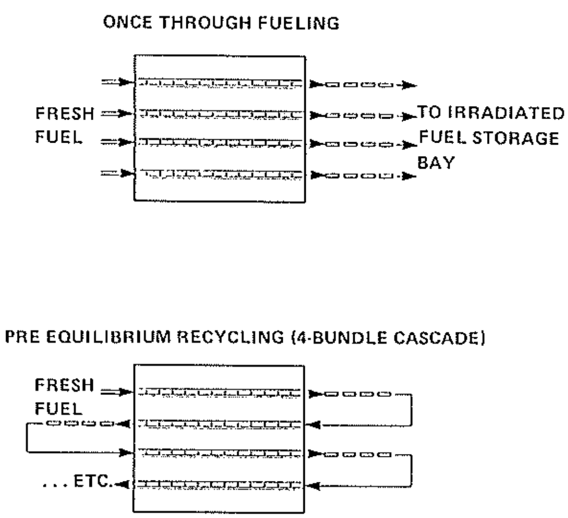

Figure 5
ONTARIO HYDRO CANDU FUELING SCHEMES

The once-through fuelling scheme has been the only scheme used to date in all Ontario Hydro owned reactors. However, recently in Bruce NGS-B (Unit 7), utilization of the first fuel charge was improved through recycling.[1] See Figure 5.

In the recycling scheme the first bundles discharged may be simply reinserted into a channel of opposite fuelling direction instead of discharging them to the fuel bay. In this case, the last bundle in each channel must be a natural fuel bundle. As the price differential between natural and depleted fuel bundles decreases, the incentive to recycle the first charge fuel becomes even larger.

The improved utilization of fuel through recycling is apparent from Figure 6. The average axial burnup distributions are compared for identical cores, only that in one of them recycling is applied before initiating normal fuelling at 3 mk. In the recycled core the axial burnup distribution is closer to the equilibrium distribution and the discharge burnup is consequently higher. Additional benefits are obtained by recycling fuel radially (Figure 6) from low flux and burnup regions to high flux and burnup regions and vice versa. By placing less irradiated fuel from the core periphery into the centrally located high flux region of the core of higher neutron importance, the core excess reactivity increases. At the same time, the higher irradiated fuel coming from the central region of the core reduces the neutron leakage when placed at the core periphery.

Axial and radial recycling results in an increase of the excess reactivity of about 12.5 mk and a delay in the onset of fuelling of about 1 month. This is equivalent to an initial fuel savings of about 750 bundles.

The reinsertion of the early discharged fuel can thus be used to obtain a fuel cost saving and to reduce the number of spent fuel bundles that must be stored.

3.2.4 Delay of the Onset of Fuelling in the Core Periphery

As discussed above, without recycling, the first bundles discharged from a channel achieve very low burnup. This is even more accentuated for channels in the 8-bundle shift region located at the core periphery. In addition to the lower burnup of the bundles in the 8-bundle shift region, losses increase further because of the greater number of bundles discharged per channel compared to 4-bundle shifting. These losses are significantly reduced by delaying fuelling as late as possible in the 8-bundle shift region and concentrating fuelling in the region of the core of higher neutron importance.

The onset of fuelling in the 8-bundle shift region is typically selected to coincide with the start of the second cycle of fuelling in the 4-bundle shift region, (the 4-bundle shift region comprises ~ 68% of all reactor channels). As a result of this delay of about 50 days (relative to

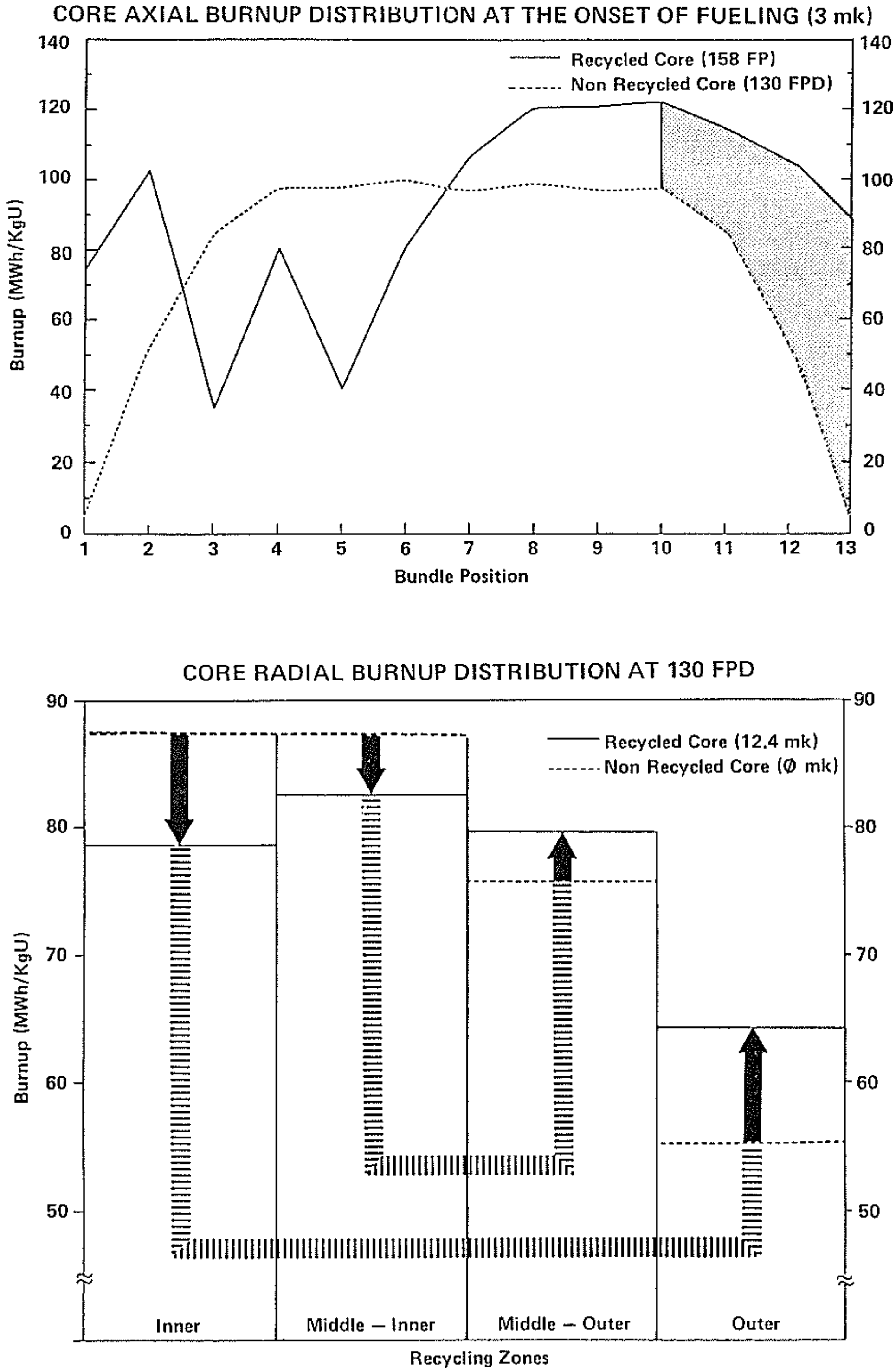

Figure 6

EFFECTS OF 4-BUNDLE CASCADE RECYCLING SCHEME
ON AXIAL AND RADIAL BURNUP DISTRIBUTIONS
BNGS—B

the onset of fuelling in the 4-bundle region), burnup increases in the core periphery, neutron leakage decreases, and the average discharge burnup increases.

If fuelling in the core periphery is further delayed, flux peaking in the centre of the reactor causes the thermal margin to decrease. An alternative could consist of fuelling the core periphery earlier using 4-bundle shifts instead of 8-bundle shifts and then resuming 8-bundle shifting at the subsequent visit.

3.2.5 Reduction of the Fuelling Frequency in the Core Periphery

Besides delaying the start of fuelling in the 8-bundle shift region as late as possible, additional burnup improvements are obtained by minimizing fuelling in this region. At Bruce NGS-B the fuelling of one 8-bundle shift channel every 2 days is acceptable. This represents about 12% of the total number of channels fuelled per day. Note that this is 4% lower than the calculated fuelling rate (channels/day) assuming a feed rate (bundles/day) per fuelling region proportional to the number of channels in the region.

The decreased fuelling rate in the 8-bundle shift region causes:

(a) burnup to increase in the core periphery (8-bundle region), and

(b) the fuelling rate to increase in the central region of the core (4-bundle region).

The combined effect reduces the neutron leakage and increases the core average discharge burnup.

BURNUP IMPROVEMENT PROGRAM

3.3 Phase III

Ontario Hydro has just recently engaged in its third phase of the burnup improvement program. Low neutron leakage schemes identified at the end of the previous phase will be pursued. The objective is to optimize the reference shape to minimize leakage and maximize operating margin. In addition, since reactor uprating has become a viable option, uprating schemes are being studied and implemented. The objective of the uprating schemes is to maximize burnup with the more stringent operating conditions.

3.3.1 Low Neutron Leakage Schemes

Depending on the "age" of the reactor different minimum neutron leakage schemes apply. At preequilibrium, the methods identified are:

(a) Radial recycling (see Section 3.2.3).

(b) Delay of the onset of fuelling in the core periphery (see Section 3.2.4).

At equilibrium it is possible to reduce neutron leakage by reducing the rate of fuelling in the core periphery (see Section 3.2.5).

In all these methods low neutron leakage will result from the substantially reduced power of the peripheral channels. Flux flattening through differential burnup between burnup zones becomes less accentuated. Consequently, power increases towards the centre of the core and reduces the thermal margin.

The maximum benefits from low leakage fuel management are therefore obtained by operating with the minimum acceptable operating margin.

3.3.2 Reduced Bundle-Shift Schemes

A method of increasing the average power in the central region of the core without reducing the thermal margin can be achieved by decreasing the number of bundles shifted per channel visit. The current 4/8-bundle shifting scheme can be replaced by a 2/4/8-bundle shifting scheme by converting the central portion of the 4-bundle region into 2-bundle shifts. This is being done at Bruce NGS-A. As a result, burnup improves for the following reasons:

(a) Reduction in Neutron Leakage

Smaller bundle shifts produce smaller increases in channel powers upon fuelling. Channel powers can therefore be better controlled to reduce the variations between adjacent channels. With a smoother radial power distribution the average channel power in the centre of core can be increased without increasing the maximum channel power or CPPF. Consequently, the power in the peripheral channels decreases as well as the neutron leakage.

(b) Increased Feedrate in the Neutronically Significant Region of the Reactor

The higher powered region of the reactor is also a region of greater neutron importance (more reactive) and fuelling is preferred here. To increase the feedrate to a certain region of the reactor it is necessary to shift fewer bundles per channel to minimize power changes. Therefore, the number of bundles shifted per channel visit should decrease from 8- to 4- to 2-bundle shifts from the core periphery to the core interior.

The number of channels that can be converted from 4-bundle shifts to 2-bundle shifts will depend on the capability of the fuel handling system. It has been estimated that by converting one third of the reactor into 2-bundle shifts, ie, one half of the 4-bundle shift region, would increase the number of visits by about 15%.

3.3.3 Schemes for Uprated Reactors

Although the thermal margin decreases with reactor uprating, in Bruce 37 element bundles and Pickering 28 element bundles, there is still a significant margin before reaching the maximum bundle power limit. Therefore, there is no need to redesign fuel bundles. However, burnup will necessarily decrease due to:

(a) increased neutron absorbing Xenon levels,

(b) negative temperature reactivity coefficient, and

(c) increased flux flattening.

Unless sufficient margins are available, flux flattening is required to increase with increased reactor power if the same thermal margin is maintained. Specifically, CPPF must decrease if the NOP detector readings are kept constant. (Recall that Detector Reading = Reactor Power x CPPF). This is achieved by reducing the fuelling rate in the core centre and increasing it at the core periphery. A higher differential burnup between burnup zones (higher burnup in the centre and lower burnup at the periphery) will result and this in turn will increase the radial flux flattening and the neutron leakage. However, the neutron losses can be reduced by introducing 2-bundle shifting as discussed in the previous section.

3.3.4 Development of C.A.F. (Computer Aided Fuelling)

The development of CAF (Computer Aided Fuelling), also called the Refuelling Program, arose from the need to ensure that burnup was maximized at all times while avoiding deratings.

Temporary losses in burnup can be caused over holiday periods, when less experienced staff replaces the unit fuelling engineer. As a result, deviations from the fuelling ground rules may occur, causing inefficiency in fuel utilization and potential power deratings. In some stations, where fuelling is very restrictive due to narrow thermal margins, it is difficult to consistently achieve full electrical power output.

As discussed in a previous section, control is very important and CAF can help identify and correct variation and ensure that the fuelling process operates in a desired state of statistical control with only random inherent variation. The refuelling program developed at Ontario Hydro uses the bundle irradiations and neutron fluxes produced by the SORO code.

The core is usually divided into 3 or more regions, each of which has established targets of fifth bundle burnup, ninth bundle burnup and average discharge burnup. Channels exceeding the targets are potential candidates for fuelling. However, before they are selected, predictions of parameters impacting on operational constraints and limits (eg, CPPF, Maximum Channel Power, Maximum Bundle Power, Channel ΔT) are determined usually through semiempirical equations. These equations are derived through in-core fuel management studies and actual operating data.

Finally, checks are made on radial and axial symmetry and if the channels successfully meet all the above criteria then the channel is placed on the fuelling list. However, the final selection is still made by the fuelling engineer, who uses the most current reactor data (ie, zone levels, outlet channel temperatures). In addition, the location of Reactor Regulating System (RRS) and NOP detectors relative to the channels to be fuelled are considered. These considerations are now qualitative, so the next step will be to incorporate the RRS control algorithm in CAF. To date, the refuelling programs used at Pickering NGS have been very successful in reducing channel selection time, deratings and in maximizing discharge burnup while at Bruce NGS CAF has just recently been implemented.

4.0 FUEL HANDLING SYSTEM EXPERIENCE

The penalties that must be paid to achieve fuel cost benefits are:

(a) higher flux peaking and associated potential loss of thermal margin, and

(b) increased fuel handling.

The fuel handling system capacity increased as it evolved through the following improvements and additions:

(a) multichannel fuelling per visit,

(b) 16-bundle fuelling head magazine,

(c) third trolley system (at Bruce NGS).

Initially the Bruce NGS-A fuel handling system consisted of 2 independent subsystems each capable of fuelling between 2 and 4 reactors. (The North Trolley System has access to any of the 4 units while the South Trolley System has access to Units 1 and 2 and the South Extension Trolley System has access to Units 3 and 4. At Pickering NGS, individual reactors have dedicated fuel handling systems.) Each subsystem consists basically of a trolley carrying 2 fuelling machine heads and auxiliary equipment. Each trolley runs on separate tracks running the length of the station.

With the development of the 4/8-bundle scheme the concept of multichannel fuelling was introduced. In this concept, 12 bundles are loaded into 1 fuelling machine head (12-bundle magazine), the other being left empty to receive the irradiated fuel bundles. In 1 fuelling machine visit to the reactor face, one 8- and one 4-bundle shift channel or three 4-bundle shift channels are refuelled. This makes more efficient use of the fuel handling system allowing for a higher fuelling capacity. With the introduction of the multichannel fuelling concept, 2 channels can be refuelled in 1 trip, instead of 2 trips, and the overall fuelling time decreases by about 16%.

Later (~ 1983), the introduction of a fuelling machine head carrying 16 bundles to the reactor face and a third trolley system allowed for further reduction in fuelling times and improvement to the overall fuel handling system.

5.0 CONCLUSIONS

(a) In order to achieve high burnup and avoid frequent deratings because of high channel powers, it was necessary for Bruce NGS-A to adopt the mixed 4/8-bundle shifting scheme.

(b) Lower Channel Power Peaking Factor associated with 4-bundle shifting schemes allows a core fuelled with a mixed 4/8 scheme to run at a higher average inner zone power, and higher burnup.

(c) The mixed 4/8-bundle shifting scheme has been successful in minimizing deratings due to flux peaking. However, with the recent increase in licensed reactor power, it was necessary to resort to a 2/4/8-bundle shifting scheme at Bruce NGS-A.

(d) The concept of multichannel refuelling has produced acceptable fuelling times. With the subsequent introduction of a 16-bundle fuelling head magazine and a third trolley, it was possible to further increase the fuel handling system capability at Bruce NGS.

(e) With increased fuel handling capability, it was possible to increase burnup further at Bruce NGS-A by expanding the 4/8 boundary (more 4-bundle shift channels), developing the 5th-bundle burnup criterion for fuel scheduling and reducing the boron concentration in the moderator for shimming purposes.

(f) Improvements in burnup continue to be sought in all of currently operating Ontario Hydro reactors. Low neutron leakage schemes and reduced bundle-shift schemes in conjunction with Computer Aided Fuelling (CAF) will be further developed.

(g) Burnup will also be maximized early in the reactor life of all new units. This is achieved by delaying the onset of fuelling, reducing the depleted fuel in the first fuel charge, recycling the initial fuel charge, delaying the onset of fuelling in the 8-bundle shift region (core periphery) and reducing the fuelling frequency in the 8-bundle shift region.

(h) Ontario Hydro has adopted the 4-bundle cascade recycling strategy for the first time in Bruce NGS-B Unit 7 to enhance the burnup of fuel discharged early in the life of the reactor. This technique does not require modifications to the fuelling machine program and there is no evidence of fuel defects resulting from this fueling strategy.

(i) The cumulative fuel defect rate has been small - less than 0.1% of fuel used to the end of 1985 has incurred a defect. Four-bundle shifting, which previously led to high defect rates at Douglas Point NGS, has been successfully reintroduced at Bruce NGS-A. Improved fuel design implemented in 1974 (graphite coated Canlub fuel) has been the main contributor to this improved fuel performance. Therefore, very few of the later defects have been attributed to power ramping or other fuel scheduling impacts. They have been due to manufacturing defects or fretting from extraneous material. The reasons for these have been identified and corrected.

6.0 ACKNOWLEDGMENTS

I would like to thank all of the Reactor Physics Section (Fuel and Physics Department, CNS), station fuelling engineers, G. Brenciaglia, A.M. Lopez, and P.T. Truant for their valuable suggestions and reviews.

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rapid population growth in many areas". Globally averaged temperatures have increased by 0.7 degrees over the past century but a further increase of 1.5 to 4.5 degrees may take place by the middle of the next century if the experiment continues unchecked. These temperature increases, over the past 100-200 years, exceed those that have taken place over the past 5000 years. The antidote is to reduce the rate of release of CO_2 and other greenhouse gases. The suggested target for the year 2005 is a 20% reduction from the present (1988) release rates.[5] This is a problem also with fossil-fuelled stations, but there is no practical way to counter it at the source, as there is with acid gases. This problem does not exist with nuclear stations.

Finally, there is a constraint that is often not considered.

Time.

The essence of a good strategy is to make available the widest and most sensible range of choices in the most timely way.

The amount of time available in which to set a strategy and start making electricity supply decisions for Ontario is limited. If time is not used effectively, the number of supply options available to us could be reduced by default to one or none.

Summary

The membership of the Canadian Nuclear Society believes that although efficient demand management is a necessary component of an electrical energy strategy, the situation of not being able to meet demand must be avoided by the timely provision of an assured electrical supply. Of the supply options available, the Society is convinced nuclear energy can provide the most cost effective long term means of providing the required electrical supply.

Ontario's present nuclear programme has demonstrated its safety. From the environmental and waste disposal aspects, nuclear has demonstrated its superiority compared to the major alternative of coal-fired generation. There are considerable economic advantages for Ontario's economy if its own mineral, manufacturing and manpower resources are applied to the supply option chosen, as would be the case with nuclear.

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Book Reviews

"Subtle Is The Lord...": The Life and Science of Albert Einstein, Abraham Pais, Oxford University Press, New York, 1982.

> *I saw Einstein for the last time in December 1954... As I entered, he was seated in his armchair, a blanket over his knees, a pad on the blanket. He was working. He put his pad aside at once and greeted me. We spent a pleasant hour or so; I do not recall what was discussed. Then I told him I should not stay any longer. We shook hands and I said goodbye. I walked to the door of the study, not more than four or five steps away. I turned around as I opened the door. I saw him in his chair, his pad back on his lap, a pencil in his hand, oblivious to his surroundings.*
>
> *He was back at work.*

With these lines, Abraham Pais, Detlev Bronk professor of physics at Rockefeller University, concludes a book whose "principal aim ... is to present a scientific biography of Albert Einstein". Quite clearly, it is much more than that.

The book is divided into seven main sections in 27 chapters, which switch from discussions of Einstein's work and achievements, and the events in his personal life and development. The treatment is to a high scholarly standard, with a wide range of scientific papers, letters, memoirs and other documents consulted and referenced. Neither the book's length (522 pages of small type) nor the mathematics and its supporting documentation should deter the prospective reader. Pais knew Einstein personally for the last decade of Einstein's life and, if anything, the book is the product of a labour of great admiration and respect.

Chapters relating personal details of Einstein's life to his scientific achievements are interleaved comfortably and the account flows onward despite some rather nasty mathematics in spots. The scenes of Einstein's elation on the occasions of his greatest scientific successes are charming: when Eddington announced the predicted bending of starlight by the sun; but especially when Einstein was able to explain the advance of the perihelion of Mercury, and was excited for days because "Nature had spoken to him".

Pais' own astonishment at the way the value of Avogadro's number pops out of Einstein's fundamental result on Brownian motion, as if out of nowhere, (it can be determined to quite good accuracy using just a microscope and a stopwatch) also comes through clearly. The book is full of such vignettes; whether they or the discussions of Einstein's scientific accomplishments (and their technical and historical provenance) are the chief attraction of the book must be a question of the reader's preference.

With such a wide range of content, "Subtle Is The Lord..." is very difficult to summarize. Lengthy discussions of tensors will not be to everyone's taste in light reading. Nor perhaps will the details of Einstein's various academic positions, his correspondence with colleagues and his struggles toward a unified field theory and with what he perceived to be the shortcomings of quantum theory.

However, there is a need to dispel various folk wisdoms and distortions about Einstein and his work (for example, the assumption that he had anything at all to do with the conception or development of nuclear weapons). And those of us who can just remember the headlines announcing his death (April 18, 1955) or who recall their first intriguing brush with notions such as "bent space", time dilations and shrinking metre sticks, have probably always been rather curious about the man himself.

Abraham Pais' fine volume is an invaluable source for satisfying this curiosity.

Keith Weaver

Chapters of Accidents

Red for Danger – A History of Railway Accidents and Railway Safety, L.T.C. Rolt, Fourth edition revised and with additional material by Geoffrey Kichenside, Pan Books, ISBN 0-330-28189-0

The late L.T.C. Rolt is recognized as the transport historian *par excellence*. He is also one of the few historians who has documented the engineering history of the nineteenth century in a manner which combines impeccable scholarship and compellingly readable style. Over the last few years his books have begun to be reprinted in paperback, including his classic biographies of the Stephensons and Brunel. None of these books should be missed by even the most general reader. Why *Red for Danger* specifically?

Red for Danger is essentially the history of the development of railway safety in Britain told via major accidents, from the very earliest days of the railways to the post-war period. People in the nuclear safety business will find this particularly interesting because of the similarities and the differences between railway development in the nineteenth century and nuclear power development in the twentieth. First one must note the revolutionary nature of the technology itself. The unheard of masses involved, and the unparalleled speed of even the earliest railway vehicles not only required materials and structures to operate in entirely new and very much more rigorous regimes, but also, as Rolt notes, "posed practical and operational problems which were quite without precedent". It should also be pointed out that the destructive potential of the railway train was recognized at an early stage and steps taken to provide a system of regulation to protect public safety.

When a Parliamentary Select Committee was set up to establish what degree of supervision of these new railways would be required in the public interest, the great George Stephenson made a lengthy appearance before them to outline his views and subsequently wrote to the President of the Board of Trade summarizing specific proposals. Central to Stephenson's argument was his firm view that some form of government regulation was an absolute requirement for protection of the public. He argued that all proposed technical changes should be reviewed by engineers from the railway companies and the Board of Trade. Their recommendations should then be presented to the Board of Trade which would then make a final decision. Stephenson had some specific technical points to make too, including the establishment of speed limits related to track condition, uniformity of signals, the need for the development of self-acting ("fail-safe") brakes and the application of standards for design and materials for critical rolling stock components, which "should bear the government stamp, to being made of the best materials."

The concept of technically informed supervision without interference was accepted and resulted in the establishment in 1840 of the Railways Inspection Department whose Inspectors were (and still are) recruited from the Corps of Royal Engineers. The Inspecting Officers were to inspect and report upon newly constructed lines which could not be opened for public use without their approval and to investigate the causes of accidents. Their first such investigation was undertaken in August 1840.

Red for Danger is as much a history of HM Inspecting Officers of Railways (and a tribute to their fine achievements) as it is the history of railway safety. Their reports, which form Rolt's principal sources, are consistently clear and comprehensive in their analyses and unambiguous in their recommendations. Rolt points out how the Inspectors had to steer a difficult course. On one hand were the railway companies and their engineers who wanted no government supervision whatsoever. Brunel, for example, said that the Inspectors would get no co-operation from railwaymen, though he **hoped** that they "would answer questions in a gentlemanly fashion". On the other hand the public outcry following any major railway accident would inevitably generate an impressive head of political steam impelling a greater, and perhaps inadvisedly prescriptive, degree of government control. Rolt describes the Railway Inspection Department's philosophy (which has a familiar ring) as articulated by its head, Captain H.W. Tyler:

> *Responsibility for safety on the Railways, he maintained, must remain with the individuals concerned. Any form of direct supervision or control by government would be harmful because it would inevitably divide responsibility and by doing so, weaken it.*

Rolt emphasizes that the very nature of rail transportation made the need for specific technical developments absolute. The distance required to bring a train to halt, from even a modest speed, meant that from the outset some method of controlling the distance between trains was an absolute requirement. Associated with this was the necessity for a method of informing drivers of the status of the line ahead of them. As well a driver must have confidence that the signals he sees accurately reflect that status. From these needs evolved the principles of "absolute block" train control (whereby once a train has entered a specific section of track no other train may enter until the first has left it) and of interlocking points and signals (whereby changes in point settings will be unfailingly reflected by their associated signal aspects). Another need was for braking on every vehicle, not just the engine and the brake van. The emergency application of brakes combined with a coupling failure (a not infrequent event) could result in the relatively flimsy passenger coaches telescoping against the massive engine – with horrific consequences. A continuous braking system **which would automatically activate should its continuity become broken** was recognized early as a major contributor to passenger safety.

Absolute block control, linked points and signals and continuous braking were all recognized as vital safety contributors – but implementation was another thing. It took continuous prodding by the Inspectors and intermittent public outrage before, in 1889, the Regulation of Railways Act gave the Board of Trade the power to order a railway company to implement the block system of control, to provide for the interlocking of points and signals and, for passenger trains, to provide a continuous braking system (brakes on all vehicles) which would automatically activate should the continuity of the system be broken. It also took many accidents.

Red for Danger organizes accidents into ten rough categories, including early double track collisions, single track collisions, mechanical failures (including boiler failures), bridge failures (including the Tay Bridge loss of 1879) and signalling failures. These are only rough categories since virtually all the accidents are found to be initiated by a number of failures, both human and mechanical.

Those accidents where "human error" can be said to play a dominating role reveal with some clarity the perspicacity of both Railway Inspectors and the general public. Investigations of such accidents were frequently parallelled by the laying of criminal charges against the individual railwaymen concerned, yet acquittals were unfailingly recorded since as both technical investigations and criminal trials made clear the failure of the individual (what we might call, loosely, "operator error") could be shown to be the direct result of failures on the part of the operating company, including failure to assign staff with adequate technical or physical qualifications (one 15-year-old signalman, for example, lacked the physical strength to operate the points at his signal box), requirement for excessive working hours (18 hour shifts were by no means uncommon) and failure to supply appropriate equipment.

A recurrent theme in Rolt's book is the degree to which rail safety was dependent upon the individual railwayman and how ill-served these individuals were by the railway companies. In contrast, Rolt shows how the technical influence of engineers of the Railway Inspection Department combined with the political force of public opinion to push frequently unwilling governments into the enactment of legislation to enforce minimum safety standards.

As a practical engineer as well as an historian, Rolt brings to bear an unusual but ideal combination of talents to deal with his subject matter. His affection for his subject, and his encyclopaedic knowledge of it, results in a book that will engross and delight engineer, transport historian or general reader alike. Rolt's modest disclaimer that *Red for Danger* has pretensions to be nothing but a book for the general reader is belied by the standard of scholarship of the work. While it is true that a complete and formal scholarly apparatus is not supplied, the Chronology and Index of Accidents and the Bibliography are more than sufficiently comprehensive to meet the needs of the serious researcher.

Tribute must also be paid to Geoffrey Kichenside (a specialist on railway signalling and safety) who has added two chapters to cover the period from the mid 'fifties to 1980. This period has seen rail safety challenged by new propulsion technology with consequently higher sustained speeds, higher traffic densities and ever more massive trains. And the advent of new technology in the fields of marshalling, signalling and train control has seen operation and maintenance practices evolve to a level of formality and rigour comparable to those of commercial aviation. Kichenside's coverage of the period is in style and content well up to the standards set by Rolt – no mean achievement.

Red for Danger is a classic account of how a society marshalled its technical knowledge and its public commonsense to come to grips with the safety implications of a revolutionary technology. We should all read it – then think about it.

David Mosey

Physics for Poets, Robert H. March, Contemporary Books, ISBN 0-8092-5532-4

In *Physics for Poets* Professor March has produced a remarkably lucid, absorbing and engaging volume covering two revolutionary periods in physics. The first is that of the rise of classical mechanics from Galileo to Newton and the second – one which is still in progress – the evolution of relativity and quantum mechanics.

Perhaps the most important achievement of this book is its articulation of what the author sees as the driving force of physics – a sense of enquiry, a sense of wonder and the delight in the "elegant" solution. That he can explain what he means by the "elegant" solution, elegantly, is what makes his title so apposite. Actually this book will bring physics to anyone who reads it – and a great deal of pleasure beside. However, in view of the title, I felt that the bulk of this review should be conducted by an established poet.

The choice of reviewer was clear – Emily Dickinson (1830-86). A significant feature of Dickinson's poetry is its extensive use of scientific and technical concepts and images. Those relating to astronomy are particularly numerous and particularly relevant to one of her major themes – the relationship between the individual consciousness and a seemingly limitless universe. Her explorations of this theme could well be considered as anticipating some of the interesting philosophical questions raised by modern physics, just as she anticipated many of the technical advances in her own field, usually credited to such as Eliot and Hopkins.

I was fortunate to be able to make contact with Ms Dickinson via a little-used sub-etheric data link. She still retains a strong sense of personal privacy and agreed to read the book and share her reactions to it with us only under certain conditions which included her right to retain possession of the only extant tape recording of our conversation and to review this material before publication. This she has done – to my gratification the few changes she has made are not substantive. What follows is an accurate rendition of our conversation.

Q *Why do you think March has written a book on physics for poets?*

A Really he has not, you know. It's a book about physics, and the intellectual processes driving it – or rather the "dark spirits" who drive those who work in physics – and it's written for any person who has any intellectual curiosity. I think it shows the risk you run with titles – it's so easy to give rise to a misleading impression. I think what Professor March had in his mind was the *relationship* between poetry and physics. Let me quote the last lines of his book:

> *Each generation of scientists finally comes to the shores of its continent of solid fact. For the time being the ocean beyond can only be crossed in the imagination. This has always been the driving wheel of scientific creativity. The thrill of holding such visions in one's mind is one of the sweetest rewards of the calling of science.*

In essence he is describing what poetry is – or at least should be – doing.

Q *But isn't that at odds with what is supposed to drive science – the objective observation of phenomena and recording of data?*

A You must be very careful how you use the word "objective", you know. It is no absolute – Professor March shows that very clearly.

Q *Yes, but –*

A Actually, in the early part of the book the author shows very clearly the danger of that sort of thinking when he compares Aristotle's theory of the motion of falling bodies to that of Galileo, and shows how the sort of approach you have described could be used to demonstrate that Aristotle's theory was in fact much closer to observed reality than Galileo's. But because Galileo excluded the effects of the medium through which the object was falling he found a far more appealing and fundamental law of nature. Professor March says

> *Science is much more than an attempt to describe nature as accurately as possible. Frequently the real message is well hidden, and a law that gives a poor approximation to nature has more significance than one which works fairly well but is poisoned at the root.*

He is quite right, of course. The misapprehension that by classifying, recording and measuring, and doing no more, you are advancing knowledge and understanding is one I have frequently had to criticize.

Q *But much of your writing in that vein is interpreted as an attack on science for unravelling and demystifying the beauties of the universe?*

A Young man, if you believe *that* then we should terminate this conversation without delay. You must be confusing me with Mr. Whitman whose poetry I [*irrelevant personal characterizations deleted*]. No, indeed, I have always argued that we must move from what we know to discover more. This must require some speculative thought, despite the prompting of our "timid life of evidence". It also requires constancy of purpose to cleave to the route you have chosen. This may frighten some people (perhaps Mr. Whitman?) because as you find out more you discover there are even bigger questions to answer and, of course, that the framework upon which you have hitherto been standing is not quite so complete as you had imagined. You must adapt. The more we understand of the universe and the more we look at it (the two actions are by no means the same) the more wonderful it becomes.

One of the exciting things about astronomy, I remember, was that the more one studied the heavens the more we realized how much more there was to study. When people use telescopes they should remember that in reality they are pushing the limit of observation further away although the *image* of an object seen through a telescope makes that object *seem* closer. A recurrent theme in literature (best expressed in Mr. Shakespeare's work) is the importance of distinguishing between image and reality. Images are sometimes useful servants but always evil masters.

Q *Surely people must have some concern about the "framework" changing?*

A Why? You must remember that the "new physics" (very new to me) takes nothing from us that was worth keeping, and gives us so much. If I have one small complaint to make against Professor March it is that he does not sufficiently emphasize what remains to us after the demolition of classical mechanics. That "demolition" simply provided a wider, deeper and more confusing set of pictures of the universe. But if Newton's model has turned out to be unserviceable for the universe, it is still true Newton has left us some perfectly serviceable tools for our day to day activities. We just have to recognize their limitations and adjust our thinking accordingly. A clock is a very useful device as a clock – but it will not do as a model for the universe, though there were some misguided philosophers who attempted to use it so. I have dealt with them elsewhere and I was glad to see that Professor March's opinion coincided with my own. Another important thing Newton has left us is the following statement from *Principia:*

> *We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances. To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for nature is pleased with simplicity, and affects not the pomp of superfluous causes.*

I was rather surprised that this was not included in the book since it is such an important reminder for a poet or a scientist.

Q *How can you cope with the paradoxical – and sometimes fantastical – concepts inherent to relativity and quantum mechanics?*

A Very well indeed! The concept of the frame of reference is one with which any poet should be extremely comfortable if not familiar. And the idea that the act of observation changes what's observed is inherent to poetry. I'm a little surprised that science has taken so long to get around to these ideas. I have used the term "frame" myself in the sense of a selected stance or point of view with the (I hope) clear implication that selection (or imposition) of such a frame profoundly influences one's experience of the universe. Please let me make it clear that I by no means pretend to have any kind of grasp of the intricacies of the theories Professor March explains ... yet. I am sure that after several more careful readings (a pleasure to look forward to, since the author is never dull) I will develop a more complete understanding. But even without fully comprehending I can share the author's excitement at how our understanding of the universe is changing. I also find great satisfaction in noting that the key to developing our understanding of the unimaginably huge may lie in our investigations of those things that are unimaginably small.

Q *So I suppose you would conclude that this book forms a valuable bridge across the gap between science and poetry?*

A What gap?

David Mosey

Nuclear Energy: Unmasking the Mystery, **Tenth Report of the Standing Committee of Energy, Mines and Resources, Ottawa, August 1988.**

The Standing Committee on Energy, Mines and Resources comprises seven members: two from Ontario, one from Cape Breton and four from the Prairies. Their report could certainly be called "in step with the times". Its two main themes are:

We can't ignore the problems of the environment any longer, and

Where is a substantial portion of our energy going to come from if not from nuclear power?

It is this sense of being in a box that appears to drive the Committee toward enunciating its concern that more needs to be done sooner in order to make the case for nuclear more complete and more palatable to the general public. The first two recommendations reflect such a concern. Recommendation 1 calls for the advancing of the schedule to establish a commercial high-level radioactive waste repository, and for the federal government to make the money for this work available as a matter of urgency. The second recommendation directs the AECB to appear before the Committee no later than June 30, 1989 and to present a list of "parameters" to be used in licensing such a site and facility.

On the first page of that section of the report entitled "Summary and Recommendations", the Committee makes its ground rules quite clear.

"... **maintaining the nuclear power option is vital to Canada's interests,** [emphasis in original] as it is vital to the interests of society in general. There is a compelling case to be made in support of continued nuclear development, a case based upon the future inadequacy of conventional petroleum resources and upon the environmental degradation arising from burning coal in progressively greater quantities for electricity generation."

On page five of the same section, after recounting the (potential) problems and risks associated with other energy technologies, the Committee is able to state that it

"... finds nuclear power to be an environmentally appealing technology."

Thus notwithstanding the problems that it poses, nuclear energy should continue to be developed and used, in the Committee's view, because its advantages outweigh those problems.

The advantages are not only the technology's relatively benign environmental aspect, but also its present and future economic importance (provider of a largish pool of high quality employment) and its position as the seat of a significant fraction of Canada's scientific and engineering resources. However, as an afterword to Recommendations 1 and 2 which relate to the demonstration and licensing of a waste repository, the Committee puts the nature of the disposal question into perspective:

"The technical problems of radioactive waste management are not insurmountable: the Committee concludes that these wastes can be safely handled, stored, transported and disposed of providing the political will is there."

Other significant recommendations concern nuclear insurance and the funding and mandate of AECL.

Recommendation 3 states that the basic insurance coverage on Canada's nuclear facilities should be raised "substantially". Of the remaining 11 recommendations, four relate to AECL and six concern the AECB. Recommendations 4 and 5 advise the federal government to increase its funding to AECL, to guarantee an increased level of funding for five years and to encourage the organization to expand its efforts into non-nuclear R & D.

There are fourteen recommendations in all, but many of them seem to be almost anticlimactic. Those dealing with the AECB, for example, sound akin to a Saturday afternoon spent tidying the pantry. They involve the AECB's financing and cost recovery, expansion of the number of full-time members of the Board to five, engaging in a "more public style of operation, including holding its hearings in public", changing its name (AECB is deemed to be too similar to AECL) and establishing an "office of public education".

The final recommendation appeals to the federal and provincial governments to co-operate more closely in identifying and promoting the more efficient uses of electricity.

Two Committee members dissented with the report. One (the MP from Cape Breton) was concerned about the encouragement given to private enterprise in penetrating the nuclear business, and especially the problems this might create concerning safety and accountability. The second (the MP from Ontario) rejected the entire report and its recommendations on what appear to be doctrinaire political grounds.

Keith Weaver

New challenges: The Ninth Annual Conference of the Canadian Nuclear Society Winnipeg, June 1988

June 1988 marked the first time that the combined CNS/CNA Annual Conference descended on Winnipeg. Some 400 delegates converged on the Winnipeg Westin Hotel, a snowball's throw from the legendary intersection of Portage and Main where, reportedly, pools of liquid helium collect in winter. No snowballs (or liquid helium) in June, though. Though the record breaking heat wave had moderated by the start of the conference the weather made cold beer and high performance air conditioning very significant factors in keeping cool – both physiologically and psychologically.

The conference format had CNA plenary sessions in the mornings and the CNS parallel technical sessions in the afternoons. As far as the latter were concerned there appeared to be general agreement among delegates that the range and technical quality of the CNS sessions was excellent. The one complaint – that of the difficulty in choosing between sessions – is perhaps the best tribute that could be paid to the efforts of the organisers and the many reviewers and authors.

Following the success of last year's "educators' programme" the conference included a series of sessions for teachers and some 40 Manitoba teachers attended background sessions on such major issues as nuclear safety and radioactive waste management. These were followed by visits to the Whiteshell Nuclear Research Establishment and the Underground Research Laboratory at Lac du Bonnet. Indications from those attending were that the lectures were well received, and regarded as a valuable contribution to increased understanding of the issues raised by nuclear energy development.

A joint CNS/CNA session took the form of a number of presentations and a panel discussion on the topic of public understanding and nuclear power. The participants, T.A. Margerison (UK Nuclear Energy Information Group), J.-P. Chaussade (Électricité de France), B. Harris (US Council for Energy Awareness) and R. Dionne-Marsolais (Canadian Nuclear Association), each gave a brief outline of the degree of acceptance of nuclear energy in their respective countries and of the public information programmes that had been established. From these, and subsequent discussions, it appeared that the general public did wish to become better informed about nuclear energy. Data presented by R. Dionne-Marsolais were interpreted to show that in Canada a well organized and well presented programme of public information can result in public opinion shifting to a greater degree of acceptance of nuclear energy. As well it was noted that there now was general agreement that the nuclear industry's public information efforts must be much more extensive than simple response to criticism.

CNS Technical Sessions

A total of 79 papers was presented at 13 technical sessions.

Session 1 and Session 10 – Operational Enhancements: The papers in this session dealt with ways in which reactor operation could be made more flexible and responsive to fluctuating grid demands, and less vulnerable to unplanned shutdowns. As well approaches to reducing downtime – planned or unplanned – were presented. As well as load following, other topics included the use of computers to handle information pertinent to operation and the application of filing programs and "expert systems" to work planning, fuel management, analysis of normal and abnormal operation and testing programmes.

Session 2 – The Design of Small Reactors: Four small reactor designs were covered: the 500 kWe Nuclear Battery, the sodium cooled MODSTAR concept, the 1500 kWth AMPS and the 2 MWth Slowpoke Demonstration Reactor. All these designs use low pressure natural convection cooling and have large negative temperature coefficients to ensure inherent safety or safe operation without active safety systems. The neutronic design of these reactors was discussed and, in the case of the Slowpoke Demonstration Reactor, good agreement was demonstrated between predicted and measured results.

Session 3 – Accident Behaviour in Fuel Channels: While dominated by concerns related to horizontal fuel channel designs, this session did include discussion of vertical channel reflooding in the Japanese Advanced Thermal Reactor (ATR) with results from tests at the ATR safety experimental facility reported. Various aspects of pressure tube and calandria tube behaviour were discussed in the remaining five papers, with the results from several experimental programmes and computer codes being presented and discussed. Steady progress is being made in increasing our understanding of pressure tube and calandria tube performance under various accident conditions.

Session 4 – Fuel Storage and Waste Management: The first two papers in this session covered the Canadian programme to develop dry storage of irradiated fuel using concrete containers. Experience to date has been excellent with no degradation of container or contents appearing over several years, giving good grounds for confidence in this storage method. Also reported was the dose rate calculation for irradiated CANDU fuel and how this information was used in the design of concrete containers used for storage of irradiated fuels from the Gentilly-1 and Douglas Point reactors. Various aspects of radwaste management were discussed in the other papers: the successful clean-up and decontamination of an Eldorado waste management site, current practices for low-level waste treatment at Chalk River and Whiteshell, assessment of the underground fuel waste disposal method, experimental and theoretical chemistry in support of the Canadian Nuclear Fuel Waste Management Programme and an experimental study of the retardation of radionuclide movement through granite.

Session 5 – Reactor Commissioning / Decommissioning: This session ranged from the impact of computer applications on commissioning activities at Darlington through aspects of the major "recommissioning" work at Pickering to the development of a validated computer code for obtaining decommissioning cost estimates. Of particular interest were two papers recounting actual practical decommissioning experience at the NPD reactor, from which it appeared that while "high technology" has its part to play in such work, there was still no substitute for conventional commonsense application of conventional materials and equipment (otherwise known as "good engineering").

Session 6 – Nuclear Safety Experiments and Modelling: Results from computer models and experimentation were compared and discussed for CANDU reactors under a variety of accident conditions, including LOCA and LOCA/LOECI. Droplet formation, aerosol release from uranium fuel and modelling of flows in large ducts were described and discussed.

Session 7 – The Next Generation Reactors: Four papers were presented covering the safety improvements, control system, fuel channel design and a computer simulation of fuel channel replacement for the CANDU-300. These were followed by a paper describing a design approach to improve CANDU tolerance of large component failure and the session was concluded with a description of a new control technology for a fossil fuelled plant designed to support the "islanding" approach to plant design and construction.

Session 8 – Advances in Nuclear Engineering Education in Canada: Representatives from five Canadian universities described their nuclear engineering programmes. In the ensuing discussion several common points emerged, including the clear structures of the programmes, the active involvement of the teaching staff in research and the close collaboration between the universities and industry – most notably with the major nuclear research centres. Some problem areas were also outlined, such as the low level of research funding, low student enrollment in nuclear engineering courses at some universities and the need for better communication between the universities.

Session 9 – Small Reactor Safety: The main thrust of this session was discussion of modelling and experimental programmes in the support of the design and development of two small Canadian reactors – the 10 MW MAPLE and the 1.5 MW AMPS. The papers covered the continuing design and validation of analysis codes and the performance and safety characteristics of these reactors in the light of computer predictions and experimental measurements of their neutronics and thermalhydraulics characteristics.

Session 11 – Fuel Channels – Current Position and Improvements: The six papers in this session ranged from developing an improved understanding of basic hydride cracking mechanisms to prediction of creep sag and corrosion processes. Possible enhancements to fuel channel performance were discussed including the use of yttrium hydrogen/deuterium sinks and changes in the crystallographic texture of the tube material.

Session 12 – Current Issues in Nuclear Safety: The first of the six papers presented results from tests of heat transport pumps under loss-of-coolant conditions and compared these with results predicted by an analytic model. A major conclusion was that loop geometry and water temperature have a large effect on test results. A special control room annunciator system at Port Lepreau was described in the second paper. This system provides monitoring and procedural information to assist the operator in executing emergency operating procedures. The design principles were outlined and the results of tests discussed. The third and fourth papers discussed results of the Darlington Probabilistic Safety Evaluation. This evaluation has proved its worth in the detection of design weaknesses before construction and commissioning. The fifth paper defined institutional failure as an important (sometimes major) element in several high consequence accidents (nuclear and non-nuclear), tracing the causes of these events way beyond "faults" of the operating crew and questioned how a "good" institution could be characterized from a safety standpoint. The final paper in this session described the role of a safety analysis group at an operating nuclear station, its activities and its needs. It concluded that further safety analysis work was essential beyond design and licensing analysis in order to keep pace with developments at the plant.

Session 13 – Medical and Industrial Radiation Applications: The seven papers presented in this session covered topics ranging from the transportation of depleted uranium calorimeter modules to Europe, through the computation of electron doses for cancer treatment to the determination of doses received by patients undergoing radiation imaging procedures. Two papers dealt with radioisotope production for medical applications including the design of facilities for both reactors and cyclotrons. The session concluded with two papers on radiation processing. The first Canadian irradiation centre at Laval was described and its objectives discussed, and the results of an investigation of radiation-cured carbon fibre composites for their suitability for radiation processing were presented.

On the Social Side

The less rigorous side of the CNS conference was no less successful. Three eminent speakers sang for their suppers (lunch actually) to considerable effect. The Honourable Perrin Beatty, Minister for Defence, not only held the attention of his audience, but aroused considerable media interest with his defence of the plan for a Canadian fleet of nuclear powered attack submarines. Dr. Kenneth Hare, the Ontario Nuclear Safety Review Commissioner, showed scholarly wit as well as scientific insight in his literate talk "On Being a Safety Commissioner". And Professor Schemilt demonstrated clearly that not only do scientific insight and scholarly wit flourish at McMaster University, but so does literary criticism of a high order. His presentation of Sherlock Holmes' "Case that Never Was" (published in the previous *Bulletin*) was a delight to hear and an example of Holmesian scholarship at its best.

Of course, at these conferences there's always the moment when you have the irresistible urge to drink a lot of beer, eat a lot of food and make a lot of noise. The conference organizers nobly pandered to these base desires with a "Western Style Fun Night" held at the Hitchin' Post Ranch - and threw in a ride on a double decker bus as well.

To all those who did the work that made this conference so successful, from all of us who appreciated it so much - thanks.

Hugues Bonin

International symposium on zirconium

The technology of zirconium alloys is extremely important to the Canadian nuclear programme since the CANDU reactor makes such extensive use of zirconium alloys for pressure retaining and constructional use in the core of the reactor. In addition they are used as fuel cladding materials. Thus the triennial International Symposium on Zirconium in the Nuclear Industry attracted a strong Canadian technical presence. This year's conference, sponsored by ASTM and IAEA, was held in San Diego in June and comprised eight sessions covering fuel channel material behaviour, corrosion, mechanical behaviour, basic metallurgy and creep and growth.

In the fuel channel session, performance in Hanford, RBMK and CANDU reactors was reported. The Hanford reactors, with Zircaloy-2 tubes, have suffered the rapid corrosion and hydriding seen in the Zircaloy-2 pressure tubes of the Pickering Units 1 and 2 (now retubed with Zr-2.5% Nb). The US data clearly showed the transition to increased oxidation and hydriding that occurs beyond certain inside surface oxide thicknesses resulting from corrosion. The Russian paper on RBMK pressure tube performance predicted, based on 15 years of in-reactor measurement, a very low axial growth. It is interesting to note that the Zr-2.5% Nb Russian pressure tubes are similar to those in preproduction for Ontario Hydro reactors (i.e. 40 per cent cold-worked, stress relieved at 500C for 6 h and then autoclaved at 400C) for which a low axial growth also has been predicted. The Canadian papers in the session dealt with reviews of corrosion behaviour in CANDU pressure tubes, solid hydride growth and cracking criteria, evaluation of removed pressure tubes, effects of hydride morphology on pressure tube toughness and means of preventing delayed hydride crack propagation. These papers selectively covered a large amount of work carried out by the research divisions of AECL and Ontario Hydro in the five years since the pressure tube rupture in Pickering Unit 2 in August 1983. There is now a considerable body of knowledge quantifying hydrogen behaviour in pressure tube alloys.

Considerable attention was paid to the performance of fuel sheathing in light water reactors, in particular, corrosion and hydriding. Zircaloy-4, a zirconium-tin alloy with minor amounts of iron and chromium, is the favoured alloy for this application in LWR and CANDU reactors. There has been considerable effort over the past 20 years to use out-reactor tests to predict in-reactor behaviour.

While the Zircaloy-4 alloy is performing adequately in current conditions, the increased corrosion and hydriding that will be associated with its use on long burn-up fuel has raised concerns about its adequacy in that role since excessive hydrogen pick-up is a likely precursor to cladding failure. A presentation from Combustion Engineering (U.S.) described the high oxide thicknesses (also detrimental to heat transfer) and high hydrogen concentrations (up to 600ppm) that can be experienced in PWR fuel cladding.

Westinghouse (U.S.) reported on fuel cladding development tests they have had underway since 1973 on zirconium alloys such as the zirconium-niobium alloys and a new zirconium-tin-niobium-iron alloy designated Zirlo. This alloy showed the best corrosion resistance of the alloys tested but the lack of specific hydrogen pick-up information made the comparison less valuable. In the course of discussions the H_2 uptake was reported to be "similar to Zircaloy-4". Zr-2.5% Nb of the composition used for CANDU pressure tubes also performed well (and likely had a low hydrogen pick up) but in the later part of the tests, during which there was a cycle of high crud levels in the water, the alloy suffered a step jump in oxide thickness.

A second Westinghouse paper examined the ductility of several materials in simulated fuel pallet-cladding interaction. Among the materials tested were Zr-4, Zr-2 lined with Zr or Zr-3A, and Zr-4 lined with graphite. Similar ductility values were measured for the Zr-2 lined with Zr and Zr-3A, but the Zr-4 lined with the graphite gave significantly better results.

A large development effort has been made by suppliers and vendors to refine the composition, heat treatment and fabrication of Zircaloy-4 to produce optimum mechanical and corrosion properties. Invariably these have been evaluated by out-reactor corrosion tests and it was disappointing to hear at the conference that zirconium alloy corrosion behaviour is so variable from batch to batch, temperature to temperature, and that there is only limited correlation between out-reactor corrosion performance and in-reactor performance. Of the out-reactor tests used to predict nodular corrosion, the steam test at 500-520C appears to give the best correlation.

The basic metallurgy papers were characterized by studies in many organizations on intermetallic precipitates and solubility limits of minor alloying elements, particularly iron in zirconium. The presence and form of these precipitates is believed to have a significant effect on corrosion and hydriding. Several papers discussed the effect of neutron fluence on the iron in the precipitates and showed that the changes in the precipitates caused the iron concentration in the matrix to be increased.

Creep and growth of fuel cladding and pressure tubes were covered in the sessions on mechanical behaviour. Such effects are important to the CANDU system since they can determine the amount of maintenance and the ultimate life of reactor fuel channels. Canadian research into these effects has been an important part of the world effort. Growth effects in LWR fuel rods are watched carefully. Thus research is ongoing to establish textures and properties in these cladding tubes that will provide optimum resistance to the deformations experienced in service.

Data were presented which showed that many of the characteristics of irradiation induced growth in Zr-4 were similar to those in other Zr alloys. The data also showed that among the effects of irradiation on alloy microstructures was a change in the dislocations, with the formation of dislocation loops in the close packed planes in the zirconium lattice.

The conference was attended by two delegates from the USSR. In addition to the USSR report on axial growth of pressure tubes (discussed earlier) a second paper from the Soviet Union, presented in a poster session, was of considerable interest to CANDU engineers. It indicated that the Russians have also had problems with hydrogen and residual stresses in pressure tube material causing cracking and necessitating channel replacement. It was reported that 20 channels had been replaced in the Kursk and Chernobyl reactors because of axial cracks which developed from the outside of the pressure tubes and grew to the inside surface during early operation. It was apparent from the description of the manufacturing process that very high residual stresses had developed in the tubes during a roller straightening operation applied to the tubes to correct straightness and ovality following the heat treatment operation. The heat treatment following this straightening was not done soon enough or was not at a high enough temperature to prevent delayed hydride cracking from initiating in regions of high circumferential residual stress. Presumably the cracks must have been deep enough to propagate under operating pressure when the reactors started up since the velocity of crack propagation is very slow at low temperatures.

In summary the Eighth International Conference on Zirconium in the Nuclear Industry showed that Canada has maintained a strong technical reputation for its research and development efforts in zirconium alloys. There is an increasing interest in niobium as an alloying element in zirconium based cladding alloys and it is hoped we will see greater use of Zr-2.5% Nb for cladding purposes. The Russian experience with Zr-2.5% Nb tubing parallels our own and shows the importance of detailed fabrication control to minimize residual stresses at each stage of operation for optimum properties and quality. However, the prediction of corrosion behaviour still is a difficult exercise because of the large number of material, surface and environmental variables which influence the final result.

E.G. Price
G.D. Moan

CNS Branch News

Toronto Branch Executive 1988-1989

The Toronto Branch Executive members for the 1988-89 season are as follows:

Chairman:	Gord J. Sullivan, Ontario Hydro, Toronto (592-7365)
Past-Chairman:	Eva B. Marczak, Ontario Hydro, Pickering (839-1151, Ext 4694)
Vice-Chairman:	Ben Rouben, Atomic Energy of Canada Limited, Mississauga (823-9040, Ext 4550)
Treasurer:	Martin Spelt, Ontario Hydro, Toronto (592-8798)
Secretary/ Public Affairs:	Shayne Smith, Wardrop Engineering Inc., Toronto (592-3312)

The Executive strongly encourages all members to participate in Branch activities.

Gord Sullivan

Call for nominations to NSED executive

The Nuclear Science and Engineering Division will hold an election for four positions on the NSED executive. The term of office for these positions is two years (1989/90). Nominations are hereby solicited. Each nomination must be made by at least one CNS member. The candidate must be a CNS member and indicate a willingness to serve. Send nominations in writing to the returning officer, Mark A. Wright, at the following address, by November 21, 1988.

New Brunswick Electric Power Commission
Point Lepreau Generating Station
P.O. Box 10
Lepreau, N.B.
E0G 2H0

Erratum

Page 3 should read page 2 and vice versa in the Technical Supplement entitled, "Nondestructive Testing and Imaging Using Radiation Scattering," by E. Hussein, published in the CNS *Bulletin*, vol. 9, no. 4, July/August 1988.

The editors of the CNS *Bulletin* apologize for the error.

Conferences and Meetings

World Materials Congress
Sponsored by ASM, to be held **October 24-30, 1988** in Chicago, Illinois. For information contact: **A.R. Putnam,** (216) 338-5151.

ANS International Meeting.
Sponsored by ANS/ENS, to be held **October 30 to November 4, 1988,** in Washington, D.C. For information contact: **P.D. Stevens-Guille, Ontario Hydro,** (416) 592-6024.

International Symposium on Safety Standards and Practices for NPP
Sponsored by the IAEA, to be held **November 7-10, 1988** in Munich, FRG. Contact: **IAEA.**

Conference on Nuclear Power Plant Operation and Thermal Hydraulics
Sponsored by the KNS/CNS, to be held **November 14-17, 1988** in Seoul, South Korea. Contact: **K.H. Talbot, Ontario Hydro,** (416) 592-8216.

Conference on Use of Elastomers and Polymers in the Nuclear Industry
Sponsored by CNS/D&M, to be held **February 20-21, 1989** in Toronto, Ontario. For information contact: **Mr. E.G. Price, AECL/ CANDU Operations,** (416) 823-9040

15th Annual Symposium on Waste Management '89
Sponsored by ANS/ASME , to be held **Feb. 26-Mar. 2, 1989,** in Tucson, Arizona.

International Conference on Availability Improvements in Nuclear Power Plants
Sponsored by the Spanish Nuclear Society / CNS / IAEA / ENS, to be held **April 10-14, 1989** in Madrid, Spain. For information contact: **K. Talbot, Ontario Hydro,** (416) 823-9040.

CNA/CNS Annual Meeting
To be held **June 4-7, 1989** in Ottawa. Contact: **P. Fehrenbach, AECL/CRNL,** (613)-584-3311; **T. Jamieson,** (613)-236-3920.

5th International Conference on Emerging Nuclear Energy Systems
Sponsored by ANS/ENS/CNS, to be held **July, 1989** in Karlsruhe, Germany. Contact: **A. A. Harms, McMaster University** (416)-525-9140.

World Energy Conference: Energy for Tomorrow
To be held **Sept. 18-23, 1989** in Montreal. Contact: **TPC,** (514)-878-3124.

IAEA Seminar on Research Reactors
Sponsored by the IAEA, to be held **September, 1989** in Chalk River, Ont. Contact: **P. Simpson, AECL/CRNL.**

Specialist Meeting on "Leak-Before-Break"
Sponsored by CNS/OECD/NEA, to be held **Oct. 25-27, 1989** in Toronto. Contact: **L. Simpson, AECL/WNRE,** (204)-753-2311.

4th International Topical Meeting on Nuclear Reactor Thermal Hydraulics
Sponsored by KFK/ENS/ANS, to be held **Oct. 10-13, 1989** in Karlsruhe, Federal Republic of Germany. Contact: **J.H. Kim, EPRI,** (415)-855-2000.

International Waste Management Conference
Sponsored by ASME/ANS/CNS, to be held **Oct. 23-28, 1989** in Kyoto, Japan. Contact: **R. Kohout, Ontario Hydro,** (416)-592-5384.

The Unfashionable Side

Jenkins' nuclear war

The call came while I was tending the grapefruit tree.

This always annoys me for some reason and I was probably a bit brusque.

"Do you know what time it is?" I asked into the telephone. It was 10:55 on a Tuesday morning, a perfectly civilized hour to receive a business call. But not while I'm tending the grape...

"What?" I demanded urbanely as the receiver began to sing to me. "Who is this?" He sounded like some forlorn yodeller atop the Clifton suspension bridge.

I should explain that a number of things had happened about this time which upset my normal equanimity. Some malicious prankster had called the papers saying that a number of piranha had been let loose in Lake Ontario. Worthing and I were both contacted for comment and Worthing (bless the man) let slip that perhaps they would mate with the alewives which were choking the lake. This speculation he based on lemma 2 of the canine principle, since piranha, like everyone else, would find alewives unpalatable. Trouble erupted immediately among the unions at all the power stations. Ultimately, Worthing and I had to go swimming in the outfall from Pickering to prove that there was no danger.

On top of this, there was the tearful farewell to Ivan Ipswich at the airport. He stood streaming amid his eight tea chests of Robert Ludlum "novels" (which he was transporting to somewhere in Saskatchewan – Medicine Cabinet, I think) and ruined three of my best linen handkerchiefs.

"Jenkins who?" I barked in exasperation, preparing to hang up. The singing at the other end became feverish, ranging all over the register. It sounded like Robert Merrill and Lucia Popp rolled into one, a Volga Boat poled by Queens of the Night.

"I'm sorry, I'm not a doctor," I said, finally understanding that he was asking for some kind of a tablet. But even this new certainty faded maddeningly under the onslaught of a fresh bout of singing.

"How the devil do I know whether Jenkins has taken his tablets?" I wailed, at the limit of my endurance.

Suddenly it all came together. I was speaking to Jenkins Tablotte, the new President of the Canadian Nuclear Society.

For those of you who don't know Tablotte, stay clear. He's acute, tough, kindly, ferocious, doesn't make mistakes. He's predictably unpredictable. I'm sure he must have learned it all from Worthing.

"Bauer, I'd like your help over the next year" he said, settling down to a vaguely Heads of the Valleys lilt. "The CNS is about to take the high road and we will need your, er, talents."

This could mean many things. Possibly he wanted to draw on my knowledge of and acquaintance with our francophone brethren. Was he planning a CNS meeting at Meech Lake? Was he expecting a confrontation with that wild genius, Wilkinson? And what about The Big Z? Aha! Was he on a collision course with the Atomic Energy Confusion Board already?

"Of course, I'd be delighted to help, Jenkins. What did you have in mind?" This was a stall tactic. I needed time to think. What did he have in mind?

"Why don't we meet for a drink?" he suggested. "These things resolve themselves better over a wee dram."

We agreed and hung up. Fortunately my reading includes a great deal of psychology so after half an hour of reflection and consulting references I knew what his plan was. It chilled me to the core.

The Tartan and Thistle is a spartanly furnished establishment on Brunswick Avenue. Patrons were thinly scattered when I entered so it took no time at all to spot him. He hadn't changed a bit. The quiet eyes, the slow, charming smile, the quick but economical motions, they were all the signs of a capable man and one to be crossed only when there was no other resort. That was me now. No Other Resort.

"Ah, Bauer. Good to see you again." It wasn't any false welcome. The man meant it. I would have been touched if three-quarters of my psychic effort wasn't being devoted to sphincter control. "Please, sit down. Have a drink." He slid a glass of whisky toward me.

"Glen Grant. Aged 16 years", I pronounced, sniffing it appreciatively.

His smile was beatific. "There's no doubt whatever, Bauer. You're definitely the man for the job." His relaxed confident air was devastating. Sphincter control effort jumped to 90%. There was only one way to proceed.

"It won't work, Jenkins. It's been tried. They're all in Potter's Field now. It didn't work for them either." We were off. There was nothing to do now but shoot to win.

His smile froze. Along with my brain, blood and, fortunately, kidneys. Sphincter effort went temporarily off scale.

Something took control of me. I saw my hand rise before my eyes holding the glass of whisky. A voice, which I recognized as my own, stirred the air. "They've been making and drinking this stuff for centuries, Jenkins, and they're still around. They eat salty porridge, standing. They bathe in sea water at the triple point. They're not lumbered with bishops. Even the Romans couldn't overcome them. Don't even think of trying it. They'll have as much clemency as Scipio Africanus at Carthage." My hand was moving alarmingly toward my own face. My jaw dropped involuntarily and the full load of Glen Grant went into free fall through a parched, dusty mouth and alimentary system, finally slamming against an already straining sphincter.

I still don't know what was going on behind those quiet eyes. Maybe he saw some inner terror being shown in replay in my own face. Perhaps my private vision of Brown, the lugubrious bartender at The Bohr's Head, swinging a five foot claymore and laughing with glee, while heads rolled and blood flew everywhere, was there to read in my eyes. Possibly a nervous tic betrayed my inner horror at the thought of Iain "The Regulator" MacDougall flying down from Ottawa, his morning star dipped in curare, to do battle side by side with his erstwhile licensee foes. And nobody, of whatever mettle, could endure the thought of that final nightmare, being trampled by an indomitable phalanx of six foot pipers, and as row after row of kilts strode overhead, of looking skyward through dimming eyes at all those...

I write these lines in the quiet of a half full first class cabin. We have just passed over Newfoundland heading east.

Jenkins and I drank into the small hours that night. His plan was brilliant, and he might well have pulled it off. But I was too fearful of the cost. Meeting one's end at the hands of wild Picts is no way for an eminent alewife authority to leave the scene. Indeed, you may laugh, but this was Jenkins' plan. He wanted to oust the Scottish mafia by force from the Canadian nuclear scene.

I'm sure that my discussions with the distillers of the Spey and of Islay will indicate a safer, if somewhat more expensive, way to proceed.

George Bauer