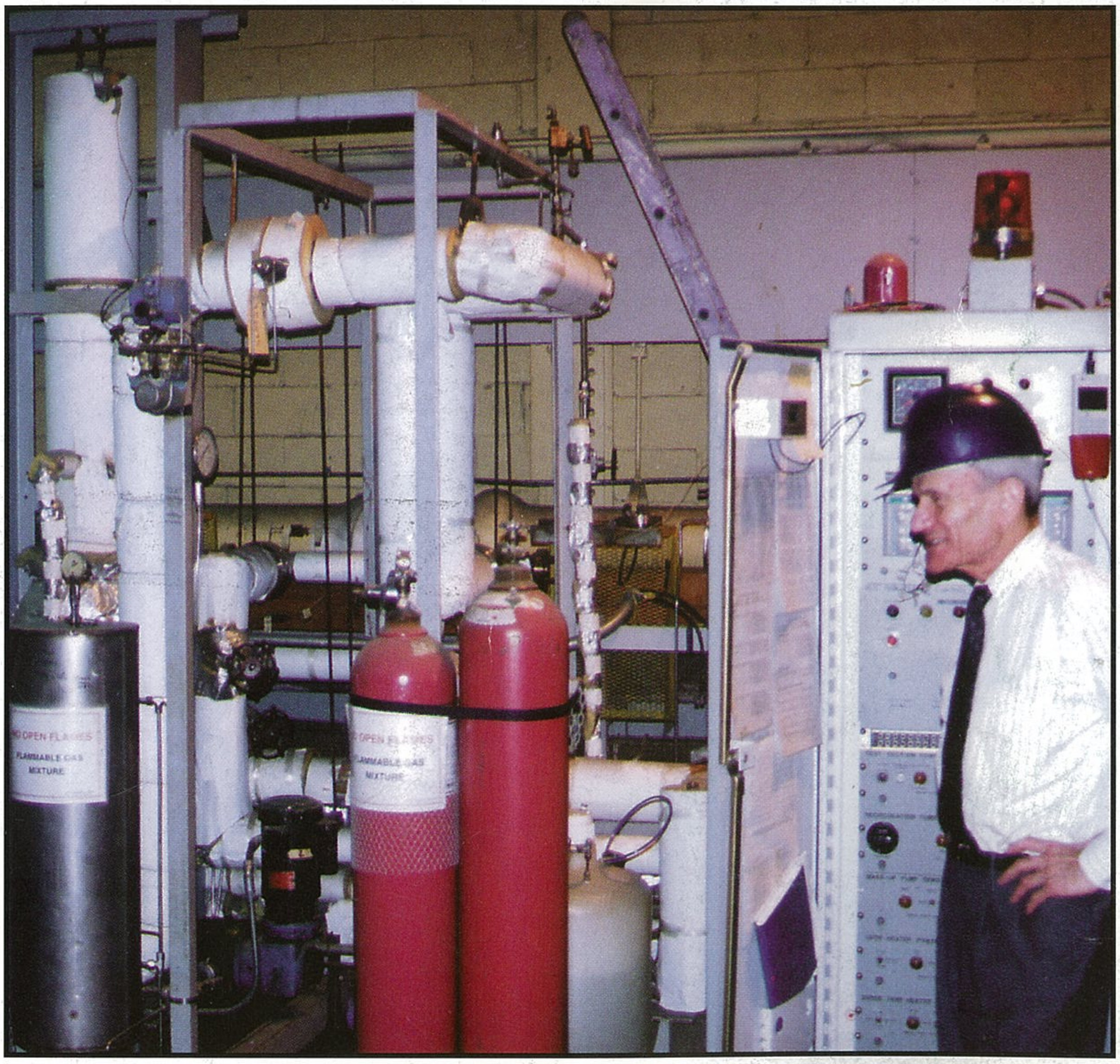
CANADIAN NUCLEAR SOCIETY
bulletin
DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

Fall / L'automne '97 Vol. 18, No. 3



- Stern Laboratories
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- Anniversaries

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Cover Illustration

The cover photograph shows Frank Stern looking at a corrosion loop, one of many facilities at Stern Laboratories. See article on p.3.

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ISSN 0714-7074

The *Bulletin of the Canadian Nuclear Society* is published four times a year by:
The Canadian Nuclear Society
144 Front Street West, Suite 475,
Toronto, Ontario, Canada, M5J 2L7.
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Fax (416) 979-8356

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

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

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Printed by The Vincent Press Ltd., Peterborough, ON

EDITORIAL

DIFFICULT TIMES

This is a personal view of the editor and should not be construed as representing the opinion of the CNS or any of its executive.

The past few months have been traumatic ones for the Canadian nuclear power program. With the presentation of the IIPA report by Ontario Hydro's new nuclear masters and the ensuing "overhaul" program, Canada has lost a third of its nuclear power capacity. The shock of the report and, especially, of the subsequent shutdowns has not yet subsided. This was particularly evident at the recent CANDU Maintenance Conference since many of the attendees had seen maintenance and refurbishing budgets cut repeatedly over the years with the inevitable decline in performance.

Perhaps, as some prominent members of Ontario Hydro have advocated, we should forget how we got to this sorry situation and get on with the job of re-structuring, re-organizing and re-building. However, as has been often stated, to ignore history is to invite repeating it.

Many of the factors that led to the current state of affairs were noted over the years but not acted upon. The lack of communication between the design and operations groups within Ontario Hydro nuclear, where even equipment numbers were different, was observed years ago. The inadequate documentation, especially of the older plants, was commented on by AECB staff and others, but little was done. Evidence that the constant cutting of maintenance and replacement budgets was affecting performance went unheeded by short-sighted senior management. The consequences of the drastic cuts in staff, especially of older, experienced, members who knew the plants despite the lack of documentation, and of the experiment in "de-centralization", were predicted by many.

Much has been said about "accountability". What about that of OH's senior management and Board? They are the ones that set budgets, they are the ones that cut experienced staff, they are the ones that de-centralized common services, and they are the ones supposedly responsible for the organization and its operation. Former chairman, Maurice Strong, who introduced the major staff cuts and oversaw the de-centralization, claims "no one told him". Four years later, when foreign consultants point out the consequences of those moves, the current chairman repeats the phrase. And the regulators, the AECB, wrote many letters but did little.

When the OH Board jumped to the drastic "overhaul" program immediately after receiving the IIPA report there is no evidence that they did any serious evaluation of the economic, social and environmental consequences. Despite the current "global warming" debate, the OH Board has in one stroke, significantly increased Ontario's CO_2 emissions by replacing nuclear with fossil-fuelled generation.

Fortunately there is a brighter side in the nuclear power picture - overseas. The continued good operation of overseas CANDU plants and, especially, the start-up this year of Wolsong 2, on time and on budget, shows that part of our industry is indeed competent.

As acknowledged by the US consultants, Ontario Hydro Nuclear's staff is highly qualified. If its members are properly organized, given the resources, and allowed to do their job, perhaps our domestic program can recover and regain the excellence of earlier times.

Fred Boyd

IN THIS ISSUE

We start off this issue with a very welcome **Viewpoint** from one of our "younger members which we believe you will find interesting regardless of your age.

The lead article concerns a small but important component of the Canadian nuclear program, **Stern Laboratories**, drawn from a visit to that Hamilton organization and much supplied material. At meeting after meeting there are papers based on tests and experimental work conducted at that facility. One of these accompanies the article on the lab, a paper first given at the CNS Annual Conference, which we have re-titled **Moderator Mixing After Pressure Tube Failure.**

Then we present the first of two reports on meetings held this fall, on the interesting **20th Nuclear Simulation Symposium** that was held in the small but historic town of Niagara-on-the-Lake. This is followed by **Selected Abstracts** from the symposium and a list of all of the papers presented.

The other meeting report is on the successful **5th International Conference on CANDU Fuel.** To augment this we have chosen one of the overview papers **Canadian Fuel Development Program in 1997/98** and part of Ron Page's luncheon talk on **Early Days of CANDU Fuel Development.** There is also a short note on the **4th International Conference on CANDU Maintenance** which took place just as this issue was "going to press", to be followed by a full report in the next issue.

Two historic events are noted in: **A Very Special 50th Anniversary**, remembering the start-up of NRX, and, **NRU Turns 40!**, commemorating NRU's 40 years of operation.

There are two items derived from the Atomic Energy Control Board; **AECB Comments on OHN Reviews and Plans,** and, **New Organization at AECB.**

There is, of course, news of the Society, including a **Note to All Members** (in both official languages) concerning the proposed incorporation of the CNS which should be considered by CNS members as a MUST read.

Some recent books and publications are noted and the event calendar is updated.

We thank contributors and authors who have allowed us to reprint their papers, and, as always, invite your reaction, comment, input, whatever.

The Next Generation

by Graham MacDonald

***Ed. Note:** As one of the "younger" members of the CNS, Graham MacDonald takes a look into the future from that viewpoint. Graham is on the staff of the Point Lepreau NGS. We invite opinions, viewpoints or other input from members of all ages.*

As the next generation gets its start in the Canadian nuclear industry, the author ponders what these new troops have to look forward to, what are some of the problems they face, and just what are they are getting themselves into?

A lively crowd came out for this Friday afternoon's bull session. A dozen or so new hires and junior staff, all early-thirties and under, had gathered at a local pub for cold beers and spirited conversation, which was predominantly focused on their work and the state of the industry. Facts, rumors and conjecture were traded back and forth, all of which ranged from reliable to wildly inaccurate.

The waitress had just returned with another round of drinks when the topic of conversation changed again. The folks around the table were taking turns describing their current jobs:

"I'm refining safety analysis uncertainties..."

"Our group is looking at component life extension..."

"We're developing QA specs for code validation..."

"Documenting preventative maintenance tasks..."

A very diverse spectrum of work, no doubt. But after a while, it all started sounding the same. . . a pattern was beginning to emerge. "Refine", "review", "document" and "maintain" were the catch-words of the day, but not words like "research", "design", "construct" and "operate". The whole thing got me thinking again about my generation and it's role in the Canadian nuclear industry, and asking questions that previous generations didn't have to think about.

The last of the pioneering veterans of the Canadian nuclear industry are gradually fading away into retirement, taking with them an enviable record of triumphs and accomplishments. These folks lived and worked in an era that is now the stuff of legend: the breaking of new ground, the thrill of new discovery, the bittersweet lessons of trial and error.

The bunch that followed had no time to ask questions; they were put to work right away in the design, construction, commissioning, operation and support of the expanding domestic nuclear power industry. The scope of the undertaking was Herculean, and there was no shortage of challenge, accomplishment and opportunity in the days of the great Canadian nuclear gold-rush. These are the people that, today, still make up the vast majority of the Canadian nuclear workforce.

Today, with the blood still wet on the floor from an industry-wide regime of cutbacks, buyouts and downsizing, and with the air still chilly from years of salary and hiring freezes, a new bunch of faces are slowly starting to show up in cubicles across the industry. With an avalanche of retirements set to hit in the next five to ten years, this blood transfusion is essential for the long-term survival of the industry. But, if you sit down and talk with a few of these Generation-Xers, you'll find a lot of them wondering about what kind of role they'll play in it's future.

You have to wonder about an industrial infrastructure that's in its autumn years. It's hard to keep focused on a 25-30 year career in the nuclear industry when most of the plants are probably going to punch the clock in 10-15. Nursing those reactors to their grave can't be a whole lot of fun. The nature of the work seems to be getting more nit-picky and trivial, depending more on the play of words than on real science or engineering.

The demographics of the industry certainly pose a problem. The industry is currently focused around an average employee who is between 40 and 50 years old, so our generation suffers from a lack of input into the decisions that affect our jobs and workplaces. With the huge population of experienced bodies ahead of us, we face the prospect of hat!, but we should enjoy the challenge of the complex issues and take pride in the fact that all that refining, reviewing, documenting and maintaining will contribute, one piece at a time, to the long term success of the industry.

This generation also brings with it a refreshing attitude. There is a hard edge behind a lot of those young faces: an opportunistic, challenging, even mercenary streak. Rather than resist change, it is sought out. Although we remain passionate about our industry, there is little stomach for the pontificating, politics and bureaucracy of yesteryear, and now there is a sarcastic chuckle for the propaganda that was once swallowed hook, line and sinker. There are no illusions about a job-for-life, but that's fine, because loyalty will not be given quickly or easily. We never had the option to wear rose-colored glasses, so fresh eyes will look for (and find) a lot of buried garbage. Reality often stinks, but it beats the alternative.

Change is in the wind. It's certainly not the first time the Canadian nuclear industry has undergone change and it surely won't be the last. This change will be embraced by some and feared by others, but either way, the new era that is dawning will have problems, solutions and an overall focus which will distinguish and define the efforts of a generation. The next generation is quietly taking shape, and it will be called upon to pick up the slack, and in some cases, to pick up the pieces.

Do we know what we're getting ourselves into? Not entirely. But if we did, that wouldn't be any fun.

Stern Laboratories

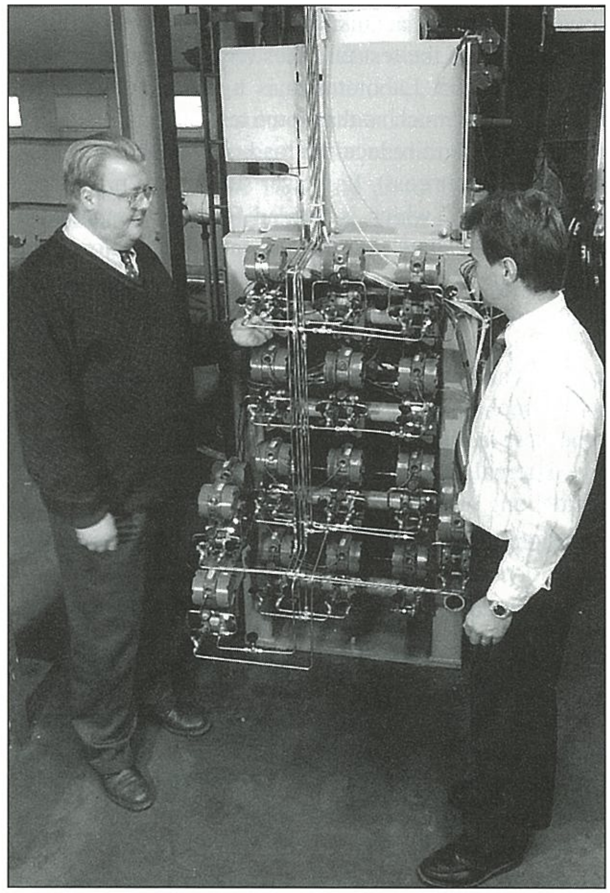
A private lab provides essential services for the nuclear industry

Ed. Note: *At various meetings, such as COG's Safety and Licensing Symposium and the recent CNS CANDU Fuel Conference there are papers on, and other references to, work conducted at the Stern Laboratories. Although well aware of this noted institution we recently asked if we could visit the lab and write about it for the CNS Bulletin. Stern chairman, Frank Stern graciously extended an invitation and personally gave us a "royal" tour of his laboratory Following is our is our report based on that visit.*

Tucked away in a corner of Hamilton's industrial south end is a small company that provides essential services to Canada's nuclear power program. Stern laboratories Inc. is Canada's largest private research and testing facility. Within its unpretentious buildings lie some of the most sophisticated testing equipment in the country and an experienced and expert staff

Although he would be the first to deny it, Stern Laboratories are very much the product of over three decades of effort by the man after which they are named, Frank Stern. Frank began his nuclear career with the Atomic Products Department of Canadian Westinghouse Company back in the mid 1950's, just a few years after immigrating from the U.K. He was attached to the Chalk River Nuclear Laboratories for three years where he worked with the early reactor development group, alongside people such as Charles Whittaker and Roy Sage.

Canadian Westinghouse decided to build a testing laboratory as a means of entering the Canadian nuclear program. (Its major competitor, Canadian General Electric Company, had, in the mid 1950's, obtained the design role for the first nuclear power plant, NPD.) When Frank came back from Chalk River in 1959 he took on the management of that small laboratory. He continued in that role until 1987 when the company decided to get out of the nuclear business in Canada.. It sold the laboratory along with its fuel manufacturing plant in Port Hope. The purchasers did not want the laboratory and offered to sell it to Frank. Although by then in his 60s Frank, together with many of his associates, accepted the challenge. Now the company is owned half by Frank Stern and the other half by the 32 members of the staff, many of whom have been with the laboratory for two decades. Frank is now chairman and CEO, looking after the long-term interests of the company, while Gordon Hadaller, as president, runs the day to day operation.



Stern Engineer Rick Fortman (R) shows the delta P transmitters at the base of the PWR fuel CHF test secion to visiting engineer Lars Nordstrom of ABB Atom,

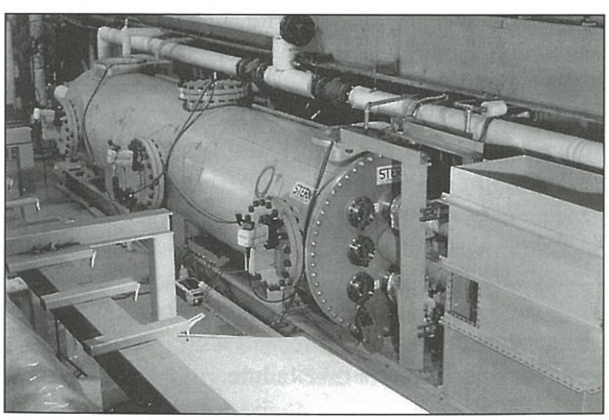
Over the years the company has grown to meet the needs of its many customers, of which CANDU Owners Group (COG) is the principal one. The Canadian nuclear utilities generally coordinate there work on generic issues, especially those involving safety and licensing, through COG. Much of the testing and research facilities are devoted to thermohydraulic problems, such as critical heat flux, flow distribution, moderator temperature, and to related issues such as pressure tube and calandria tube failure.

Stern Laboratories is recognized world-wide. It has conducted a number of tests on light water reactor (LWR) fuel, and is continuing to do so for US and Swedish customers. (On the day of our visit a representative from ABB Sweden had just arrived to participate in a number of tests on new Swedish fuel.)

The testing facilities can be grouped into three topical areas: reactor safety and reliability; high pressure steam/ water loop testing; and environmental testing and qualification. These are connected to and backed up by advanced data acquisition and analysis capabilities. Since many of the test facilities require a large amount of power, Stern Laboratories is a major consumer of electricity (so much so that some tests are conducted on the week-ends to reduce the load on the grid and minimize the power cost). Its power supply can provide up to 16 MW DC which is needed for high temperature, high power testing of simulated fuel. In addition Stern Laboratories is now recognized as a prime supplier of high reliability indirect electrical heaters. These are custom designed to meet the particular needs of the application. The lab has also built many directly heated simulated fuel assemblies for its own testing and for use in other test facilities. An associated product is an innovative internal thermocouple which can slide and rotate inside long tubes.

Among the capabilities in the area of **reactor safety and reliability** are:

- horizontal and vertical test loops for critical heat flux measurement
- a CANDU fuel channel for high pressure and temperature endurance testing with controlled acoustic pulsations
- a full scale header / feeder arrangement for emergency coolant distribution studies
- a pressure tube burst facility with nine full scale channels
- a 1/4 scale model to study moderator distribution in the calandria
- test loops for high flow, high pressure endurance testing of BWR and PWR fuel



The pressure tube burst facility.

- a high temperature and pressure corrosion test loop

In the area of **High pressure steam and water loop testing** the facilities include:

- a fossil-fueled boiler capable of 6.9 MPa and a 4 MW electrical boiler for up to 12 MPa.
- many pumps of 400, 350, 100 and 60 HP providing up to 1200 m head
- high pressure heat exchangers
- cooling towers
- ion exchange column
- gamma densitometers, laser Doppler anemometer, ultrasonic flowmeters.

Under the general heading of **environmental testing and qualification services** Stern Laboratories has qualified equipment for in-containment service, such as electric motors, instruments, cable spices, etc. the facility and procedures have been accepted by the U.S. Nuclear regulatory Commission as well as meeting CSA Z299.3 standards. The facilities include:

- a 6m long, 2.2 m diameter horizontal chamber
- a 5.5 m high, 2.2 m diameter horizontal chamber
- high pressure autoclave
- corrosion test loop

And the lab has access to irradiation test facilities at the McMaster reactor.

The core of the data acquisition and analysis system is a DEC VAX 4000-100 computer, clustered with two VAX station 3100 computers running under VMS. The system currently has 560 A/D channels, expandable to 1000, with signal conditioning for thermocouples, RTDs, pressure transmitters, etc. Data is stored on several devices including fixed disk drives, optical disk drives, tape and several CD-ROMS. Specialized software has been developed for on-line data acquisition and process control, post-test analysis, graphical output and communication

Although much of the work of the laboratory is reported privately to the customers, there have been many papers presented at various symposia. One such is reprinted in this issue of the *CNS Bulletin.*

The expertise of the Laboratory personnel is evident in the many innovative techniques they have developed for conducting difficult testing, such as making detailed measurements inside fuel bundles (real or simulated). Their dedication is evident is the many years most have been associated with the laboratory and in their willingness to work odd hours when needed to conduct tests.

In this writer's view, Stern Laboratories is an essential component of the Canadian nuclear program.

Moderator Mixing After a Pressure Tube Failure*

by J.C. Mackinnon[1], R.A. Fortman[2] and G.I. Hadaller[2]

Ed. Note: *The following paper was originally presented at the CNS Annual Conference in June 1997. The work described is representative of that conducted at Stern Laboratories which is the subject of a separate article in this issue of the CNS Bulletin. We thank the authors and Ontario Hydro management for their permission to reprint this paper.*

1. INTRODUCTION

During a guaranteed shutdown state (GSS) in a CANDU reactor, there must be sufficient negative reactivity to ensure subcriticality in the event of a process failure. In one of the acceptable states, the reactor is kept subcritical by a high concentration of a neutron-absorbing chemical (the poison gadolinium nitrate) dissolved in the moderator (*i.e.,* the moderator is guaranteed overpoisoned). A postulated accident scenario which is considered as a part of reactor safety analysis is the rupture of a fuel channel (*i.e.,* a pressure tube/calandria tube break) when the reactor is in a GSS. If one of the channels in the core breaks (requiring a simultaneous failure of both the pressure tube and the surrounding calandria tube), coolant from the primary heat transport system will be discharged into the moderator, causing an associated displacement of fluid through relief ducts at the top of the calandria vessel. The incoming (unpoisoned) coolant may mix quickly with the moderator, or may mix slowly while displacing poisoned moderator through the relief ducts. The effectiveness of mixing generally depends on the break location, the coolant discharge rate and the moderator circulation. If an in-core loss of coolant accident occurred while the reactor is in this overpoisoned state, it must be guaranteed that even with the dilution of the poison by the incoming coolant the reactor will remain subcritical on both a local and global basis.

This paper presents an overview of an experimental program in progress at the Moderator Test Facility at Stern Laboratories to investigate coolant/poison mixing for a simulated in-core fishmouth pressure tube/calandria tube rupture. The nominal system conditions investigated are of a reactor in a GSS, with coolant in the primary heat transport system at the same temperature as the heavily poisoned moderator, i.e., a depressurised 'cold' state. The results presented are those obtained during the commissioning of the modified Test Facility.

The contents of the paper are as follows. First, the objectives of the experimental program are summarized, and a description of the facility is given, with a discussion of the loop modifications required to perform the mixing study. Then a description of the conditions studied during commissioning in the Moderator Test Facility is given. Results obtained during the commissioning, both flow visualization and measurements, are presented. Lastly, an overview of the tests to be performed during the remainder of the program is given.

2. OBJECTIVES OF EXPERIMENTAL INVESTIGATION

It is of interest to understand the nature of poison/coolant mixing which results when a discharge of unpoisoned fluid from a single ruptured channel enters a calandria geometry containing fluid of a different concentration. Aspects of interest are the factors which affect the evolution of the flow and concentration fields, the concentration variation throughout the vessel and poison displacement. The Moderator Test Facility is appropriate to simulate the mixing resulting from a fishmouth type rupture, due to its ability to provide the qualitative and quantitative information required for the geometry and conditions of interest.

The following are the primary objectives of the program:

- *Gain an understanding through flow visualization of the roles of the calandria tubes, moderator inlet jets and the overall circulation pattern on the mixing of incoming fluid from a fishmouth break with that of the original fluid in the vessel.* The resistance to flow caused by the calandria tubes relative to that in the unobstructed reflector region may result in preferential flow outside the core. The effect of the inlet jets may be expected to vary according to the relative

*Original title: Experimental Investigation of Coolant and Poisoned Moderator Mixing Due to a Simulated Pressure Tube / Calandria Tube Fishmouth Rupture During an Overpoisoned Guaranteed Shutdown State

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strength of the discharge, and the fuel channel location at which the break occurs. The overall circulation pattern is key in determining the long term dispersion characteristics.

- *Identify the effect of fuel channel location and the direction of the break discharge on the displacement of the original fluid in the vessel.* Breaks at the edge of the core, for example, directed towards the vessel wall may result in different flow fields than those occurring in the centre of the core.
- *Determine concentration throughout the vessel and at the top outlet at the simulated relief duct to assist in understanding the flow.* Measurements of fluid conductivity at the top outlet provide information on poison displacement and the amount of poison remaining in the vessel. The measurements throughout the vessel supplement the qualitative information gained through flow visualization.
- *Obtain experimental data to assist in validating computational tools which may be used to simulate system characteristics.*

The investigation is performed in three stages. First, loop modifications were made to allow the conditions of interest to be simulated. These modifications were then assessed during a commissioning period, in which a break at only one channel location was investigated. The results obtained from this first stage are presented here. In the second stage, custom conductivity probes were designed, constructed and tested to allow for good coverage of the concentration field in the vessel. The program is now entering the third stage, in which breaks over a range of discharge rates at a number of fuel channel locations are being investigated.

3. EXPERIMENTAL FACILITY

3.1 Summary of existing features

The experimental facility, located at Stern Laboratories Inc., has been used for approximately ten years to enhance the understanding of flow phenomena occurring in the moderator fluid in the calandria of a CANDU reactor (1). In addition, it has provided experimental data to aid in the development and validation of thermalhydraulics codes (e.g., MODTURC_CLAS (2)) that calculate the velocity and temperature fields in this type of flow. Examples of experimental investigations completed at the Moderator Test Facility include: steady state and transient moderator temperature distribution tests for a wide range of conditions involving different ratios of inlet momentum to buoyancy forces; experiments to determine the pressure loss for flow through the calandria tube tank; and scaled moderator inlet nozzle flow distribution tests.

The test facility is a one quarter scale (2 m diameter) which reproduces the important characteristics of moderator circulation and heat transfer in a slice (0.2 m thickness) of the calandria vessel. Relevant conditions are derived through non-dimensionalization of the governing equations, and identifying and maintaining equivalence of key dimensionless quantities between the full scale calandria and the test facility. The test section walls have been fabricated from clear polycarbonate sheets to allow flow visualization and Laser Doppler Anemometry. Flow visualization is provided by injecting an acid or base into the circulation loop, which already contains a dissolved pH indicator. Four hundred and forty 1/4 scale electrical tube heaters (mounted in a square array with a lattice pitch of 71.4 mm) provide heating to the fluid if required. The heaters are designed so that all power connections can be made from one side to leave the other side free for instrumentation and flow visualization. A circulating pump, heat exchanger and connecting pipe provide coolant circulation and heat removal. The working fluid is light water. The loop circulating pump can provide inlet flow rates up to 4 kg/s, distributed between the inlet ports which span the full thickness of the test section and are mounted on the side walls. The outlet port at the bottom of the test section covers the full thickness of the test section and is 16 mm wide. A schematic of the facility is given in Figure 1.

3.2 Loop Modifications

The present mixing investigation is a new application of the facility. A number of significant modifications to the loop were required for the present work. Firstly, a high pressure line was added to inject water (representing the coolant discharge) at a preset rate through a simulated calandria tube break. The injection line is instrumented with a thermocouple for temperature measurement and an orifice for flow measurement. An eductor is also provided in the injection line to allow for the addition of an acidic solution required for flow visualization. A second modification was the construction of a simulated fishmouth break tube from which the coolant discharges (replacing the original heater tube at the fuel channel location at which the break occurs). This tube is connected to the high pressure line at one end. A slot spanning the length of the vessel is milled through the wall of the tube. The tube has a flexible inlet connection (to allow rotation), and provides a discharge at any angle without draining the test section.

The simulated relief duct is located at the top of the test rig. It consists of a rectangular perforated plate section, 286 mm wide by 200 mm depth, with a pyramidal shaped channel fastened to it. The channel converges to a 2 inch diameter pipe which discharges to a catch tank. A conductivity probe is installed in the converging channel/pipe to monitor the conductivity of the discharged coolant.

During the initial commissioning, conductivity was

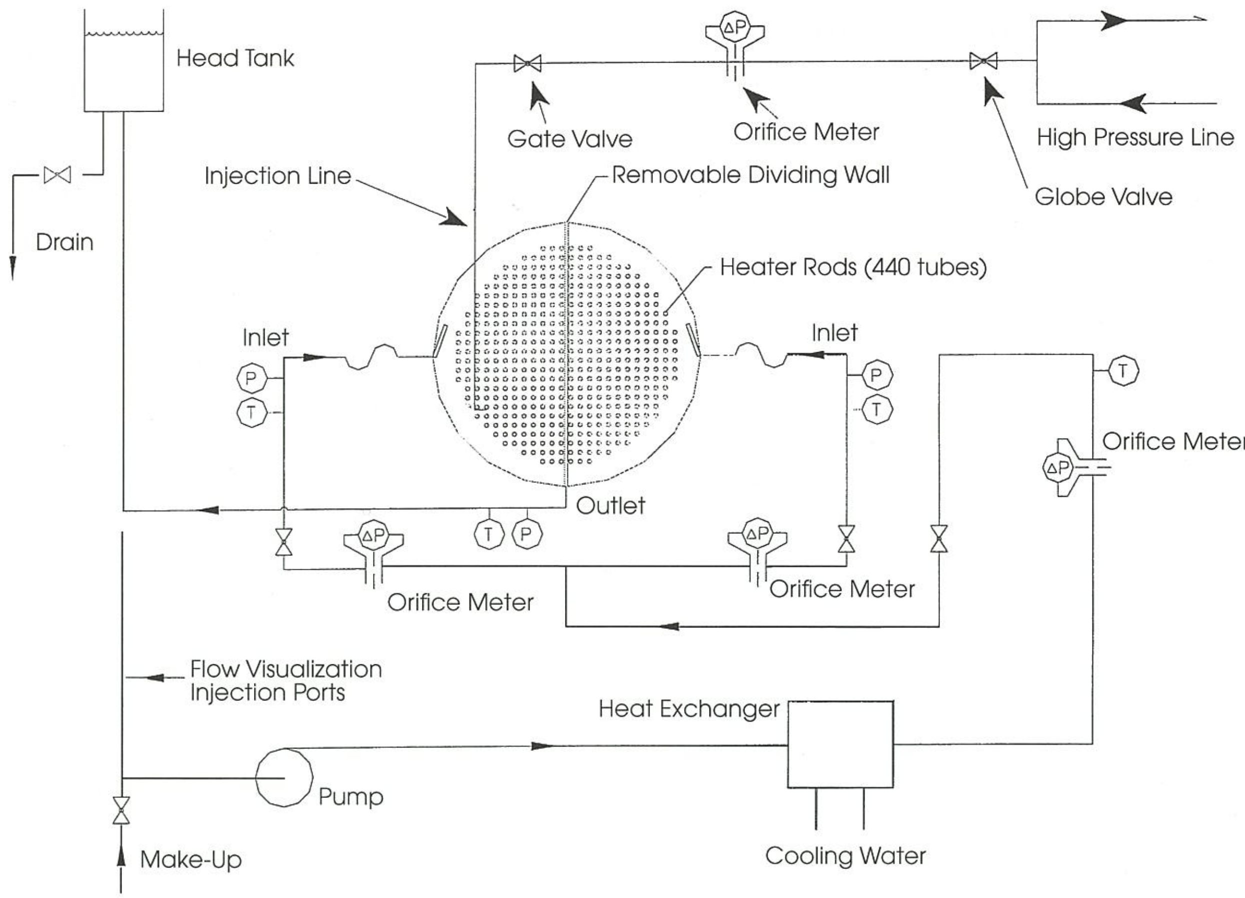


Figure 1: Schematic of test loop

measured only at the relief duct. Subsequently, custom conductivity probes were constructed to allow for measurement throughout the vessel. These probes may be placed at any of 54 locations throughout the core and reflector regions (at the original 40 thermocouple locations and 14 new locations). Additional probe locations include a point upstream of the discharging inlet (providing inlet concentrations), and downstream of the bottom outlet (in the piping immediately below the vessel, to provide outlet concentrations).

4. TEST CONDITIONS

Details of the original design and scaling of this experimental facility are given in Reference (3). That work describes the derivation of the nominal operating conditions at the facility representative of full power operation of a typical CANDU reactor. In that document, a detailed similarity analysis of the governing mass, momentum and energy conservation equations was performed which specified the dimensions and operating conditions of the test facility so as to achieve (as closely as possible) thermalhydraulic similarity in the flow pattern and temperature field within a typical CANDU calandria. Due to the significantly different conditions between full power and GSS operation and associated governing phenomena determining the flow field in the vessel, the nominal operating conditions relevant to the present GSS analysis will be different from those derived in Reference (3). In this section, the Moderator Test Facility conditions used to simulate the cold GSS scenario will be presented.

4.1 Nominal system conditions for cold GSS

For the GSS conditions of interest in a typical CANDU reactor calandria vessel, moderator fluid is drawn from the calandria outlets by an auxiliary moderator pump (reducing the flow by an order of magnitude from that under normal operation). Because the moderator and primary heat transport fluids are at 30°C, no thermal phenomena are involved and the temperature remains constant in both the pre- and post-break stages. Experimental conditions for the Moderator Test Facility are chosen by seeking fluid dynamic similarity with the operating parameters of a typical CANDU calandria vessel. If the fluid is to behave in a dynamically similar fashion in the prototype (the CANDU vessel) and the model (the Moderator Test Facility), then the governing conservation equations, boundary conditions and geometry in both systems should be equivalent. The conventional manner to derive the parameters which provide this similarity is to recast the conservation equations and boundary conditions into non- dimensional form. By introducing reference system parameters and appropriate non-dimensional variables into the equations and boundary conditions, the dimensionless coefficients which result completely determine the quantities which must be the same to ensure similarity.

The governing equations describing the prebreak flow are conservation of mass and momentum. Non-dimensionalizing the equations, the dimensionless group which describes the system is the vessel Reynolds number, based on the inlet nozzle velocity and vessel diameter. The Reynolds number for flow in the reactor calandria is 2.1x106, corresponding to an average inlet velocity of approximately 0.24 m/s. The Moderator Test Facility nozzle inlet velocity calculated by equating the Reynolds numbers for the two vessels is 0.84 m/s, corresponding to a total inlet mass flowrate of 2 kg/s. It should be noted that one constraint imposed in deriving the nominal model GSS conditions is that the present Moderator Test Facility geometry (*e.g.,* inlet slot jet width and flow area) will not change.

4.2 Calculation of Fishmouth Break Characteristics

In order to completely specify the problem, the following information must be specified: the geometry of the break (length and opening width) and its location relative to it surroundings, the inlet mass flow rate of the discharge, and the concentration.

4.2.1 CANDU Characteristics

First, the geometry of the break will be considered. For the present experimental design, a rupture length of 2.5 m (consistent with rupture lengths considered in previous analyses (4)) is chosen. The rupture is assumed to be diamond-shaped, with the greatest opening occurring at the centre. The rupture is assumed to be fully open upon the initiation of the transient. Lastly, the total cross-sectional flow area is taken to be equal to twice the available flow area in the fuel channel (based on the flow area for a 37 element bundle associated with fluid in the fuel channel approaching the rupture from either side). The maximum opening is 0.0055 m, corresponding to a circumferential opening of approximately 5°. Rupture characteristics in the CANDU vessel over the central 0.8 m must be derived in order to calculate similar conditions over the 0.2 m wide Moderator Test Facility. The flow area over the central 0.8 m is approximated as a uniform crack height of 0.0046 m, which corresponds to an opening angle of 4°.

The rupture flow conditions required to obtain similarity between the CANDU scenario and that for the Moderator Test Facility are obtained by requiring the non-dimensionalized velocity boundary conditions to be equal. At the inlet nozzles the dimensionless velocity U* equals 1, obtained by dividing the inlet velocity U_i by a reference velocity $U_{ref} = U_i$. The dimensionless velocity condition over the rupture, U*, may then be calculated for a given discharge flow rate.

From non-dimensionalization of the concentration equation, similarity is maintained if: i) the Schmidt numbers (ratio of momentum to mass diffusivities) are equivalent; and ii) the non-dimensional concentration boundary conditions are equivalent at the inlet nozzle and the location of the break.

4.2.2 Moderator Test Facility Characteristics

Due to the existing geometrical characteristics of the rig, two degrees of freedom remain to specify the rupture geometry and flow conditions: the size of the rupture and the discharge flowrate. These are derived by applying similarity for the geometry and velocity boundary conditions respectively. This geometrical similarity is desired in order for the surrounding tubes to have an equivalent impact on the development characteristics of the jet issuing from the rupture, *i.e.,* the size of the opening relative to the tube pitch must be equivalent for both. Because the design of the Moderator Test Facility is to 1/4 scale, the appropriate opening should be (0.25x0.0046 m) = 0.00115 m. Maintaining this geometrical similarity also results in an equivalent opening angle.

By ensuring equivalent dimensionless velocity boundary conditions, the relationship between the discharge flowrate in the two facilities is derived. For the conditions used in commissioning, the 1.7 kg/s discharge rate corresponds to approximately 17 kg/s in the calandria. The equivalence of concentration boundary conditions at the inlet nozzles will only strictly be valid at the initiation of the break, for beyond this time the inlet concentration differs somewhat with time as a result of the relative difference in the transit times of the vessel fluid leaving the bottom outlet of the vessels and re-entering the vessel at the inlet nozzles.

4.2.3 Commissioning Test Conditions

Commissioning of the rig was performed by focusing on a break at one fuel channel location (the U5 channel, located at the bottom outer edge of the core) and three different discharge directions (6, 9, and 12 o'clock). These conditions were chosen for a number of reasons, with a major consideration being the investigation of the relative flow resistance for fluid in the reflector versus the core region. The focus was on flow visualization and monitoring the concentration of fluid leaving the vessel at the top outlet. For the nominal conditions investigated, the flowrate through each of the two inlet nozzles on the sides of the vessel was 1 kg/s for a total of 2 kg/s. The break discharge rate was 1.7 kg/s.

5. COMMISSIONING RESULTS

5.1 Procedure

The simulated break tube was placed at the U5 channel location. For each of the three discharge directions investigated, two types of tests were performed:

- Flow visualization tests (denoted FV) in which a high concentration HCl solution (exact concentration unknown) was injected into a basic solution in which the indicator bromothymol blue was dissolved. The initial solution in the tank was blue (pH greater than 7.6); colour change to yellow occurs at a pH of approximately 6.0.
- Transient outlet conductivity measurement tests (denoted TRC) in which de-ionized water (conductivity approximately 1 μmho/cm) is injected into fluid of conductivity of approximately 100 μmho/cm.

Prior to any discharge experiments, a FV test was conducted to qualify the pre-test conditions. In all tests, flowrates (discharge, inlet nozzles), temperatures (discharge, circulating loop) and conductivity (at the top relief duct) were measured at a frequency of 10 Hz. The flow visualization tests were videotaped and photographed with a 35 mm camera (every five seconds). After approximately five minutes for the TRC tests or when the total colour change has occurred for the FV tests, the discharge was stopped and data acquisition was terminated.

5.2 Results

Results from the flow visualization tests are discussed first. For these tests, it is estimated that the duration of the acid injection is approximately 15 seconds. This quantity of acid injected is sufficient to cause a complete colour change. In interpretation of the flow visualization results, care must be taken in inferring concentration levels at the interface of the colour change. Fluid of colour yellow does not necessarily denote a very low concentration; relative to the high injected acid concentration, the differences in concentration corresponding to the pH values at which the colour changes (of 6.0 and 7.6) may be negligible.

Although not shown, the pre-test visualization (*i.e.,* without discharge) shows a symmetric flow pattern where the inlet nozzle jets merge at the top of the test section and the combined jet is re-directed downward. Photographs taken with approximate elapsed time, from start of injection, are shown in Figures 2 and 3 for discharges in the 6 and 12 o'clock directions. The flow patterns for all injection tests are asymmetric. For the 6 o'clock discharge (Figure 2) the jet travels counter clockwise, primarily around the periphery of the test section (*i.e,* in the reflector region), and merges with the right hand side inlet nozzle jet. Due to the greater strength of the combined injection/nozzle jet relative to that issuing from the left hand side nozzle jet, the jet stagnation point moves to approximately the 10:30 position (from the 12 o'clock position under no injection conditions). This scenario clearly shows the preferential flow through the reflector region.

For the 12 o'clock discharge case (Figure 3), the injection jet merges with the left hand side inlet nozzle jet to form a clockwise dominant flow pattern. As observed for the 6 o'clock case, the jet stagnation point also shifts from the 12 o'clock position. Relative to the other discharges, there is a greater amount of fluid discharged towards the core during the initial part of the transient.

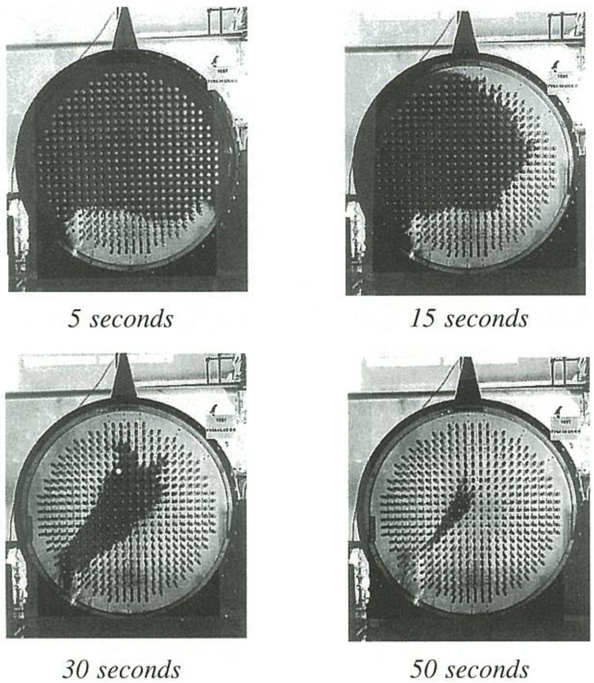


Figure 2: Flow visualization results for discharge in 6 o'clock direction.

5.3 Analysis

In order to quantify the transient mixing characteristics, the vessel-average concentration throughout the experiment may be derived from the measured outlet conductivity at the relief duct and the total volume of the test section (loop piping, vessel and relief duct nozzle to the probe location). The derived average concentration may then be compared to that calculated by assuming uniform mixing in the vessel. This analysis was performed for all TRC tests.

continued next page

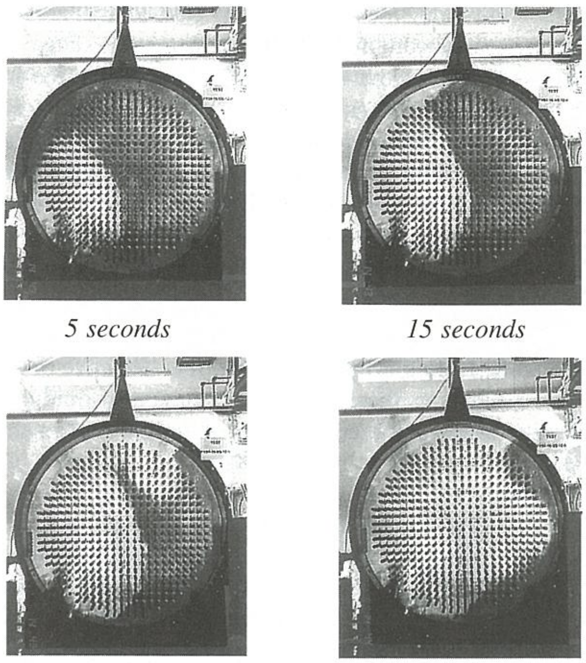


Figure 3: Flow visualization results for discharge in 12 o'clock direction.

5.3.1 Derivation of vessel-average concentration from measured conductivity

The interest is in the ratio of the average concentration in the vessel at any time to the initial concentration, defined as the average concentration ratio and denoted as $N_a(t)$. This quantity may be obtained by considering the molarity of the solute, and a mass balance on the system:

$$N_a(t) = \frac{N_o V + Q_i \int_0^T (N_{inj} - N_{out}) dt}{N_o V} \qquad (1)$$

where N_o is the initial vessel-average concentration, V is the total volume, Q_i is the volumetric break injection flowrate, N_{inj} is the concentration of the injected solution, and N_{out} is the concentration of fluid displaced through the relief duct. The total volume used in the calculation is that in the test section, the piping associated with the pump (between the bottom outlet and the inlet nozzles on the side of the vessel), and the portion of the simulated relief duct below the conductivity probe location). With the conductivity, K, proportional to the concentration, N, the vessel-average concentration ratio may be expressed as:

$$N_a(t) = \frac{K_o V + Q_i \int_0^T (K_{inj} - K_{out}) dt}{K_o V} \qquad (2)$$

where K_o is the initial test section conductivity, K_{inj} is the conductivity of the injected solution (1μmho/cm), and K_{out} is measured conductivity of the solution displaced through the relief duct. Equation (2) may therefore be used to determine the average concentration ratio of the test section.

5.3.2 Calculation of average concentration for a uniformly mixed solution

A uniformly mixed solution is one in which all fluid in the vessel is at a uniform concentration, and equal to the concentration of the fluid displaced through the top outlet. The concentration ratio for a uniform mixture, denoted as $N_{a,T}$, is derived from equation (2):

$$N_{a,T} = e^{-\frac{Q}{V}t} + \frac{K_{inj}}{K_o}(1 - e^{-\frac{Q}{V}t}) \qquad (3)$$

5.3.3 Evaluation of mixing

For each of the TRC tests performed, the calculated vessel-average concentration (equation (2)) was compared to that which results from uniform mixing (equation (3)). A typical result is shown in Figure 4 for the discharge in the 9 o'clock direction. The three curves shown are the derived vessel-average concentration evaluated using equation (2) (denoted as Average in the figure), that would result form uniform mixing evaluated using equation (3) (denoted as Theoretical), and the ratio of the measured relief duct outlet to the initial concentration (denoted as Outlet). A value of time equalling zero seconds corresponds to the time at which the injection valve was opened.

Over the initial period of approximately 10 seconds, the displaced fluid concentration is close to the initial value. Subsequently, it drops below that resulting from uniform mixing until approximately 50 seconds. After this time, it is clearly shown that the Average and Theoretical curves are very similar, a result observed for all three discharge directions. This comparison indicates that the average mixture concentration in the test section is very well described by a uniform mixing model.

6. CONTINUATION OF EXPERIMENTAL PROGRAM

The commissioning results with the modified loop have demonstrated the viability of the design. Subsequently, custom conductivity probes have been constructed and tested. These probes will allow for determining the concentration field throughout the vessel.

In the next phase of the experimental program, the

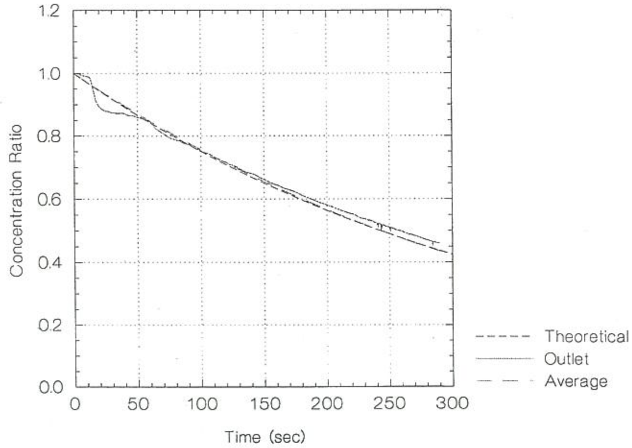


Figure 4: Concentration ratios for discharge in 9 o'clock direction.

following aspects will be considered:

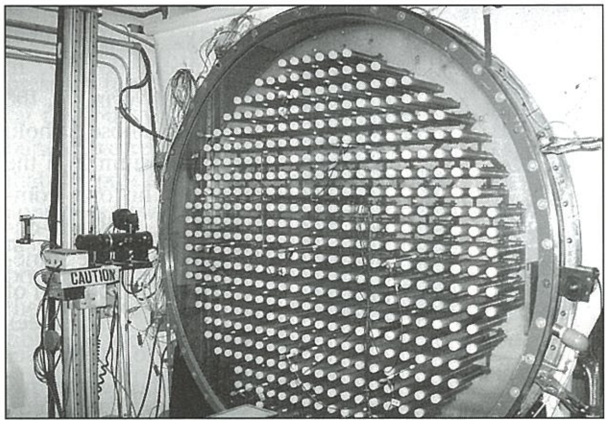
- investigate breaks at a number of channel locations and discharge directions (including repeating the U5 tests),
- introduce a range of discharge flowrates, between approximately 0.2 and 3 kg/s,
- perform experiments with and without forced circulation, to understand the effect of the inlet jets on poison displacement,
- perform velocity measurements using Laser Doppler Anemometry for certain experiments to better understand the development of the discharging jets, and
- measure conductivity (and hence derive concentration) at approximately 15 locations throughout the vessel.

Consideration will also be given to a limited number of tests in which the discharge is a flashing jet.

The end product from the program will be a data base (concentration and velocity measurements) and flow visualization records to provide an understanding of mixing characteristics for use in the validation of tools used in the analysis of coolant/poison mixing.

7. CLOSURE

This paper has presented an overview of the experimental program in progress at the Moderator Test Facility to better understand simulated coolant/poison mixing due to a pressure tube/calandria tube fishmouth rupture during an overpoisoned guaranteed shutdown state. A number of modifications to the facility were required to perform the experiments, primarily associated with introducing a discharge of fluid from an arbitrary fuel channel location in the vessel. Conditions of interest were derived through maintaining equivalence of relevant dimensionless groups, boundary conditions and geometry. Commissioning of the loop modifications proved the viability of the design. Flow visualization indicated the impact of different resistance to flow in the reflector versus the core region. Analysis of conductivity measurements at the top of the vessel demonstrated that for the conditions investigated the vessel-average concentration was well described as being uniformly mixed. The next phase of the program includes testing for a wide range of fuel channel break locations and discharge rates, and conductivity measurements throughout the vessel .



A view of the facility to study mixing in the moderator.

ACKNOWLEDGEMENTS

The work is funded by Ontario Hydro, Hydro Quebec and New Brunswick Power via CANDU Owners Group Working Party 23. The contributions of G. Balog, M. O'Neill, F. Dermarkar and J. Szymanski of Ontario Hydro via many useful discussions are acknowledged.

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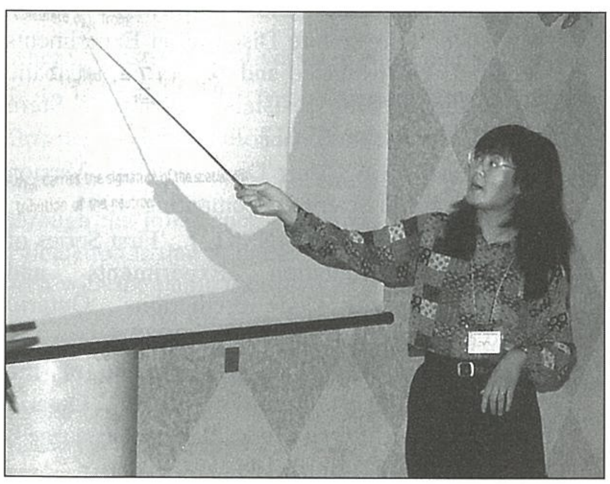
20th Nuclear Simulation Symposium

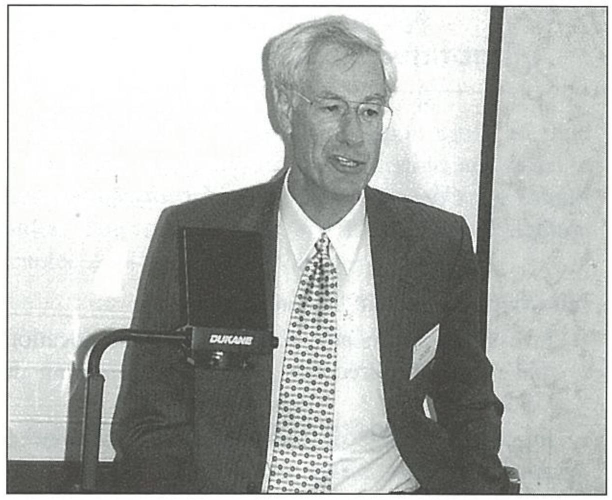
Glenn Harvel

The Twentieth Annual Nuclear Simulation Symposium of the Canadian Nuclear Society was held September 7-9, 1997. In an innovative move, the organizers chose to hold the Symposium in a the small but historic community of Niagara-on-the Lake With the somewhat isolated location of the hotel, attendees remained together over the two day gathering, enhancing the important person-to-person contacts and discussions. The organizers also chose an "all inclusive" formula with the attendance fee including hotel, meals and, as for a bit of culture and diversion, an evening at the Shaw Festival and a trip to see Niagara Falls at night.

The approximately 60 people attending the Symposium included participants from Japan, the Netherlands and Russia, and a luncheon speaker from the USA. as well as those from the Canadian nuclear industry and universities.



Dr. Hong Chen, from AECL-CRL, gives the first paper at the CNS Nuclear Simulation Symposium in Niagara-on-the-Lake, September 1997.



Dr. Albert Reynolds, of the University of Virginia and author of the book "Bluebells and Nuclear Energy", gives the invited talk at the lunch banquet during the 20th Nuclear Simulation Symposium, September 1997.

Papers covered many aspects of nuclear reactor modeling and simulation. The Symposium had eight sessions covering three topical categories: thermalhydraulics, reactor physics, and safety analysis, in which 38 technical papers were presented.. (Selected abstracts are included elsewhere in this issue of the CNS Bulletin.). Most papers inspired active discussion among the participants.

At the "banquet" lunch on the first day, Professor Albert Reynolds, University of Virginia, gave an invited talk on 'teaching the teachers' on nuclear matters. That university has been running a one-week, summer, introductory course on nuclear science and technology for high school teachers, for several years. It is being used as a model for a similar course sponsored by the Canadian Nuclear Society to be presented at McMaster University in June 1998.

Glenn Harvel was the principal organizer, supported by Krish Krishnan and Peter White. The event was co-sponsored by Atomic Energy of Canada Limited and the CANDU Owners Group.

<u>20th Nuclear Simulation Symposium</u>
Selected Abstracts

__Ed. Note:__ At the 20th CNS Nuclear Simulation Symposium in September 1997 there eight sessions dealing with three broad topical areas: physics; thermalhydraulics; and (reactor) safety. To give readers some flavour of the nature and scope of the highly technical papers presented, following are six abstracts, selected rather arbitrarily from the three categories. A set of Proceedings of the Symposium, with copies of the full papers presented, is available from the CNS office.

PHYSICS

Photoneutron Source Strength Studies in Pickering Reactors

Mark W. Hersey, Ka Fai So
Charles G. Olive, Fred C. Shanes

Reactor power measurements and reactivity change measurements taken during the execution of approach to critical procedures following long outages (> 100 days) on Pickering reactors revealed the presence of a neutron source of greater strength than predicted by the 15 group delayed and photoneutron precursor model. The apparent additional neutron source has been characterized by modelling it as a sixteenth group in the Ontario Hydro code SPARK (Simulation of Photoneutrons and Reactor Kinetics). Data are available from three Pickering-A outages and two Pickering-B outages. The duration of each Pickering-A outage was greater than 250 days. The Pickering-B outages were of 117 days and 154 days duration. Two interpretations of the available data are possible: (i) after about 150 days, neutron source power is relatively constant, or; (ii) owing to differences in reactor structural materials, the source power is quite different on PNGS-A from PNGS-B. Characterization of the source for the stations is of practical benefit because it allows engineering staff to predict when to expect significant milestones in the approach to critical procedure. Examples of such milestones are: (i) the core reactivity at which regulating system ion chamber signals come on scale, and (ii) the critical power level.

Effect of Pressure-Tube Creep on the Void Effect of a CANDU Fuel Bundle

M.S. Milgram, AECL Chalk River

The results of a study of the effect of an increase in pressure tube diameter due to radiation induced creep on the total void effect of a CANDU 37-element fuel bundle are reported here. The calculation presupposes that the pressure tube diameter increases by ~6%, and considers how the laKice reactivity and nuclide components of reactivity change between the two extremes in both voided and cooled conditions. MCNP4A is used as the basis for predictions. Fresh fuel nuclide compositions are used throughout.

For the model considered, MCNP4A predicts that the void effect increases by about 3 mk, due to a decrease in laKice reactivity for the case of the cooled channel as the pressure tube diameter increases by 6% and the flux distribution varies. This is due to the fact that the yield rate from U235 decreases because the fuel is in a lower flux region. No significant reactivity differences are predicted to occur for the voided channel in the presence of diametral creep. An experimental test of the predictions is proposed.

THERMALHYDRAULICS

Darlington NGS A: SGECS Condensation Induced Waterhammer Analysis and SGECS Hot Commissioning Test

C.W. So, P. L. Chang and D.G. Meranda
Darlington NGS

In the event of an accident such as the main steam line break the Reheater Drain pump and the Feedwater pump could fail. As a result, feedwater to the steam generators (SG-l and SG-3) will stop, and the inventory in the SGs flash. This would cause depressurization of the SGs and formation of steam void in the piping of the Stearn Generator Emergency Cooling System (SGECS). The subsequent low SG pressure will initiate

the SGECS injection into the SGs. Upon the injection of the cold SGECS fluid to the stearn filled SGECS piping, condensation would take place, and condensation induced waterhammer in the SGECS may occur. As an interim measure to protect the SGECS piping, the Second Stage Reheater Drain flow to the SGs was suspended. This resulted in a 3% loss of power, a significant economic penalty to the heat cycle of the turbine.

To remove the economic penalty, the original design of the SGECS was revised. To ensure the adequacy of the revised design, condensation induced waterhammer analysis were performed for 6 design basis events. The predicted pressure transients were submitted for stress analysis and have passed the allowable level of stress limits.

The analysis was presented to the AECB. Although the AECB has accepted the analytical results, the A~CB requested a 'hot' commissioning test at site to demonstrate that the revised design does meet the operation requirement.

The test was successfully performed. Subsequently, the AECB has allowed OH to re-instate the Second Stage Reheater Drain flow to the SGs.

Transient Melting and Re-Solidification of Candu Core Debris in Severe Accidents

J.T.Rogers and M.Lamari
Carleton University

This paper describes a computer program simulating the transient behavior of CANDU core debris in the calandria following a severe accident. The program, DEBRIS.MLT, simulates debris heat-u p from a quenched state to the melting point, melting of the debris, superheating of the molten debris above the melting temperature and its eventual cooling and re-solidification and the cooling of the solidified material. While the details of the debris melting process are unknown, the simplified models used in DEBRIS.MLT for the geometric changes occurring in this process provide the appropriate initial and final states for the debris. Simplified but physically reasonable heat transfer models are used in the program.

Results obtained by applying the model to a dominant-frequency late core disassembly accident sequence in a CANDU-6 show that the calandria would remain well-cooled throughout the entire transient as long as sufficient water is present in the shield-tank. This conclusion is insensitive to wide variations in the initial porosity and pore-size of the debris and to variations of the thermal properties of the molten material. Failure of the calandria resulting from the boil-off of the shield-tank water would not occur until more than 24 hours after the initiation of the accident, allowing time for operator intervention to mitigate the effects of the accident. Thus, the analysis strengthens the conclusion of earlier studies that the calandria vessel in a CANDU acts as an inherent core-catcher in a severe accident involving late core disassembly and debris melting.

SAFETY

An Analysis of Effect of Correlation of Response in the System Reliability Analysis in a Seismic PSA of a Nuclear Power Plant

Yuichi Watanabe, Tetsukuni Oikawa and Ken Muramatsu

In seismic probabilistic safety assessments of nuclear power plants, it has been recognized important to consider the effect of correlation among responses and/or capacities of componentS The authors developed a new method to calculate a failure probability of a system considering the effect of correlation of component failures by a direct Fault Tree quantification using the Monte Carlo method. By this method, the failure probability of a system can be calculated with the effect of arbitrary correlation not only on the occurrence probabilities of intersections of component failures but also on the occurrence probability of a union of component failures, which has been ignored by the calculation method developed in the phase-1 of the Seismic Safety Margins Research Program in the U.S.A. The usefulness of this method was demonstrated by the calculation of the failure probability of a Residual Heat Removal (RHR) system in a Boiling Water Reactor. This result showed that the correlation of response significantly lowered the occurrence probability of the union of component failures and influenced the calculated failure probability of the RHR system, indicating that the neglect of effect of correlation on the union of component failures might cause an excessive overestimation of failure probability of a system.

Optimization of the Operating Envelope and Safety Margins Using PRA Methods

Cristian Stoica, Cernavoda Nuclear Power Plant
C. Keith Scott, Atlantic Nuclear Services Ltd.

A major challenge in the operation of a nuclear power plant is the maintenance of an acceptable level of risk when equipment performance degrades through component failure or system ageing. The special safety systems play a particularly significant role in this regard. They are routinely tested to demonstrate compliance with availability requirements. The minimum allowable performance capability of systems is derived from safety analysis and other simulations of system performance and response to abnormal events. Overall station performance and risk management can be improved by linking the analyzed operating envelope with the operational performance of systems. The purpose of this paper is to report on investigations of the use of PRA methodology to optimize the operating envelope and safety margins using "live" plant data.

20th Nuclear Simulation Symposium
List of Papers

REACTOR PHYSICS

1. H Chen and P. J Laughton, "The Method of Subgroups in the Calculation of Shielded Cross-Sections for WIMS-AECL." AECL
2. P.J. Laughton, "On the Preparation of Library Data for an Implementation of the Method of Subgroups in WIMS-AECL." AECL
3. V.I Arimescu, M. Couture, M Klein, and A. Williams, "Calculation of the Volumetric Heat Generation Rate Radial Profile in a Cylindrical Fuel Rod." AECL
4. B.T. Adams and J.E. Morel, "An Acceleration Scheme for the Multigroup Sn Equations with Fission and Thermal Upscatter." Delft University of Technology, The Netherlands and University of California, USA
5. B. Arsenault, J.V. Donnelly and D.A. Jenkins, "History-Based Calculations Using WIMS-AECL in RFSP." AECL

1. T.C. Leung, "Analysis of the Fast Neutron Spectrum Inside the Materials Test Bundles in the NRU Loops." AECL
2. M. S. Milgram, "Estimates of the Neutron Flux Distribution in an End-Fitting of the Bruce Unit 2 using Analog Monte-Carlo." AECL
3. V.A. Khotylev and J.E. Hoogenboom, "Study of Nuclide Field Behaviour in Reactor with Continuously Changing Core Parameters." Delft University of Technology, The Netherlands
4. B.T. Adams, L. Moberg, R. Stammler, A. Ferri, F. Guist, "Validation and Benchmarking of the HELIOS/RAMONA Model of Dodewaard." Delft University of Technology, The Netherlands and Scandpower, Norway
5. S. Day, "The Placement of Lateral Region in lD MTR Fuel Lattice Cell Models." McMaster University
6. M.W. Hersey, K.F. So, C.G. Olive, and F.C. Shanes, "Photoneutron Source Strength Studies in Pickering Reactors." Ontario Hydro

1. J.C. Handbury, C.W. Newman, "Modelling Techniques for Vanadium Detector Compensation." Atlantic Nuclear Services and NB Power
2. D.A. Jenkins, "Dynamic Modelling for Shutdown-System-1 Depth Analysis." AECL
3. H. Basha. "Reactor Physics Simulation of the MNR January 1994 Fuelling Incident." MNR, McMaster University
4. M. S . Milgram, "Effect of Pressure Tube Creep on the Void Coefficient of a CANDU Fuel Bundle." AECL
5. V.A. Khotylev, N.V. Schukin, A.V. Filatov, S.D. Romanin, A.A. Semenov, Yu.B. Chizhevskiy, V.S. Sidorov, "System for Neutronic and Thermalhydraulic Diagnostics of Channel Type Reactor Parameters." Delft University of Technology, The Netherlands and Moscow Engineering Physics Institute, Kurchatov Institute, Russia
6. B.T. Adams, "A Scaling Law Verification of the Delft Simulated Reactor (DESIRE)." Delft University of Technology, The Netherlands

THERMALHYDRAULICS

1. T.G. Beuthe, "CATHENA Study of Two phase Water Hammer Inter-Peak Timing." AECL
2. T.G. Beuthe and J.B. Hedley, "Preliminary Investigation of the Solution of Sparse matrices in CATHENA." AECL
3. G.R. McGee, "Refill Effectiveness using High-Boiling Point Emergency Coolant." AECL
4. C.W. So, P.L. Chang, and D.G. Meranda, "Darlington NGS A SGECS Condensation Induced Waterharnmer Analysis using the TUF Code." AECL and Ontario Hydro
5. Y. Zhuang, A.O. Banas, and R.Q.N. Zhou, "A Three-Dimensional Modeling Analysis of CANDU 9 End-Shield Cooling Effects with CFX-4: A Preliminary Report." AECL

1. K.M.Lee and K.M. Nho, "Assessment of Refuelling Effect in High Power Channel on Fission Product Releases for Following an End-Fitting Failure." KNFC,KEPRI, Korea
2. V.I. Arimescu ,"Numerical Schemes in CANSIM and Some Sensitivity Studies." AECL
3. R.A. Gibb, P.J. Reid, and T.J. Chapman, "Fission Product Inventory and Distribution at Point Lepreau Generating Station." NB Power and ALARA Research
4. A. Kwan, R. Dam, M. Soulard and G.D. Harvel, "NUCIRC Simulation of a Large Header for the CANDU Type Nuclear Reactor Heat Transport System." McMaster University and AECL
5. K.R. Chaplin, S.R. Douglas, D. Dunford, L.F P. Lo, C.A. Daza, "Detailed Simulation of Ultrasonic Inspections." AECL

1. L.K.H. Leung, D.C. Groenveld, and G. Hotte, "A Generalized Prediction Method for Single-Phase Pressure Drop in a String of Alinged CANDU-type Bundles." AECL and Hydro-Quebec
2. R.F. Dam, K.F. Hau, J. Vecchiarelli, and N. Lee, "Critical Heat Flux Evaluation of a Conceptual Fuel Bundle Design with the ASSERT Subchannel Code." AECL
3. G. Hotte, M. Soulard, L. Leung "Simulation of CANDU Bundle Cross-Sectional Averaged Actual Flow Quality and Void in One-Dimensional Two-Phase Flow Models" Hydro-Quebec and AECL
4. P. White, R.F. Dam, M.R. Soulard, and N. Lee, "Modelling Methodology for Obstructions in the sub-channel Code ASSERT IV." AECL
5. D.R. Novog, S.T. Yin, and J.S. Chang, "High Heat-Flux Transfer and Pressure Drop Correlations for Reactor Thermalhydraulic Simulations." McMaster University and AECL

SAFETY

1. Y. Watanabe, T. Oikawa, M. Kondo, M. Mizuno, K. Muramatsu, "An Analysis of the Effect of Correlation of Response in the System Reliability Analysis in Seismic PSA of Nuclear Power Plants." JAERI, Japan
2. K. Muramatsu, M. Himi, and K. Amagasa, "Development of a Computational Framework of Uncertainty Analysis for Level 2 PSA to Consider both Aleatory and Epistemic Uncertainties " JAERI Japan
3. C. Stoica, C.K. Scott, "Optimization of Operating Envelope and Safety Margin Using PRA Methods." Cernavoda Romania and Atlantic Nuclear Services
4. T.H. Nguyen and W.M. Collins, "A Spatial Convergence Study for Flows and Hydrogen Distribution in the CANDU 6 Reactor Vault following a Loss of Coolant Accident using the Gothic Containment Analysis Code." AECL

1. L.C. Water, J.W. DeVaal, and N.K. Popov, "Development of a Model for Calculating Sheath Thermocouple Finning Losses for Application in In-Reactor Severe Fuel Damage Tests." AECL
2. J.T. Rogers and M. Lamari, "Transient Melting and Re-Solidification Model of CANDU Core Debris in Severe Accidents." Carelton University
3. N. Popov, L.A. Morris, and D.N. Padhi, "CATHENA Model of the CANDU 9 End Shield Cooling System in the Event of Loss of Forced Circulation " AECL
4. J. Vechiarelli, R.F. Dam, K.F. Hau, and F J. Doria, "Thermalhydraulics Response of a Conceptual CANDU Reactor, with a highly Advanced Core subject to various Loss-of-Coolant Accidents." AECL
5. E.N. Sokolov, "Safety Analysis Uncertainty Related to Design and Manufacturing Quality Assurance."

19TH ANNUAL CONFERENCE OF THE CANADIAN NUCLEAR SOCIETY

The Canadian Nuclear Society's 19th annual conference will be held in Toronto, Ontario, October 18 - 21 , 1998.

This will be the first time that the CNS Conference has not coincided with that of the Canadian Nuclear Association

Papers are invited on technical developments in all subjects relating to nuclear science and technology.

The deadline for summaries is 1 April 1998. Summaries should be of 750 to 1200 words long, with tables and figures counting as 150 words each. The summaries should report on work done and results achieved and should present new information or represent a state-of-the-art review.

Summaries should be submitted to:

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Fifth International Conference on CANDU Fuel

***Ed. Note:** The following report is based on a summary prepared by Paul Chan of the organizing committee for the very successful 5th International CANDU Fuel Conference. Also included in this issue of the CNS Bulletin is the Canadian overview paper and excerpts from the talk by Ron Page on the early days of CANDU fuel development. The organizing committee, under the chairmanship of Joseph Lau, of AECL Sheridan Park, deserves congratulations for this very well organized and executed meeting.*

Over 130 people from 14 countries participated in the Fifth International Conference on CANDU Fuel held in Toronto from September 21 to 25,1997. The many delegates from outside Canada, including Argentina, Austria, Egypt, France, India, Indonesia, Korea, Pakistan, Romania, Russia, Turkey, the United Kingdom, and the United States, gave the Conference a truly "international" flavour.

The Conference was sponsored by the Canadian Nuclear Society, with additional support and sponsorship from Atomic Energy of Canada Limited (AECL), the CANDU Owners Group (COG), Cameco Corporation, General Electric Canada, the International Atomic Energy Agency, and Zircatec Precision Industries Inc..

The three-day Conference included one plenary and 10 parallel sessions for presentation of technical papers. During the plenary session, representatives from India, Korea, Romania, Argentina and Canada made presentations on the status of CANDU®fuel-related developments in their respective countries. These presentations reflected a vigorous international CANDU fuel program that will help to ensure the continued success of the CANDU reactor.

The technical sessions covered topics on CANDU fuel design and development, including, the CANFLEX® fuel bundle design, fuel model development, fuel manufacturing and quality assurance, fuel performance, fuel safety, CANDU advanced fuel cycles, fuel performance assessment, and spent fuel management. Highlights for each session are summarized below.

1. **CANFLEX® Fuel Bundle Design:** The CANFLEX bundle will offer fuel solutions to issues such as reactor aging, and it will also be the bundle to carry advanced fuels. As the CANFLEX fuel bundle approaches implementation, it is useful that the basis for CANFLEX verification and qualification are presented in the setting of this conference, to facilitate information exchange and peer review.

Joseph Lau

2. **Fuel Design and Development:** The rapid load growth in Indonesia and Turkey is expected to be met by nuclear power development. The fuel development programs in these countries are designed to support nuclear development. Papers related to the use of graphite to reduce void reactivity in CANDU reactors, the option to improve the corrosion resistance of fuel sheathing, and the fatigue behaviour of the bundle assembly weld were presented.
3. **Fuel Model Development - Part 1:** Presentations were given on the validation of best-estimate computer codes used for the prediction of fuel performance during normal operation (ELESIM code) and for the simulation of fuel-channel mechanical behaviour during accident conditions (FACTAR). Models were also proposed for the deterministic prediction of the release of low volatile fission-products during transient conditions, and the transport of steam, hydrogen, and fission products in the fuel-to-sheath gap of defective fuel elements.
4. **Manufacturing and Quality Assurance:** Presentations were made by representatives from Romania, India and Canada. These papers highlighted the achievements in the development of fuel manufacturing technologies, inspection technologies and quality assurance programs.
5. **Fuel Performance:** Fuel performance in an Indian PHWR (19-element bundle) and Gentilly-2 were presented. Also described were a comprehensive database on sheath strain and fission-gas release; the role of technical specification on fuel perfor-

mance; the root cause of failed fuel at Wolsong-1, attributed to high hydrogen content in the sheath; and the manufacturing of UO_2 pellets in Egypt.

6. **Fuel Safety:** Papers were presented on the current status of computer codes used to model CANDU fuel response to an accident, experimental programs investigating the fuel behaviour under off-normal conditions, and the behaviour of advanced CANDU fuel under loss-of-coolant accident conditions.
7. **CANDU Advanced Fuel Cycles:** Papers were presented on dispositioning plutonium from dismantled weapons as CANDU mixed-oxide fuel, the use of SiC as an inert-matrix fuel material for plutonium or actinide waste annihilation, and the progress in the DUPIC (Direct use of PWR Spent Fuel in CANDU) program at AECL.
8. **Fuel Model Development - Part II:** This session dealt with thermal and mechanical aspects of fuel behaviour. Code developments such as BACO, CYRANO3 , SOURCE 2.0, FEAT and BOW were described.
9. **Fuel Performance Assessment:** Papers describing fuel performance in CANDU reactors and experimental techniques to assess fuel performance were presented.
10. **Spent Fuel Management:** A range of topics including the dry storage program at Gentilly-2 and the final disposal of spent fuel were presented.

The papers were all of high quality, and the authors made excellent presentations. Most papers elicited active technical discussions which took place took place both during and outside the sessions.

Speakers at the luncheons were two alumni of CANDU fuel development: Alistair Bain, who spoke on "Development of the CANDU Reactor", and Ron Page who presented some insights and personal reflections on "Early Days of CANDU Fuel". The traditional banquet was replaced by an enjoyable meal aboard a boat cruising the Toronto harbour. The speaker at that event was Frank Stern, chairman of Stern Laboratories Inc., who presented his thoughts on "CANDU, Building the Future". All three speakers gave interesting talks which captured the attention of the delegates and their guests.

The technical sessions ended on September 24, with a technical tour, the following day, of the Darlington NGS, which attracted most of the overseas delegates.

Frank Stern attempts to talk over the background at the dinner cruise in Toronto Harbour during the CNS 5th International Conference on CANDU Fuel, September 1997.

Members of the organizing committee for the 5th International Conference on CANDU Fuel, held in Toronto, September 1997, pose with conference chairman Joseph Lau (centre seated)

Early Days of CANDU Fuel Development

by Ron Page

***Ed. Note:** The organizers of the 5th International Conference on CANDU Fuel, held in Toronto, Canada, September 1997, asked two veterans of the CANDU fuel development program to give luncheon addresses based on their early experiences. The two were Alistair Bain and Ron Page. As it turned out, Alistair Bain spoke about the early nuclear power research and development program in general, drawing on his participation in as one of the authors of the recently published history "Canada Enters the Nuclear Age" (see CNS Bulletin, Vol. 18, No. 2) while Ron Page reviewed some of the early development work specific to CANDU fuel from his own participation. Now retired from AECL, Ron is a member of the "CANDU Origins and Evolution Committee", chaired by Gordon Brooks, which is preparing a history of the development of today's CANDU reactor.*

The following account is excerpted from the notes Ron Page used for his talk.

Introduction

The evolution of fuel in Canada can be traced to Dr. George C. Laurence who tried very hard to make a nuclear critical mass, called a pile in those days, in 1940-41, when he experimented with a U3O8 (Yellow Cake) & Graphite at National Research Council in Ottawa.. He was the first person in the world to study neutron multiplication in a large assemblage of carbon and uranium. He got very dirty building a number of piles of graphite and Yellow cake and therefore he was the first to dirty his hands with Uranium fuel. Due to the low of density of Uranium in the Yellow cake and the impurities in the graphite (Calcined coke) plus the paper bags. He was not successful but it did start the ball rolling.

Personal Involvement

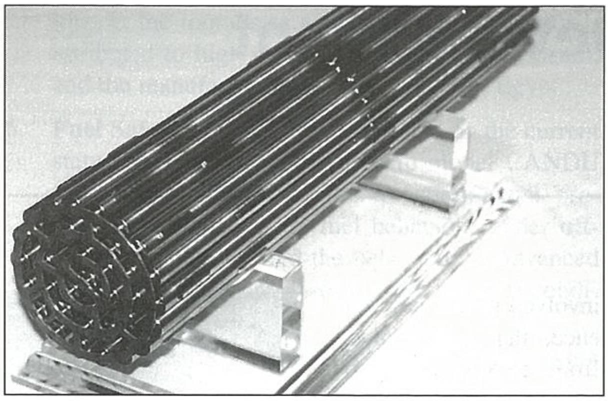
My first contact with Canada's nuclear program was in 1957, when I attended a seminar at Peterborough and was introduced to Dr. W. B. Lewis as "WB and his boys". The subject was Nuclear Power which they were developing, but at that time, I had no thought of being involved in this new science, that had evolved from the Manhattan project that had produced the atom bomb. I was employed then by Orenda Engines at their test establishment at Nobel, near Parry Sound, Ontario. There we were testing and developing components of the Orenda Iroquois jet engine for the Avro Arrow program.

Ron Page

Just before Christmas 1957, I was offered a posting to Chalk River, on attachment to Atomic Energy of Canada Ltd., as Orenda wished to diversify and get in on the ground floor of this budding new industry and science. My first question was where was the location of Chalk River? I was told it was 300 miles to the east on the Ottawa river. When I asked my wife, Bette if she wanted to go, as she was eight and half months pregnant, she said yes. The reason being if we waited for the baby to be born and strong enough to travel, the posting may have been filled by someone else. We moved in early January 1958 and arrived at the AECL company town of Deep River. The temperature was minus 30 and the roads at that time many years ago from Parry Sound to Deep River via North Bay were just barely passable in the winter.

I was seconded to Dr. Laurence's division with Jack Horsman's branch and given an office in building 145. Some of the members of the branch at that time were John Melvin and John Jennekens, but there were others scattered about in other buildings.. I was there with a number of other Orenda personnel, one of whom was Dr. George Pon. The objective of my attachment was to learn about the fuel loops, so that Orenda could design and fabricate these systems and other components for this exciting new program.

To expose myself to all the subjects associated with the nuclear program, I was able to move myself around the laboratory attaching myself to various units in Operations. These were the people who operated the research reactors NRX and NRU. I put myself on shift with the people who operated the loops that were then running in NRX. It was here that I met Muts Konyagi



Candu fuel bundle.

and Danny Nishimura and heard about J.A.L. (Archie) Robertson, Mike Notley and Ross McEwan whom I was to work with later. After a number of months on shift at both NRX and NRU, I moved myself into the NRX physics office. It was there I really got my first exposure to reactor physics under the guidance of Don Milley. Art Passanen was in the NRU physics office at that time.

In 1959 Dr. A. J. Mooradian asked me to join AECL and form the Fuel Engineering group, as he was bringing all fuel associated projects and experiments under one roof. Archie Robertson was to look after the fundamental understanding of fuel and 'WE' in engineering were to direct the design, development, irradiation and production of all CANDU power reactor first fuel core loadings.

I was a group of one until George Fanjoy joined me on attachment from CGE, replacing Ray Fortune (CGE). George had been involved with the design of fuel for NPD and had started the design of the Douglas Point fuel bundle. It was the blind leading the blind, as we all had limited knowledge of the fuel and materials that we were developing. At the same time NRU fuel was going through a bad development period after the fuel jammed in the reactor and fuelling machine and a broken off piece caught fire when the fuelling machine was dragged off the reactor in 1958. I and numerous others volunteered to vacuum some of the spent fuel off the top of the reactor. That was my first taste of protective clothing and gas mask in an empty reactor hall (receiving 2.5 R in the process).

Al Lane was my first AECL employee and he was sent down to Peterborough to decide how we should load the NPD-2 core with the special dimensioned bundles of 7 & 19 element.

One of our first major jobs was to commission the new E-20 loop (now U-2). The problem was to make four 3"(76.2 mm) diameter 19 element bundles to fit the thick pressure tube that had been installed. Nobody had any faith in this new Zircalloy-2 material and made the pressure tube with a wall thickness near to a half an inch (12.7 mm)! This resulted in an inside diameter of only 3 inches (76.2 mm). We assembled these special bundles with screws and special thick end plates which mated into each other. The whole assembly was held together with a birdcage designed by Gavin McGregor. The irradiation was a success and the E-20 loop worked well. With natural UO_2 fuel in the bundles, the power from these small elements did not approach that expected from NPD-2 at full power, but we had made and irradiated 19 element fuel bundles for the first time in Canada.

Our next task was to test full-scale NPD-2 types of fuel. This required a proper thin walled 3.25 inch (82.55 mm) diameter pressure tube to be installed in E-20. There were two fuel designs for NPD-2, the 19 and the 7 element. The 7 element bundle with larger element diameter was designed to increase the amount of Uranium in the core. To ensure that the large diameter 1 inch (25.4 mm) elements in the seven-element fuel bundles would not be overpowered in the high flux of NRU, we used depleted UO_2 fuel. When the irradiation of the six NPD bundles had been operating for some time we noticed that the overall power of the loop fuel was increasing. After scratching our heads and consulting the physicists we realized that the seven-element bundles were breeding plutonium and producing more power than the natural uranium in the 19 element bundles. When we examined the fuel in the hot cells we found that the seven element bundle elements had extensive grain growth with a central void, indicating significant fuel rating.

Bundle Diameter

The initial fuel design for NPD-1 *(the original vertical, pressure vessel design, ed.)* was to consist of rods of uranium metal clad in Zirconium, as it was now known that Hafnium free Zirconium could be a suitable cladding material rather than stainless steel that the American enriched reactor designers were using. The number of important "givens" were assumed at this time. It was to have a vertical steel pressure vessel. It was to be cooled and moderated with heavy-water with on-power fuelling, with the control and shutdown of the reactor to be by mechanical control rods. This was a direct evolution from NRU but with a vessel allowing heavy water at high pressure and temperature to produce steam with a useful thermal efficiency to produce electricity. The fuel core length was to be 4 metres. The studies first done at Chalk River by Arthur Ward assisted by Gene Critoph suggested an optimum homogenous cell of the fuel, coolant and cladding should have a cross-section area of 50 cm2 . This translated, for engineering purposes, into a circular fuel channel of 3.25 ins. bore (82.55 mm) (from John Foster via G. L. Brooks). Thus the resultant bundle diameter was chosen. The rodded fuel assembly was retained even though plate and annular designs of metal uranium fuel looked attractive and a modified hexagonal array of 19 elements was chosen. The same size of channel and fuel was used in the subsequent design of Douglas Point.

Before going on to bundle length I would like to jump ahead to the larger channel we know today. With the larger reactors like Pickering it was necessary to increase the size of the channels to minimize the number of channels required, to keep the size of the reactor as small as possible, and allow for even larger reactors in the future. There was a great reluctance on Chalk River's part to go to bigger pressure tubes, as it would require major modification to the loops to accommodate the nominal 4 inch pressure tube. It was resolved by stipulating that the bundles would employ elements of the same diameter as those for NPD and Douglas Point, thus the Pickering fuel bundle design using 28 such elements and standard minimum spacing, resulted in a pressure tube diameter of 4.07 inches (103.38 mm) which has been our standard bore every since.

Element Diameter

The fuel element size or diameter of each rod was chosen to provide a minimum inter-spacing of 0.050 ins (1.27 mm) with the 19 elements fitted within the 3.25 in. fuel channel diameter. It was proposed that the inter-element spacing would be provided by a spiral wire wrap around each element, mechanically joined at each end of the element or rod. It was assumed that this spiral pattern would promote sub-channel coolant mixing. The minimum 50 thou's (1.27 mm) inter-element spacing was recommended by Dave Coates at CAPD *(Civilian Atomic Power Department of Canadian General Electric,ed.)* based on heat transfer tests performed at Columbia University and other work which was performed during and after the Manhattan Project.

Pressure Tubes and Bundle Length

With the change to the horizontal, pressure tube design of NPD-2, the original core length (from NPD-1) of 4 metres and short fuel length of one foot was adopted. John Foster thought that the 1 foot bundle length was very arbitrary and seemed unnecessarily short. So he did a number of calculations and came up with the solution of dividing the 4 metres by 8, resulting in 50 cms or 19.685 inches. Dr. Lewis had also done a similar study and agreed. The length was rounded down to 19.5 inches (49.53 cm). So that is how we obtained the magic 19.5 inches bundle length, which has lasted for many years. The designers evidently added two half bundle lengths to each end of the fuel channels so that the latch and the rolled joints were not directly in the core! Thus we ended up with 9 bundles in the NPD-2 channel with an effective core length of 384 cm . So the stage was set for Canada's power reactor program, a horizontal pressure-tubed reactor, cooled and moderated with D_2O, using natural uranium UO_2 fuel and on-power fuelling. Thus the CANDU reactor concept as we know it today was conceived.

Zirconium and Zircaloy

At the end of 1947 staff at Oak Ridge Laboratories in the US discovered that zirconium occurring in nature, was combined with the element hafnium. It was this element at 2% by weight which gave the zirconium such a high level of neutron absorption. They found that it was possible to reduce the hafnium to a very low level, thus making zirconium attractive as a cladding material in reactor. The Westinghouse Atomic Power Department (WAPD) at Bettis Lab. under Dr. Kroll went on to develop Zircaloy -1 by adding 2.5% tin.

In 1952 by the accidental addition of stainless steel to a zirconium ingot, Dr. Kroll and his associates found that there were beneficial effects by adding small amounts of iron, nickel and chromium. This new alloy, named Zircaloy-2, had a better corrosion resistance than Zircaloy-1. Later they found that by replacing the nickel component with iron produced an alloy which cut the hydrogen absorption in half and had good corrosion resistance. This was initially called Nickel-free Zircaloy and later became known as Zircaloy-4, as we know it today.

Ammonia Di-Uranate (ADU)

Producing UO_2 powder from Yellow-cake was difficult in those days until personnel of the Mines Branch *(of the Department of Mines and Technical Surveys, ed.)* and of Eldorado Mining and Refining produced the ADU process. Joe Howieson reminds me that the Chalk River Metallurgical Branch was a separate organization reporting to Mines Branch. It was this connection that led to the development of the Ammonia Di-urinate(ADU) process for UO_2 powder production. Canada was the pioneer in this route. Alan Prince, who later became President of the AECB, was in charge of the work.

We had difficulty in producing pellets and NPD fuel had relatively low density, 10.2 gm/cc, compared to today's production of 10.7 gm/cc. Also obtaining pellets with a U/O ratio of 2.0 was not achieved until later in the production. The quality of pellets with chips, size of dish and shoulder produced many debates, the pellet chamfer came later. Vibratory compaction and swaging were also explored as alternative ways to produce elements without pellets. Norton Co. In Niagara Falls demonstrated UO_2 fusion and provided different grades of fused powders for vibratory compaction work..

Wire Wrap

Element spacing was tried with mechanical wire wrap attached to either end of the element but was quickly changed to resistance spot-welded to the sheath to prevent movement in the coolant flow. For Douglas Point 19 element bundle the wire wrap pitch was increased to promote coolant mixing and better spacing along the elements length and extra thicker wire was attached to the outer elements as bearing pads. The end caps were resistance welded as well as the elements to the end plate thus getting rid of the laborious tungsten inert gas (TIG) welding. The rest of the nuclear world took a long time to copy us in the use of resistance welded elements.

Split Spacer

During the development of Douglas Point bundles a growing concern of possible significant element fretting was expressed and a directive was issued to come up with alternative designs without wire spacing and if possible no end-plates for replacement fuel. This led to a number of innovative designs.

The brazing program was developed at AMF, Port Hope, later Westinghouse Canada and now Zircatec. This technique of joining Zircaloy led to a bundle design without end plates and all the elements joined together by three planes of spacer to a thick central element. Though it was a very strong bundle it did not work under irradiation due the lack of accommodation for differential longitudinal expansion of the elements. Joe Howieson dropped one from the roof at Westinghouse to prove its strength to his staff. So we replaced the two end planes of spacers with end plates and cut the centre plane of spacers in half. To prevent inter-locking of the spacers, they were skewed relative to each other and thus the split-spacer bundle design as you know it today was born. That is a very simplistic story, as we went through a long list of methods to produce the spacers until we settled on the beryllium coated method with induction heating. We looked for other alloys of Zirconium but none work as well as beryllium. The same wide ranging search occurred with bearing pads of different designs, such as rollers and graphite to name a few.

Materials

Corrosion of Zircaloy and its H2 pickup were a major worry with the early production alloys but with time it was never a real problem as long as a high degree of cleanliness and good quality control were maintained.. Thirteen 7-element bundles were left in NPD during its whole operating life *(over 25 years, ed.)* without failure. They were a bit white when they came out but none the worse for that exposure to the coolant for such a long time.

We observed our first stress corrosion crack sheath failure in a test we did in the Heavy Water Component Test Reactor in the US, when we did our first bundle power shift during the irradiation. We did not recognize what had happened, as the Americans dropped the string of bundles in the bays. Because Dr. Lewis and Dr. Mooradian wished to prove that the bundles could achieve the political/scientific target of 10,000 MWd/teU (240 kWh/kgU), we were prevented from doing any power shifts in the loops until much later.

Dryout

We pioneered the first in-reactor heat transfer tests in the world, when investigating fog-cooling and defined 'Dryout' of the coolant on the sheaths, before going into a full boiling program. These series of tests ended up with full-scale reactor bundle heat transfer tests in the U-1 loop, again first in the world. These 36 element bundles were designed for central melting using enriched Thoria fuel with a central void and thick sheathing, as we wished to get the maximum power out of the six bundle string. The tests culminated with pump rundown experiments, where the pumps were shut off before the reactor was tripped. During these tests I saw the effect on the reactor neutron flux as the channel voided due to the large scale boiling and dryout, causing the flux to peak before collapsing due to the reactor shut down.

Fuel Costs

The simple design of the fuel with good neutron economy led to one of the objectives of the fuel program, which was to demonstrate that fueling costs of 1 mill/kWh were achievable. This was done in the late 60's and early 70's as the production volume grew and the bundle discharge burnups were obtained.

Conclusion

The successful CANDU fuel program is Dr. A. J. Mooradian's real legacy. He died on October 4, 1996 after a painful battle with cancer, at the age of 74 years. He and Dr. W.B. Lewis drove the program with clear and far reaching directives and the type of project management that mixed science with engineering realities.

Canadian Fuel Development Program in 1997/98

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Abstract

This paper describes the CANDU® fuel development activities in Canada during 1997 through 1998. The activities include those of the Fuel Technology Program sponsored by the CANDU Owners Group. The goal of the Fuel Technology Program is to maintain and improve the reliability, economics and safety of CANDU fuel in operating reactors. These activities, therefore, concentrate on the present designs of 28-element and 37-element fuel bundles. The Canadian fuel development activities also include those of the Advanced Fuel and Fuel Cycle Technology Program at AECL. These activities concentrate on the development of advanced fuel designs and advanced fuel cycles, which among other advantages, can reduce the capital and fuelling costs, maintain operating margins in aging reactors, improve natural-uranium utilization, and reduce the amount of spent fuel.

Introduction

CANDU fuel has an excellent performance record. More than 1.3 million fuel bundles were irradiated in Canada by 1996. Of these, less than 0.1% had defects. As most failed bundles have single-element failures, the cumulative fuel element defect rate is about 0.003%. The defect rate is even lower if the failures from the earlier years of the CANDU program are excluded. For example, the cumulative bundle defect rate for fuel irradiated in Canada from 1991 to 1994 is about 0.02%. Moreover, from 1992 through 1997, the Gentilly-2 reactor operated without any single fuel bundle failure. All of these indicate significant improvements in performance over the years.

The successful performance of CANDU fuel is the result of a number of contributing factors, including a simple and robust fuel design with conservative design margins, reliable and specialized manufacturing processes developed over the years, and fuel operations conforming to the fuel operating limits.

Another reason for the success of CANDU fuel performance is the openness and cooperation with which the fuel designers, the reactor operators, fuel procurement staff, the fuel manufacturers, and the UO2 suppliers disclose and discuss fuel-related problems. When a fuel problem occurred at a particular nuclear station, the reactor operators, the fuel designers and the manufacturers collaborated to identify the root cause and eliminate the problem.1,2 Such openness and cooperation enable the industry to learn and benefit from the fuel failure incidents and avoid reoccurrence.

The need for continuous improvement is also recognized by the industry. The industry cannot afford to be complacent because of the good fuel performance record to date. It has to actively maintain and improve the fuel performance. Fuel defect excursions have occurred periodically, and effort must be exerted to avoid re-occurrence. Under the auspices of the CANDU Owners Group (COG), Hydro Quebec, New Brunswick Power, Ontario Hydro and Atomic Energy of Canada Ltd (AECL), jointly or in part, sponsor work programs under the Fuel Technology Program to maintain and improve the reliability, economics and safety of CANDU fuel in operating reactors. The work programs centre on the present fuel designs of 28-element and 37-element CANDU fuel bundles, and address issues related to fuel operation and performance.

In addition, to be competitive with other reactor systems and, in fact, with other energy generating systems, there is a need for continuous advancement of the CANDU fuel products. AECL has maintained an integrated development program to develop advanced fuels and fuel cycles.3,4,5,6 The goal of the Advanced Fuel and Fuel Cycle Technology Program is to develop fuel and fuel cycle products that can reduce both capital and fuelling costs, increase the operating margins, improve natural-uranium utilization and provide synergy with other reactor systems to improve resource utilization and spent fuel management.

This paper describes the fuel development activities in Canada during 1997 through 1998. The activities are discussed in two parts: the work packages in the COG Fuel Technology Program and the work packages in the AECL Advanced Fuel and Fuel Cycle Technology Program.

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2 Ontario Hydro, Toronto, Ontario M5G 1X6
3 AECL, Chalk River Laboratories, Ontario K0J 1J0
4 Hydro-Québec, Gentilly, Quebec G0X 1G0
5 New Brunswick Power, Point Lepreau, New Brunswick E0G 2H0

COG Fuel Technology Program

The COG Fuel Technology Program has the goal of maintaining and improving the reliability, economic and safety of CANDU fuel in operating reactors. The program has been in existence for many years, originating in the late 1970s when it was a part of the Common Development Program. The scope of the program, or work packages, is defined and agreed to by the sponsoring organizations at the beginning of each fiscal year. Some work packages are multi-year programs, whereas some work packages span one or two years. In the following, the 1997 through 1998 program is described:

Data on Failed Fuel

In CANDU stations, failed fuel bundles can be removed while the reactor is on-power, then canned and stored in the fuel bay. To determine the root cause of failure so that remedial action can be taken, the fuel bundles may be inspected at the fuel bay. Bundles or elements may also be shipped subsequently to a hot-cell facility for detailed destructive examination. Our experience has shown that the manufacturing data for these bundles, the operating conditions under which the bundles have been irradiated, and the inspection or examination results will be useful in determining the cause of failure. Also, the information, when compiled over time, will be useful for monitoring whether there have been any changes in the fuel behaviour, brought on by changes in operation conditions, manufacturing processes, or other causes.

A work package in the Fuel Technology Program will compile the operating conditions to which failed fuel has been exposed in Canadian nuclear stations. As the first step, a reporting specification had been prepared for use at stations to report data regarding failed fuel. The specifications recommend important parameters that should be reported, for example, the power burnup histories, locations of the fuel in the channel, fuel manufacturers and gross fission-product signals. This year, the cumulative failed fuel data from a CANDU station will be compiled according to these specifications. This database will then be used to define the conditions for which the fuel has been exposed in the station and for which fuel failures resulted.

A companion work package is to compile and examine the post-irradiation examination (PIE) data obtained in hot cells for power reactor fuel. Reference 7, presented at this conference, shows an application of such a database. It determines the range of sheath strains and fission-gas releases from power reactor fuel over the last 20 years. Recently, under this work package, the PIE of fuel that had experienced load following in the Bruce B Nuclear Generating Station was documented and compared with a reference fuel examination. It confirmed that the load-following power transients applied had no negative effect on the fuel performance. Reference 8, also presented in this conference, uses the database to evaluate the effect of uranium mass increase in CANDU fuel bundles in Canada over the years.

Fuel Design Experience and Methodology

Another work package in the Fuel Technology Program is the preparation of the Fuel Engineers Manual. This is a "sequel" to the Fuel Encyclopedia that was prepared in 1988. The Fuel Engineers Manual covers in detail all aspects of the present CANDU fuel bundles, including CANLUB coating, design development testing, fuel materials, fuel manufacture, as well as design evolution and history. The Manual is being prepared by authors in their field of expertise, and the document is expected to be a valuable resource to help to understand design and operational problems regarding fuel. It can also be used as a training tool for new members entering the nuclear fuel industry. This manual is expected to be ready for industry use by mid-1998.

Fuel Specifications Update

From the many years of fuel operating experience, fuel PIE and development work, the knowledge on fuel behaviour, fuel design and fuel manufacturing have significantly advanced. To ensure that new important information is captured in the fuel technical specifications, the Fuel Technology Program has a work package to review and update the specifications. The fuel specifications are the working documents for fuel design and procurement. To date, the review of the specifications of Zircaloy tubing and UO2 powder have been completed. Reference 9, presented in this conference, describes the review and the conclusions. During 1997 through 1998, additional specifications including "UO2 pellets" and "Beryllium Metal for Brazed Joints" will be reviewed.

Special Bundles Irradiation and Examination

To guide the designers to confirm, and refine if required, the fuel specifications, the Fuel Technology Program also sponsors the irradiation and PIE of special bundles. To date, well-characterized bundles manufactured at the specification limits of density and pellet/sheath radial gap have completed their irradiation at Point Lepreau Nuclear Generating Station. They have been shipped to the hot-cells at the Chalk River Laboratories (CRL) where they are awaiting destructive examination. Two additional bundles with and without the CANLUB coating have also been irradiated, discharged and will be shipped to CRL after the required cooling period. The irradiation of fuel at the specification limits of density and gap can provide information that may affect the uranium mass in a bundle, and hence the fuel burnup and the fuelling cost. The CANLUB irradiation will provide further insight into the chemistry of CANLUB in-reactor and the active ingredient of CANLUB in protecting the sheath from stress-corrosion cracking.10

In-Bay Fuel Inspection

Fuel behaviour is often the first indicator of a performance problem in the reactor. Therefore, defects in the fuel need to be found and the root cause determined as soon as possible. In addition, safe response of the fuel in any safety assessments requires that the fuel condition be in a defined state. All of these often require fuel examination in a hot-cell facility, which tends to be time-consuming, relatively expensive, and therefore rather infrequent. For example, fuel bundles normally cannot be transported to hot-cells until after a cooling period of about 3 to 6 months after discharge. There is an incentive to maximize the information gained by inspection at the fuel bay, thereby increasing the value and the frequency of data collection on the condition of fuel. A new work package is being set up and implemented to develop, design, and construct prototype equipment for in-bay inspections. The first step in this work package is to identify the type of inspection required and develop the specifications for the prototype equipment.

Fuel Failure Maps

For postulated fuel-handling accidents, irradiated fuel is held up during its transfer from the reactor to the fuel bay. As a result of this delay that may cause degraded cooling, a fuel bundle may heat up at decay power. The time to sheath failure governs the response time that cooling should be restored to the fuel bundles. The time to failure is dependent on the bundle power and the specific heat transfer environment in which the bundle is located. To provide the operator with realistic estimates of the response time, several work packages have been implemented in the Fuel Technology Program. In one package, electrically heated fuel bundle simulators have been used to assess the heatup transients of the sheath under various cooling conditions. Work this year will deal with heatup in a fuelling machine. In another package, the failure criteria of the fuel sheath that is due to sheath oxidation and hydriding were confirmed by laboratory oxidation tests. This year, a work package is underway to combine the results of the two programs into fuel failure maps. The maps provide the predicted failure times as a function of decay power and various cooling conditions.

Fuel Performance Modelling

For reactor operation, fuel performance models can be used to assess whether certain power transients may have a greater chance of causing fuel defects, or whether certain fuel manufacture deviations may have an adverse effect on the fuel performance. For design, a model can be used to evaluate the performance of a new fuel design, and reduce the total cost of implementing changes that would otherwise require expensive laboratory tests to simulate the fuel performance. The Fuel Technology Program has been supporting the fuel modelling effort for a number of years. Because of development history and priority, two fuel performance models are now available, each focusing on different aspects of fuel behaviour. The ELESIM code 11,12 concentrates on the behaviour of the UO2 and fission-gas release during irradiation. The ELESTRES code 12,14 concentrates on the pellet hourglassing behaviour and local ridge strain on the sheath, while using similar UO2 and fission-gas release models as ELESIM. Both ELESTRES and ELESIM are mature codes, and have been used in design and safety work in their areas of applications. The work package in this current year is to physically combine the two codes into one integrated package (ELESTRES-IST) with a common numeric solution scheme. This new Industry Standard Tool (IST) will then be subjected to validation using the databases that have been or are being compiled within the Fuel Technology Program. Further code development will be based on ELESTRES-IST.

Advanced Fuel and Fuel Cycle Technology Program at AECL

Present CANDU fuel bundle designs, based on natural uranium, have been successful in meeting the needs of the CANDU reactor program. The excellent performance record, the simplicity in design and the ease of manufacture localization have made the CANDU fuel one of the distinguished features of the CANDU reactor system. All countries that have CANDU reactors have also developed the capability to manufacture their own fuel. However, at some point in the future, the incentives for using the current fuel bundle design and natural uranium may be outweighed by the advantages of advanced fuel bundles and fuel cycles, on the basis of either economics, resource utilization or performance.

To advance CANDU fuel products, AECL has maintained an integrated Advanced Fuel and Fuel Cycle Technology Program. Figure 1 shows a schematic of the program. The program consists of the development of specific fuel products such as the CANFLEX bundle, the development of generic fuel technologies such as an improved CANLUB coating and improved welding technology that are independent of fuel type and geometry, and the development of advanced fuel cycles such as enriched uranium, thorium, or plutonium.

CANFLEX is the next step in the evolution of the CANDU fuel bundle geometry. The CANFLEX bundle has been developed jointly by AECL and KAERI since 1991, and before that by AECL since 1986.15The CANFLEX fuel bundle has lower linear element rating for the same bundle power as a result of the greater element subdivision and the use of two element sizes, and is therefore is well suited for use in advanced fuel cycles, particularly those that can attain high fuel burnup. The CANFLEX bundle has also incorporated the latest critical heat flux (CHF) enhancement technology developed by AECL and therefore can also be used in existing reactors to offset the reduction in dryout margins when the reactors age.

Because of the lower linear element rating and higher CHF performance, AECL's vision is that the CANFLEX bundle will be the preferred carrier of advanced fuel cycles. Successive improvements in the CANFLEX bundle will continue. Beyond the improved CANFLEX bundles, an advanced CANDU bundle is being developed as the fuel bundle for the next generation of CANDU reactors.

Complementing the fuel product development is the development of generic fuel technologies. This includes improved welding techniques to replace beryllium brazing as the attachment method for the bundle appendages (i.e., bearing pads, spacers); low void reactivity fuel (LVRF) concept that can reduce void reactivity to any given value; the cool fuel concept to reduce the fuel operating temperature; CHF enhancement techniques to further enhance the CHF performance; improved CANLUB coating and optimized internal element design to enable the fuel to operate at high burnup. These technologies will be selectively incorporated into the CANFLEX bundle as the needs for their applications are required.

The CANDU reactor system has the highest neutron economy of all commercial power reactors, and is the only commercial reactor capable of using natural uranium. The on-power refuelling feature also allows flexibility to adjust reactivity and to shape the flux without reactor shutdown. The CANDU reactor system is therefore well suited for the use of advanced fuel cycles. The Advanced Fuel and Fuel Cycle Program contains work packages in slightly enriched uranium (SEU)/recovered uranium(RU) fuel, plutomium mixed-oxide (MOX) fuel, the DUPIC cycle (Direct-Use of spent PWR fuel in CANDU), thorium and inert matrix fuel.

Fuel and fuel cycle development involves a multidisciplinary effort. The program therefore integrates work activities in many disciplines, including fuel design, fuel bundle thermalhydraulics, fuel materials, reactor physics and fuel manufacture. In the following, the program activities for 1997 through 1998 are briefly described.

CANFLEX (natural uranium) Bundles

The CANFLEX natural-uranium bundle, with its CHF enhancement, is able to offset the reductions in dryout margins that occur as the reactor ages. The CANFLEX bundle design and qualification are now near completion. Enhancements in the critical heat flux have been confirmed in the thermalhydraulic test loop at the Chalk River Laboratories (CRL).16 The tests were performed with a 12-bundle-length CANFLEX heater string in Freon. Prototype bundles have been irradiated successfully at the NRU reactor at CRL. All mechanical tests to qualify that the bundle meets its requirements have been completed at KAERI and AECL, except for the 3000-h endurance test that is targeted for completion by the end of 1997.17,18 Work activities in Canada this year include the completion of the safety and licensing analysis, bundle fabrication, demonstration irradiation of 24 CANFLEX natural-uranium bundles which is planned for the Point Lepreau Nuclear Generating Station, and preparation for the critical heat flux tests in water.

SEU/RU Fuel

The easiest first step in the CANDU fuel cycle evolution is the use of SEU fuel with 235U content between 0.9% and 1.2%. Generally, enrichment between 0.9% and 1.2% can increase the burnup in a CANDU reactor by a factor of 2 to 3, and reduce the fuel cost by 20 to 30%.3 Alternatively, reactor power can be uprated by flattening the channel power distribution across the reactor core with the use of enriched fuel.19

A variant of the SEU fuel cycle is the use of RU. Recovered uranium is a by-product of conventional reprocessing of spent fuel from light-water reactors (LWRs). Recovered uranium has an enrichment of about 0.9%, with the actual enrichment depending on the spent fuel that it originated from. The fuel cost savings with RU, which is a by-product of reprocessing, will be greater than for conventional SEU.

AECL has established bilateral programs with British Nuclear Fuel Limited (BNFL) and KAERI to demonstrate the use of RU in the CANFLEX bundles in CANDU reactors. Reactor physics studies were completed confirming that existing CANDU reactors can change to the use of RU fuel.20 BNFL has identified that for RU, the integrated dry route (IDR) process is their preferred "conversion route" from uranyl nitrate solution to UO2.

AECL has extensive experience with the irradiation of enriched fuel over the years. The enriched UO2 was obtained by the ammonia di-uranate (ADU) process. Because the RU uses the IDR process, an irradiation program to compare fuel from the two types of powder is planned. In this year, CANFLEX bundles with RU (IDR) pellets and SEU (ADU) pellets will be fabricated for irradiation in the NRU reactor at CRL. Other works related to the RU program this year include the development of a model to study the economics of using RU fuel in an existing CANDU reactor.

DUPIC

The DUPIC cycle involves converting spent PWR fuel into CANDU fuel using a dry process. The process avoids selective element removal, and with the remaining high radiation field, offers a very high level of protection from proliferation. The DUPIC program is a joint program supported by AECL, KAERI and the US Department of State. The objective is to confirm the technical feasibility of the processes, process optimization, and obtain technical information for cost evaluation. A detailed discussion of AECL's progress in DUPIC fuel development is provided in Reference 21, a paper presented at this conference. The program this year centres on the fabrication, using the OREOX process21 (i.e., oxidation/reduction of the spent PWR pellets), of several DUPIC elements at AECL's Whiteshell Laboratories for test irradiation in the NRU reactor in Canada and the HANARO reactor in Korea.

Low Void Reactivity Fuel

Positive void reactivity is an inherent feature of the current CANDU lattice design. It is accommodated through the reactor design in such features as the provision of two independent fast-acting shutdown systems, each having a high degree of reliability and each being able to act alone to effectively shut down the reactor. Nonetheless, some countries may require reduced or even negative void reactivity for licensing, political or other considerations. As a response, AECL has a development program for this type of fuel.

The LVRF bundle uses a combination of fuel elements containing enriched fuel and elements containing depleted uranium with dysprosium, which is a neutron absorber. The enrichment and dysprosium levels can be adjusted to result in a given value of void reactivity. The LVRF concept can be embodied in a number of geometries, including the 37-element and the CANFLEX bundle. Testing related to 37-element bundles for natural-uranium burnup applications is being performed this year. This includes thermalhydraulic testing, reactor physics assessments, and irradiation and PIE of two prototype bundles and elements in a demountable bundle geometry. Testing of CANFLEX geometries intended for higher burnups is in progress. For the longer term, more advanced options are also being developed, that would achieve a significant reduction in void reactivity while preserving good neutron economy.

Thorium Fuel

AECL has many years of experience with thorium fuel, ranging from scenario studies of the different thorium cycles, fuel management studies, reactor physics measurements with ThO2 fuel and the fabrication and irradiation of the ThO2 fuel. The program this year includes re-analysis of earlier reactor physics measurements using more updated core physics methods, evaluation and improvement of core physics methods for treating flux-history dependence of cross sections in reactor, fuel cycle scenario studies to obtain the fuel management strategies in thorium cycle implementation, and the continuation of ThO2 fuel irradiations in the NRU reactor.

MOX Fuel and Dispositioning of Weapons Plutonium

The higher initial enrichment and discharge burnup of LWR fuel, compared with the CANDU fuel, result in a higher concentration of plutonium in the spent fuel. Moreover, the CANDU reactor is a more efficient burner of fissile material. Twice as much energy can be derived from the plutonium in spent LWR fuel by burning it in a CANDU reactor than by recycling it in a LWR. These features form the basis for the plutonium MOX fuel cycle in which plutonium MOX fuel is used in the CANDU reactor, with the plutonium coming from the reprocessing of LWR fuel. A variation of this is the dispositioning of weapons grade plutonium, in which plutonium from the weapons programs could be fabricated as MOX fuel and burned in the CANDU reactors. Details of the plutonium dispositioning programs that AECL participates in are discussed in References 22 and 23, both of which are papers presented at this conference.

Actinide Burning

This is a fuel cycle in which transuranium actinides separated by reprocessing can be fabricated into fuel and burned (transmuted) in a CANDU reactor. To ensure that no further plutonium is generated in the process, a suitable inert material needs to be selected to contain the actinides for irradiation. The AECL program on actinide burning focuses on silicon carbide as a candidate matrix material, and is described in Reference 24, a paper presented at this conference.

Generic Technology Development

Generic improvements in fuel technology are being developed, which can be exploited by a range of fuel cycles and bundle geometries. For example, elements with various CANLUB coatings have been fabricated and will be irradiated and power ramped in the NRU reactor to test the stress-corrosion resistance of the coatings. Elements with optimized internal element designs had been fabricated and are under irradiation in the NRU reactor. Freon tests will be performed later this year to further improve the CHF enhancement technology.

Conclusions

Present CANDU fuel bundle designs, based on natural uranium, have been successful in meeting the needs of the CANDU reactor program. To further enhance the competitiveness of operating and new CANDU power stations, fuel development activities are continuing in Canada. The Fuel Technology Program, sponsored by the CANDU Owners Group, has the goal of maintaining and improving the reliability, economics and safety of CANDU fuel in operating reactors. The Advanced Fuel and Fuel Cycle Technology Program at AECL concentrates on the development of advanced fuel designs and advanced fuel cycles.

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CANDU Maintenance Conference

Ed. Note: Just as this issue of the CNS Bulletin was "going to press" the 4th International Conference on CANDU Maintenance took place in Toronto. Following is a preliminary report on that conference. A more comprehensive review, augmented with papers from the conference, will be presented in the next issue.

Close to 300 delegates gathered in Toronto, November 16 to 18, 1997, for the **4th International Conference on CANDU Maintenance.** The theme of the conference was: Maintenance, the Pathway to Nuclear Excellence.

The numbers attending and the active participation of those present attested to the importance of maintenance in the CANDU nuclear power program. Over the two and a half days delegates listened to excellent papers, examined informative displays and joined in active discussions, all focused on the critical issue of maintaining (and improving) the operation of CANDU nuclear power plants. The international flavour was injected through the participation of representatives from Argentina, India, Korea, Pakistan, Romania and Thailand.

The current program at Ontario Hydro, with the planned "lay up" of seven of the older CANDU units and the challenge of bringing the remaining units up to "world class" performance, was a major topic. Among the invited speakers were: Carl Andognini, executive vice president and chief nuclear officer of Ontario Hydro, who gave a succinct but pointed luncheon address, and Bob Strickert, site vice president of Darlington NGS, whose "wrap up" presentation kept delegates enthralled well after the scheduled closing hour. Gene Preston, recently appointed site vice president Pickering NGS (and a member of the Nuclear Power Advisory Group brought in to review Ontario Hydro Nuclear) and Joe Kappes, senior adviser, maintenance, at Bruce, (another US consultant) presented a session on "Business of Maintenance from an International Perspective" to an overflowing audience. Paul Lafreniére, technical superintendent at Gentilly 2, reflected operators of single unit stations with an invited plenary paper on "Configuration Management" and another technical one on Maintenance and Incapability.

Dominic Iafrate opens the 4th 30 International CANDU Maintenance Conference in

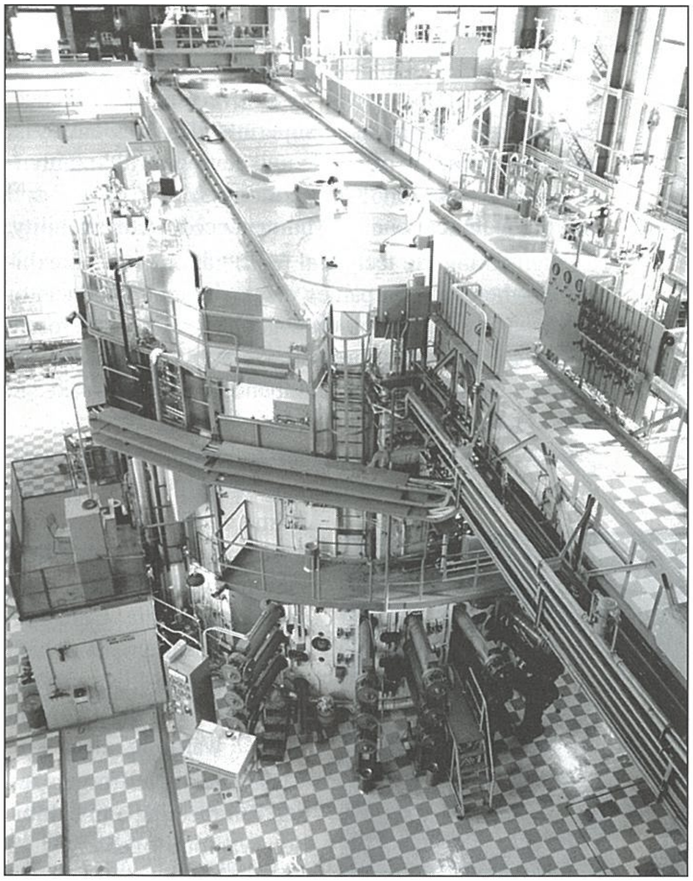
Augmenting the technical presentations was an exhibition where 15 companies displayed their products or services. The exhibition drew good crowds of interested delegates, helped through the clever arrangement of holding the opening reception, and the coffee breaks, in the exhibition area.

Presenting a non-technical, but still very relevant, view, Hugh Segal, former head of staff of the office of Prime Minister Brian Mulroney, gave an entertaining while pointed perspective on the Canadian nuclear program in which he decried the silence of the industry in the current "global warming" debate.

This very well organized and run meeting and exhibition was put togehter by an organizing committee chaired by Dominic Iafrate from Darlington NGS. Rod White, vice president nuclear at NB Power was the conference chair.

GENERAL news

A Very Special 50th Anniversary



An overall view of NRX (circa 1975).

Fifty years ago an event occurred that launched Canada's fledgling nuclear program, the start-up of NRX.

In the early hours of July 22, 1947, after hours of pumping heavy water into the calandria of the just completed NRX reactor, the neutron monitors indicated that criticality had been achieve. Although full design power of 20 MW would not be reached until the following year, early operation of NRX showed what was to become a reality, that it would have the highest neuron flux of any research reactor in the world. That was a record it would keep for many years.

The basic design of NRX had been done by the small team of scientists and engineers of the Montreal Laboratory. That group had been set up in late 1942 with a number of scientists from the UK and Europe, as well as Canadians. Their major tangible asset was a quantity of heavy water that had been smuggled out of Europe during the early months of World War II. Working with very little background (the USA refused to cooperate at first) this small group developed the reactor physics, analyzed materials , studied radiation effects and produced the conceptual design of a large heavy water moderated natural uranium research reactor.

The task of completing the detailed engineering design and building the reactor was given to Defence Industries Limited (DIL) which had been involved with designing and building explosives plants during the war. Despite the many restrictions on labour and materials, the design went ahead rapidly and construction began at the chosen Chalk River site in 1944 . In just 2 years NRX, as well as the basic Chalk River laboratory project, were built. Along the way the small ZEEP reactor was built and started up in 1945.

When it reached its initial design power of 20 MW NRX had a maximum thermal neutron flux of 3 x 1013 n / cm2.sec., then the highest in the world. This enabled advanced physics experiments, in-reactor engineering tests and the production of radioisotopes of high specific activity. The last capability soon led to the beginning of nuclear medicine in Canada and eventually to Canada's predominance in the production of radioisotopes for medical purposes.

On December 12, 1952 an event occurred that almost ended Canada's burgeoning nuclear program. During some experiments at NRX a combination of errors and failures led to a reactor runaway. The reactor was severely damaged. Since the second large research reactor, NRU, was at least five years away from completion it was decided to try to rebuild NRX. Despite high radiation fields the fuel and calandria were removed and replaced along with some of the equipment. Fourteen months later NRX started up again, this time to reach a power of 40 MW.

NRX served as a source of neutrons for physics experiments, as a major engineering test reactor and as a producer of isotopes for over 40 years until it was shut down in 1989.

Not only does NRX leave a legacy of significant contributions to nuclear science and engineering, it was also the first nuclear "school" for many who went on to become leaders in the Canadian nuclear program.

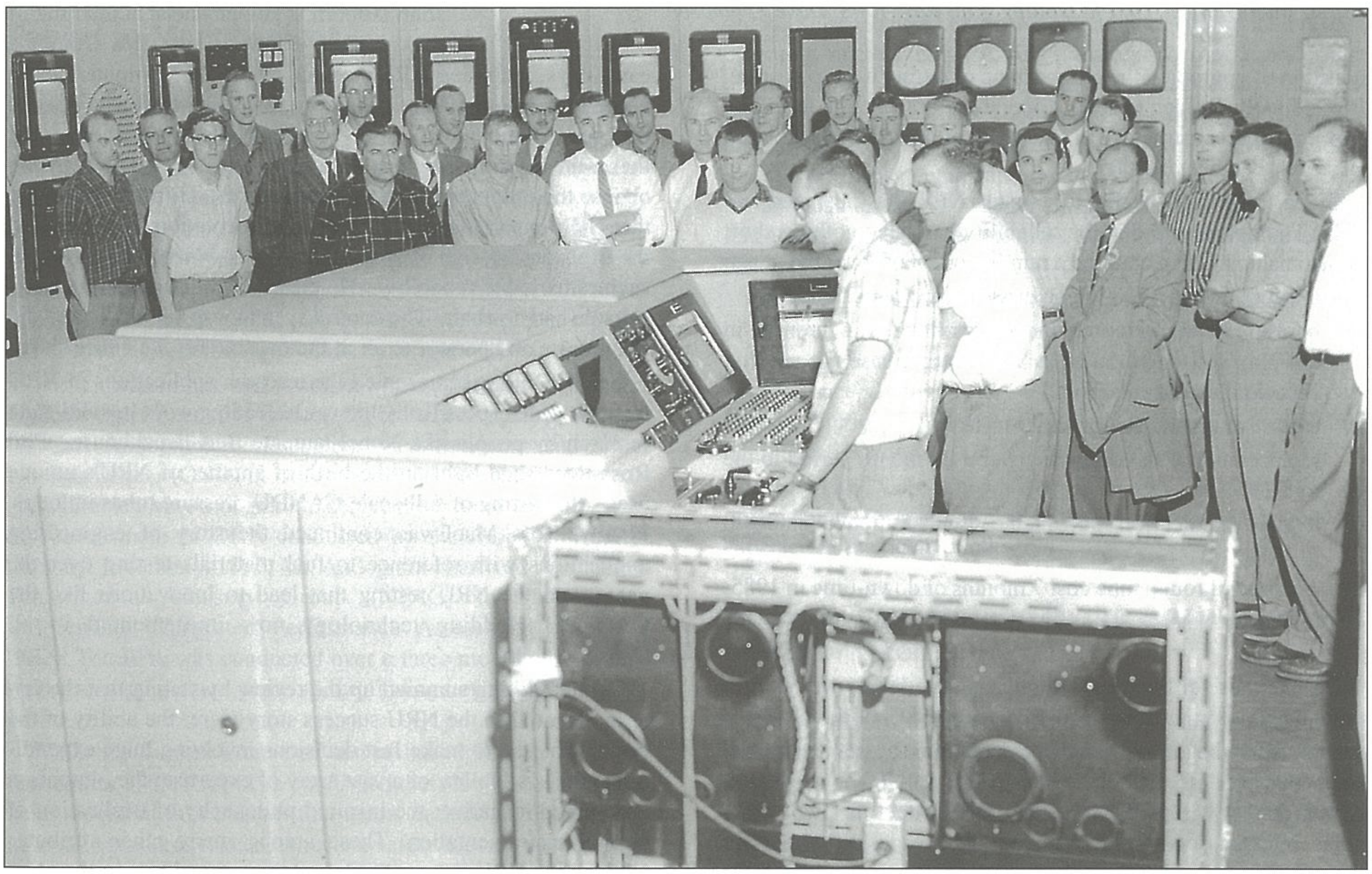
NRU Turns 40!

Ed. Note: Our thanks to Jeremy Whitlock, chairperson of the CNS Chalk River Branch, for providing copies of his note for the AECLNet and of the article written by AECL/AECB retiree Al Rose in the Deep River newspaper, on which this report is based.

The age of 40 can be a traumatic experience. For some it is the end of "youth" , for others the beginning of the second half of their life. For a research reactor, designed and built in the very early years of the nuclear program, reaching the age of 40, still in good health, is an achievement and a credit to all of those involved over the years.

On November 6, 1997, the Chalk River Branch of the Canadian Nuclear Society and the Reactors Division of AECL's Chalk River Laboratories, co-sponsored a retrospective look at NRU, to mark the 40th anniversary of its start-up on November 3, 1957. An evening of fond memories and old friends was shared by a standing-room-only crowd at the J.L. Gray Centre in Deep River.

The theme of the evening, *"NRU - Then and Now"*, was introduced by Dave Thompson, director of the Reactors Division, who presented the seven member panel along with a photo of the November 3, 1947 start-up (with panel member John Inglis at the controls, and the others in the background). Dave encapsulated the reactor's 40-year history with a short slide presentation, and noted that NRU is the world's longest-running, large-scale, research reactor, while remaining in the top four for performance. He characterized the first eight years as ones of euphoria, where NRU was the crown jewel of research reactors. The next twenty years concentrated on production, followed by a period of budget cuts and dwindling resources. In 1990 some renewal began and then the heavy water leak of 1991 raised the



This historic photograph of the start-up of the NRU reactor in the early morning of November 3, 1957, shows John Inglis, then senior reactor supervisor, at the controls while many of those associated with the project look on. In the crowd are (L to R): M. Pearce, W. Henderson, E. Critoph, D. Hone, D. Stewart, G. Baines, D. Hurst, A. Ward, J. Hilborn, J. Christie, A. Hart, D. MacCready, E. McDorman, D. Keys, E. DeGrey, G. Laurence, G. James, H. Collins, F. Gilbert, W. Fletcher, J. Sproule, J. Hueton, E. Philip, C. Sandrelli, C. Mawson, R. Dagenais, T. Burnup, P. Tunnicliffe.

NRU veterans pose for the camera during the special gathering at Deep River November 6, 1997, to commemorate the 40th anniversary of the start-up of the NRU reactor on November 3, 1957. L to R: John Inglis, Harry Collins, Ross MacEwan, Don Hurst, John Hilborn, Gerald Dolling, Phil Ross-Ross, Dave Thompson.

question of upgrading the old machine or letting it go to pasture. It was finally decided to keep it operating long enough to fill the gap until the construction of the planned new IRF (Irradiation Research Facility) in 2005.

Given the state of technology when NRU was designed and built, Thompson said that the reliability had been nothing short of astonishing. He recounted a number of events over the years:

- a rod failure in 1958 which caused a 4 month shutdown;
- conversion of the core, which was done in 6 months in 1963, to run on enriched uranium to increase the neutron flux available for research;
- extensive repairs to the vessel in 197;
- replacement of the calandria over a 27 month period in the mid 1970s;
- a failed fast neutron rod which caused a 2 month shutdown in 1984;
- a leaking through tube cost 7 months of down-time in 1985;
- the heavy water leak of 1991 that shut the unit down for 11 months.

Despite these difficulties, Thompson stated that, over its lifetime, the reactor has been available nearly 88% of the time

Don Hurst began the panel presentations by reviewing the steps that lead to the choice of NRU as NRX's successor. Although that was NRU's intended role, in fact the two workhorse reactors served side by side for decades to come. He reviewed the considerations that went into the choice of reactor design After reviewing many alternative designs it was decided to stay with the heavy water concept and a development panel was set up which narrowed the selection down to six types Dr. W.B. Lewis chose the name National Research Universal and the designation NRU was born. The USA provided a major source of funding in the early years by buying the spent NRU fuel elements (for their plutonium content). This also meant that Canada had no need to build a problematical reprocessing plant. Hurst pointed out that on-power fueling was at first rejected as being too difficult but as design progressed better than expected it was reinstated.

Harry Collins followed with stories of the reactor's construction, pointing out that NRU was the first reactor to become contaminated before startup, when an outside inspection company mishandled their radioisotopes in the reactor hall in February of 1957.

John Inglis, the man at the control panel in the famous photograph of November 3, 1957, shared his memories of that fateful day. A previous management decision avoided choosing a specific operator for this historic task by handing the honours to whichever shift happened to be on duty at the time.

John Hilborn, a key physicist at the time of startup, related a number of tales from the early days, including NRU's advanced use of "computer" technology for fuel shuffling. Duty physicists wrote details of each fuel rod on individual cards with specially-placed holes, and then slid knitting needles through a stack of such cards to choose the proper rods for a particular shift. Hilborn also noted that NRX experience with safety instrumentation was critical to the triplicated design of the NRU systems which has resulted in such remarkable reliability. He closed by noting that the NRU console had no chair. The control system was automatic and did not require an operator to sit at the console for the entire shift.

Gerald Dolling represented the research applications of NRU over the years, specifically the world-leading work in solid-state research by people like Nobel-laureate Bert Brockhouse. Phil Ross-Ross shed light on the birth of another of NRU's unique uses - the testing of full-scale CANDU pressure tubes in loops. Finally, Ross MacEwan continued the story of engineering applications with reference to fuel materials testing over the years, and the NRU testing that lead to innovations like the CANLUB cladding technology now implemented in all CANDU units.

Gerald Dolling summed up the review by stating that the criteria essential to the NRU success story were; the ability of the powers that be to make fast decisions involving huge expenditures; the availability of a vast array of expertise; the plutonium production incentive; the inspired philosophy of triplication of control instrumentation. These among many other attributes allowed the NRU reactor to play such a critical role in the pressure tube and fuel development for CANDU power reactors, to remain one of the worlds primary research tools and to provide nearly 85% of the world's medical radioisotopes.

AECB Comments on OHN Reviews and Plans

On August 13, 1997, the Chairman of Ontario Hydro released a report on the results of the *Independent Integrated Performance* Assessment conducted (IIPA) by a *Nuclear Performance Advisory Group* (NPAG) headed by Carl Andognini, a consultant from the USA and now Executive Vice President and Chief Nuclear Officer. Also that day, Ontario Hydro announced an "overhaul" program in which the four units of the Pickering A nuclear station and the three units at the Bruce A station still in operation would be "laid up", and the Bruce heavy water plant permanently shut down.

In September the Atomic Energy Control Board (AECB) issued a preliminary response to the IIPA report and the proposed overhaul program. A final report by AECB staff was tabled at the AECB Board meeting in mid November.

Following are excerpts from the Executive Summary of the IIPA report, from the announcement of the "overhaul" program, and from the AECB response report.

Excerpts from Executive Summary of IIPA Report to Management

Long standing management, process and equipment problems in Ontario Hydro Nuclear (OHN) plants are well known but have not been aggressively resolved. As a result, the overall performance of OHN is well below the level of performance typically achieved by the best nuclear utilities. Immediate attention is needed to improve performance so that the value of OHN's assets does not depreciate beyond recovery. There is still a tendency to look backward at past performance and take comfort rather than address the significant challenges of the future.

These concerns as well as other strategic issues led Ontario Hydro's Chief Executive Officer, Dr. O. Allan Kupcis to hire Mr. G. Carl Andognini as Executive Vice President and Chief Nuclear Officer (CNO) in December, 1996. Dr. Kupcis immediately directed Mr. Andognini to secure the type of "brutally honest" assessment of OHN conducted by the American nuclear industry. In January, 1997, Mr. Andognini chartered the Nuclear Performance Advisory Group (NPAG) to perform an Independent, Integrated Performance Assessment (IIPA) of OHN. The IIPA was conducted over a three month period. This report to management presents the findings of the IIPA assessment.

While the current course of action has significant financial consequence, the IIPA team confirmed that all of the plants were being operated in a manner that meets defined regulations and accepted standards related to nuclear safety. During the course of the assessment, a few issues were identified by the team that could undermine defense in depth barriers. These issues were raised to senior plant management and resolved to the satisfaction of the team.

In general, the IIPA team ranked all of the operating, stations (Pickering, Bruce and Darlington) <u>"Minimally Acceptable".</u> Immediate management attention however, is needed to improve performance or even to maintain current performance. The rank "minimally acceptable" is consistent with the lower ranks that the Institute of Nuclear Power Operators (INPO) would issue and still permit the plants to operate if in America. NPAG believes it is also consistent with a United States Nuclear Regulatory Commission (NRC) Systematic Assessment of Licensee Performance (SALP) rating that would likely result in the plants being placed on the "NRC watch list".

Unless fundamental problems, most notably <u>a lack of authoritative and accountable managerial leadership,</u> are addressed and corrected, there is limited potential for success at OHN. Moreover, many problems are so deeply entrenched within all aspects of OHN (organizational structures, practices, policies and systems) that individual managers are unable or unwilling to take corrective action.

Clearly, OHN did not make a smooth transition from it's original and highly successful design and construction phase to the second stage, focused on operating and maintaining its nineteen operating nuclear units. A full transition to the second stage requires a new approach to the culture, structure, and management of OHN, as well as a rethinking of employee skill mixes and the regulatory process. To excel, OHN must transform itself into a world class organization with a primary focus on operating and maintaining its existing assets. These standards of excellence were the basis for the IIPA assessment convened by the CNO.

OHN staff at every level are reluctant to ask difficult questions of themselves and others. Failure to establish a questioning attitude is a primary cause of the reduction in the "defense-in-depth" concept. There is no real independent evaluation of proposed operations by people not directly involved in formulating the planned actions.

In summary, there is much work to be done, at all levels in the organization, to reach the established standards of excellence expected in the nuclear industry.

Excerpts from Ontario Hydro Announcement of Major Overhaul

Ontario Hydro today (August 13, 1997) announced that its board of directors has approved a major overhaul of the Corporate production facilities in response to an extensive evaluation of its nuclear assets conducted during the past months by a team of experts.

Extensive upgrades will be made at the Bruce B and Pickering B units and at the Darlington generating station over the next three years. As part of its near-term plan, the A units of the Pickering and Bruce nuclear generating stations will be laid up over the next year.

To replace the electricity production from the laying-up of the Pickering A and Bruce A units, Hydro plans to run its Nanticoke and Lambton fossil generating stations at higher levels, as well as bring back into service mothballed units of the Lennox station.

Planned actions over the next five years include:

- The actions at the Pickering and Bruce B units and its Darlington plant will include updating engineering designs and processes, developing new management and organizational procedures, implementing improved maintenance and work practices and providing extensive staff training in all plants.
- Four units at Pickering A, and the three units at Bruce A, now in operation, will be laid up, and the Bruce heavy water plant will be permanently shut down. The timing of a return to service for the Bruce and Pickering A units will be determined by Hydro's Board, based on economic and market conditions.
- Hydro will replace the electricity generated by the Bruce A and Pickering A units by operating existing fossil plants such as Nanticoke and Lambton at higher levels and bringing back mothballed units at the Lennox station.

Excerpts from AECB Staff Report on Ontario Hydro's IIPA and SSFI

1. Introduction

In January 1997, Ontario Hydro announced that a team of nuclear industry experts from the United States, called the Nuclear Performance Advisory Group (NPAG), had been employed to help manage its nuclear program and to implement needed improvements in Ontario Hydro Nuclear (OHN) operations. In the spring of 1997, NPAG initiated a series of detailed reviews of OHN's operations, at its Pickering, Bruce and Darlington nuclear generating stations and in OHN's Head Office groups. These reviews, called "Independent Integrated Performance Assessments" (IIPA) and "Safety System Functional Inspections" (SSFI), were carried out in April and May of this year with the objective of developing "an integrated, accurate, and comprehensive understanding of the performance of OHN" (Reference 1). They were conducted in response to a request from the President of Ontario Hydro for a "brutally honest" assessment of Ontario Hydro Nuclear. NPAG has since been integrated into Ontario Hydro's line organization.

This report summarizes the detailed review of each IIPA and SSFI finding by AECB staff, as well as presenting a consolidation of these reviews and conclusions.

2. Description of the IIPA and SSFI Reports

The IIPAs applied performance objectives and criteria developed according to criteria of the World Association of Nuclear Operators (WANO), the U.S. Nuclear Regulatory Commission (USNRC) and OHN. Their results were judged against industry standards (defined by Ontario Hydro as the key parameters used by the Institute of Nuclear Power Operations (INPO) / WANO in their performance monitoring program). These key parameters include the essential nuclear safety and environmental aspects of operation. Additionally, Ontario Hydro applied criteria related to cost competitiveness, such as the efficiency of station operations, the utilization of resources and long term viability of corporate assets, which are not within the AECB's regulatory mandate. Ontario Hydro did not generally judge the IIPA results against Canadian regulatory requirements or standards.

SSFIs are modelled after the "vertical slice" audit methodology developed by the USNRC. An SSFI reviews the design and maintenance of a system by investigating change control, operations, maintenance, training and other areas. The purpose of an SSFI is to confirm that the system or function being reviewed will fulfill its safety mission and to ensure that inadequacies do not exist which may cause challenges to safety systems. AECB staff also uses this inspection technique, although usually to a reduced scope.

3. AECB Staff Renew of the IIPA and SSFI Reports

In assessing the safety significance of individual IIPA/SSFI findings and the need for prompt regulatory action, AECB staff considered the following factors:

- previous or existing AECB positions with respect to the issues identified in the reports,
- compliance with AEC regulations, licence conditions, station Operating Policies and Principles and AECB regulatory documents,
- comparison with IAEA Codes, Practices and Safety Guides,
- effect on defence-in-depth (processes, safety barriers, etc.),
- compliance with applicable Nuclear Codes and Standards (Canadian Standards Association, American Society of Mechanical Engineering, etc),
- changes in overall risk relative to information in OHN Probabilistic Risk Assessments and licensing submissions,
- potential for and magnitude of changes to predicted consequences of accidents reported in station Safety Reports, and
- potential changes in risk to workers.

The AECB staff review of individual findings has determined that no individual finding required immediate and decisive regulatory action to ensure public and worker safety. The majority of the findings were already known to AECB staff.

Almost ten percent of the findings relate almost exclusively to efficiency or cost effectiveness and are therefore of little or no regulatory interest to the AECB.

3.1 Configuration Management and Change Control

Configuration management is the process that assures that safety analysis, design, operating, maintenance and training documentation remains up-to-date, consistent with the physical state of the plant and that changes are documented and in accordance with the change control process.

Our assessment has put almost 15 percent of the IIPA and SSFI findings into this category. Ontario Hydro's SSFI and IIPA reports concluded that in the majority of cases there was a failure to control change and a lack of configuration management. Ontario Hydro found that this has led to the absence of accurate up-to-date records of changes in addition to incomplete evaluations of the impact of these changes on plant risk.

Our review identifies that while the original design bases appear to be adequately documented, Ontario Hydro does not have sound change control or configuration management processes.

3.2 Environmental Qualification

EQ was the subject of an Ontario Hydro SSFI and the conclusions state that the EQ program at Ontario Hydro suffers from inaction and management neglect.

AECB staff is in full agreement with the IIPA/SSFI findings regarding EQ. AECB staff raised the issue of EQ in the early 1980s during the commissioning of Bruce B, Pickering B, Darlington and the CANDU 6 plants. In the late 1980s, Ontario Hydro established a corporate EQ program for its nuclear stations. Ontario Hydro generated a corporate EQ policy and associated guidelines, and regular update meetings were held between Ontario Hydro and AECB staff. Work progressed reasonably well under the direction of a corporate Ontario Hydro group. In Ontario Hydro's 1993 reorganization, this corporate group disappeared and EQ responsibility shifted to individual stations. Ontario Hydro has made little progress since then, despite AECB staff raising several action items. AECB staff has expressed concern for this lack of progress.

3.3 Maintenance, Testing, Inspection, and Surveillance

Almost 15 percent of the IIPA and SSFI findings deal primarily with maintenance, testing, inspection, and surveillance.

AECB staff agrees with these IIPA/SSFI findings, and has noted similar findings in its audits, assessments, inspections and routine regulatory monitoring for the past few years.

AECB staff believes that poor maintenance is a significant contributor to the problems that Ontario Hydro now faces.

Each Power Reactor Operating Licence already includes a specific condition on maintenance and Board Member and AECB staff concerns regarding maintenance have been communicated to Ontario Hydro at licence renewals, in AECB staff audit and assessment reports, in annual assessments of station operation and during AECB staff's routine interaction with Ontario Hydro. Although Ontario Hydro has introduced many programs to improve maintenance, the implementation has been slow and of variable quality.

3.4 Management / Leadership / Organization / Resources

Our assessment has put almost 25 percent of Ontario Hydro's IIPA/SSFI findings in this category. Ontario Hydro's review found all of the above areas to be deficient.

Ontario Hydro, in its 1993 reorganization, made the decision to reduce the corporate support services and distribute the responsibilities and staff to individual stations. At that time, AECB staff expressed some concerns. However, AECB staff accepted Ontario Hydro's assurances that they could successfully implement a decentralized Ontario Hydro.

Other findings comment on the lack of resources for various activities associated with station operation. AECB staff has made similar comments in its annual assessments of station operation and during its audits and assessments.

A percentage of the findings comment on poor management and leadership. AECB staff's routine regulatory work focuses on results and therefore does not directly assess licensee management and leadership.

AECB staff is currently working to develop tools and techniques to assess licensee organizational and management effectiveness.

Our audits and assessments have identified a lack of corporate direction for many programs since the 1993 reorganization.

3.5 Procedures

A number of IIPA/SSFI findings deal with procedures and compliance to procedures. Our audits, assessments and routine review of licensee event reports continue to identify problems with procedures and compliance to procedures.

3.6 Quality Assurance

In this category, we include those findings related to self-evaluation of performance, problem identification, corrective action process and quality assurance programs in general. Our assessment has put almost eight percent in this category. Ontario Hydro's review found all of the above areas to be deficient.

In our routine regulatory work, AECB staff has found that Ontario Hydro does a reasonable job of identifying specific technical deficiencies in its nuclear power stations. However, over the past few years, our audits, assessments and other inspections have consistently found that Ontario Hydro has not always identified human performance deficiencies or completed the necessary root cause determination for specific technical deficiencies.

AECB staff has not yet found any Ontario Hydro station Quality Assurance Program to be fully satisfactory.

3.7 Radiation Protection

Radiation doses to Ontario Hydro workers are well below regulatory limits. This is, in AECB staff's opinion, partly due to the effectiveness of Ontario Hydro's radiation protection programs.

AECB staff concurs that contamination control is a problem at some Ontario Hydro stations. We have investigated these problems thoroughly and reported our findings to the Board in Significant Development Reports and in AECB Staff Annual Assessments of Station Performance. We expect strong action on contamination control now that Ontario Hydro's IIPAs and SSFIs have recognized the extent of the problem.

AECB staff has generally been satisfied with Ontario Hydro's ALARA efforts.

Ontario Hydro changed from corporate coordination and control of radiation protection programs to station control in its 1993 reorganization. At that time AECB staff, and some Ontario Hydro staff, expressed some concern over the effectiveness of the proposed changes. The IIPA/SSFI findings confirm that these concerns were well founded. However, AECB staff believes that either system can work provided it was implemented correctly.

3.8 Safety Assessments

About 10% of the IIPA and SSFI findings relate to issues that could affect the consequences of design basis accidents or external events, such as earthquakes, as reported in Safety Reports and assessments submitted to the AECB in support of the licensing of the Bruce, Darlington and Pickering stations.

AECB staff agree with IIPA/SSFI findings that Ontario Hydro does not pay enough attention to the seismic qualification of its stations. AECB staff did not know of these specific details prior to its review of the IIPAs and SSFIs.

Fire protection has long been a concern of AECB staff. In the late 1980s, AECB staff initiated a review of Ontario Hydro's in-station fire response capability. Fire response experts on contract to the AECB concluded that Ontario Hydro's capability was less than adequate. Ontario Hydro formed a team under its Quality Improvement Process of the early 1990s to review the state of fire response in Ontario Hydro nuclear generating stations.

Subsequent assessment of fire response capability by AECB consultants confirmed that these changes were effective and concluded that Ontario Hydro staff could successfully deal with a large fire in the station.

Canadian Standard Association standard CSA N293-95, Fire Protection for CANDU Nuclear Power Plants, was issued in 1996. Since they were built prior to this standard coming into effect, Ontario Hydro nuclear generating stations do not meet all the requirements of CSA N293-95. However, in September 1996, AECB staff placed an action on all nuclear power plant licensees requiring that licensees assess their current program against the standard and review each station's Fire Hazard Assessment. Ontario Hydro has submitted plans and schedules for this work.

3.9 Training

Almost ten percent of the IIPA/SSFI findings deal with training issues.

AECB staff has not systematically evaluated training programs or Ontario Hydro Shift Supervisors and Control Room Operators since Ontario Hydro had committed to major changes to those training programs. AECB staff assesses the competence of potential Shift Supervisors and Control Room Operators through a set of comprehensive, rigorous examinations prior to certifying them for those positions.

AECB staff's routine regulatory work, including audits, appraisals and other inspections, often touches on training programs. In every case, AECB staff has brought deficiencies to Ontario Hydro's attention, with requests for specific action.

4. Defence-In-Depth

4.1 General

To compensate for potential human and mechanical failures, a defence in depth concept is implemented at nuclear power plants. This concept is centred on providing several levels of protection, including successive barriers, to prevent release of radioactive material to the environment. The concept includes protection of the barriers by averting damage to the plant and to the barriers themselves. It includes further measures to protect the public and the environment in case these barriers are not fully effective.

Defence in depth is one of the fundamental principles of power reactor design and operation. It underlies the safety technology of nuclear power. All safety activities, whether organizational, behavioral or system and equipment related, are subjected to layers of overlapping provisions so that if a failure should occur it is compensated for or corrected without causing harm to individuals or the public. Two corollary principles of defence in depth are accident prevention and accident mitigation.

4.2 Accident Prevention

Accident prevention is achieved by conservative design, quality manufacturing and construction, quality in operations and maintenance, safety culture and quality assurance. AECB staff considers that Ontario Hydro stations were well designed and constructed in accordance with codes and standards in place at the time they were built. However, AECB staff agrees with the IIPA/SSFI findings that a commitment to high standards of quality did not necessarily carry forward into station operations and maintenance.

AECB staff judges that, while defence-in-depth has been eroded at Ontario Hydro stations in the area of accident prevention, sufficient safety margins remain.

4.3 Accident Mitigation

Accident mitigation is achieved by having systems, equipment and procedures for the control and mitigation of design basis accidents, providing emergency operating procedures and guidelines to aid the operators in accident management, providing engineered safety features to minimize and control releases of radioactivity to the environment and having in place preparations for off-site emergency actions should they be necessary.

AECB staff judges that, although the IIPAs and SSFIs indicate departures from the defence in depth approach related to accident mitigation, the state of the accident mitigation provisions at OHN plants is currently adequate. The basis for this judgment is that mitigation systems on these reactors are well designed and contain sufficient redundancy that they are expected to perform adequately during accidents.

AECB staff is aware of the weakness in Ontario Hydro's emergency preparedness.

5. Basis for Continued Operation

As part of the IIPA and SSFI reviews, Ontario Hydro prepared a document titled Basis for Continued Operation for its Board of Directors. Although Ontario Hydro considered it to be the key justification for continued operation of its reactors, the Basis for Continued Operation was, by itself, insufficient for regulatory purposes. Therefore on August 29, 1997, AECB staff actioned Ontario Hydro to provide, among other things:

1) a formal assurance to the AECB that Ontario Hydro considered it safe to continue operation of the reactors, in light of the findings of the IIPA; and,
2) the basis for such assurance, which takes into account the limitations in the extent of the IIPA.

We received Ontario Hydro's reply on September 15, 1997. This reply contained a clear statement from Ontario Hydro that " it... has a high level of confidence that it is safe to continue operation of (its) reactors." based on the information it had to date.

AECB staff met with senior Ontario Hydro staff on September 30, 1997 to discuss the September 15th response. At that meeting, Ontario Hydro made it clear that a process called Technical Operability Evaluation was the key to determining acceptability of continued operation in light of current and future review findings. The probabilistic risk assessments mentioned in the Basis for Continued Operation and again in their September 15th response were only used to provide additional support for the results of the Technical Operability Evaluations.

Neither AECB Staff s detailed reviews of individual IIPA and SSFI findings, nor the integration of these individual findings, have revealed an issue requiring immediate licensee action to put Ontario Hydro stations into a safer state.

We judge that the systems important to plant safety are expected to perform their safety function successfully when called upon to do so, and believe station operating experience supports this expectation.

6. Ontario Hydro Improvement Program

6.1 Nuclear Asset Optimization Plan

Ontario Hydro's long term plans to address IIPA findings are outlined in an Ontario Hydro document titled Nuclear Asset Optimization Plan (NAOP).

AECB staff judges that NAOP addresses all of the areas identified by the various IIPAs and SSFIs.

6.2 Performance Indicators

Ontario Hydro submitted to the AECB a set of 136 performance indicators it intends to use to measure its own performance in the future. Again, it is important to note that this is an Ontario Hydro document created for internal use. The performance indicators were not specifically created to satisfy the AECB.

AECB staff has completed a preliminary review of Ontario Hydro's indicators to determine their usefulness to both the Board and AECB staff, and has concluded that Ontario Hydro's performance indicators may not be suitable for use by the Board or AECB staff to measure improvements in operational safety, even if the performance indicators suit Ontario Hydro's own needs.

7. Conclusions

Based on the results of its reviews of the IIPA and SSFI reports, it is concluded that:

1. AECB staff agrees with most of the Ontario Hydro's IIPA/SSFI findings. However, although there are some concerns regarding contamination control, AECB staff is generally satisfied with Ontario Hydro's radiation protection program and has seen examples of good performance in other areas.

2. Other than some very specific plant equipment condition findings, IIPA/SSFI findings were known to AECB staff.

3. AECB staff review has not identified any reason why the reactors cannot continue to operate safely in the short-term.

4. Defence-in-depth has been eroded at Ontario Hydro nuclear generating stations. Although sufficient margin remains at present, significant improvement is necessary in Ontario Hydro's operations, as we have stated and concluded in previous reports to the Board, to improve safety margins and to prevent further deterioration in performance.

5. AECB staff will need to track Ontario Hydro's plans. Ontario Hydro's Nuclear Asset Optimization Program provides a starting point for this.

6. Ontario Hydro performance indicators may not be suitable for use by the AECB in measuring safety improvement at Ontario Hydro nuclear generating stations.

New Organization at AECB

Dr. Agnes Bishop, president of the Atomic Energy Control Board has announced a modification to the organization of the agency to take effect in January 1998.

The five directorates and their directors-general remain the same but the distribution of divisions and responsibilities of those divisions has been changed.

Directorate:	**Director General**
Secretariat	Pierre Marchildon
Corporate Services *(Formerly Administration)*	George Jack
Reactor Regulation	Jim Harvoe
Fuel Cycle and Material Regulation	Murray Duncan
Analysis and Assessment	John Waddington

Secretariat

Three divisions and three special groups

Divisions:

External Relations and Corporate Documents	Cait Maloney
Communication	To be announced
Non-Proliferation, Safeguards and Security	Harold Stocker

Special Groups:

New Act Implementation	Ross Brown
Board Services	Bernard Gerestein
Secretary, Executive Committee	Bernie Ewing

Corporate Services:

Human Resources	
Finance	H. Dupéré
Information Management	Bill Goodwin

Reactor Regulation

Power Reactor Operations	Robert Leblanc
Power Reactor Evaluation	Mike Taylor
Safety Evaluation "A"	Peter Wigful
Safety Evaluation "E"	Kurt Asmis

Fuel Cycle and Material Regulation

Uranium Facilities	Tom Viglasky
Materials Regulation	Ron Thomas
Wastes and Decommissioning	Richard Ferch
Research Facilities and Accelerators	Aly Aly

Analysis and Assessment

Radiation and Environmental Protection	Mary Measures
Organizational Assessment	Ken Piereira
Personnel Assessment	Gary Schwarz

and two special groups

Technical Training	Joe Didyk
Research and Support	to be announced

In her communication to AECB staff, Dr. Bishop emphasized that there would be more of a "project management" approach wherein specialists from different divisions would work together on a common issue or problem It was this philosophy that resulted in the transfer of the two Safety Evaluation divisions from the Directorate of Analysis and Assessment to Reactor Regulation Most of the work of these divisions is directed at power reactors. Also, the new Power Reactor Evaluation division is intended to work primarily on a "project management" basis.

The division on External Relations and Corporate Documentation is a new one to enable the AECB to relate better with other government departments and agencies and other organizations. Access to Information and Studies and Codification will be included in this new division.

The position of director of the Communications Division is open since Hugh Spence, the current chief of public information, has announced his intention to take early retirement.

Another new division, Organizational Assessment, will, among other things, include reviews of quality assurance and human factors and investigation of events. The Personnel Assessment division will pick up the work of operator certification and will become responsible for assessment of competence of key staff at all major licensees.

Call for papers

Papers are invited for a special session at the 1998 ASME International Congress and Exposition being held in Anaheim, California, 15 - 20 November 1998. The session is on Characterization of flow Patterns in Multi phase Flow systems.

Abstracts of approximately 500 words should be sent by 5 January 1998 to:

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Reducing Global Carbon Dioxide Emissions

Ed. Note: *Following are extracts from a recent statement issued by the International Nuclear Societies Council (INSC) on the role of nuclear power in reducing emissions of CO2. The INSC is made up of representatives from almost all of the nuclear societies in the world, including the Canadian Nuclear Society. The CNS has sent this message to federal and provincial leaders in their preparation for the Kyoto Conference.*

The International Nuclear Societies Council believes that the world's capacity for generating electricity from nuclear power must be increased substantially, if we are to meet the ambitious targets for reducing global emissions of carbon dioxide.

A central tenet of the Third Conference of the Parties (COP3), to be held in Kyoto in December 1997, is that carbon dioxide from the combustion of fossil fuels may cause changes in the earth's climate. An objective of the Conference will be to set limits on the emissions of carbon dioxide.

Little progress has been made in meeting the target of the Rio Accord of 1992 to reduce carbon dioxide (CO2) emissions to 1990 levels. While over the last 30 years there have been increases in CO2 emissions from the US and other countries of the organization for Economic Co-operation and Development (OECD), most of the increase has occurred in the developing world, as those countries strive to develop market economies and raise their standards of living. Over the period 1990-1995, this large increase was offset by a reduction in emissions from the Former Soviet Union (FSU) and the Eastern European countries, because their economies slowed dramatically. It is to be expected that there will be no further decreases in their emissions. Today, about one quarter of the carbon dioxide emissions comes from the US, one quarter from the rest of the OECD, and half from the rest of the world.

It is now generally accepted that the global energy demand will increase by two to three times by the middle of the next century. Energy demand in the developing countries is growing by over 4% per year and already accounts for over 30% of the global total. Its growth is likely to continue at a much higher rate than in the OECD countries.

With these patters of growth, reductions of 20% in emissions from the OECD countries will not achieve a global reduction in carbon dioxide emissions. For example, if the OECD countries were to reduce emissions by 20%, and if the developing countries were to maintain their economic development with emissions following the trends of recent years, then the resulting global emissions in 2015 would be30% higher than in 1995.

Thus energy conservation programs in the OECD are by no means sufficient. Furthermore, the major gains in energy efficiency during the 1970s and 1980s have already attacked the easy targets; further gains will be more difficult and costly. To have any real impact on global carbon dioxide emissions, the principal emphasis must be on energy sources other than fossil fuels.

Renewable energy sources can contribute to the solution. The only commercial large scale renewable energy in use is hydroelectric power, which today contributes about 3% of the global energy supply. It could be expanded to replace about 3% of the additional energy demand, if all potential rivers were developed. In any event, the additional energy provided would have little influence on the total energy picture. No other renewable energies have yet demonstrated commercially economic and reliable energy production on a large scale, and today they have no measurable contribution to the global energy supply. Even with large government development and operating subsidies, it is doubtful that these could provide even 10% of the energy supply within two decades.

Nuclear power is the only sustainable energy option available today that can significantly reduce carbon dioxide emissions. After several decades of development by governments and investment by electric utilities, it currently provides about 7% of the world's energy supply. Nuclear power is a zero-carbon energy source that is commercially proven, safe in operation, does not produce other greenhouse gases, and contains its waste products. The technology for permanent disposal of waste is already well advanced and needs firm political action to put it into operation. By using demonstrated technologies, nuclear fuel reserves in nature can be extended for centuries of operation. An important feature of nuclear power is that the cost of fuel and operation is relatively small compared with capital cost. Thus, once built, nuclear power plants produce electricity at a cost that is relatively insensitive to inflation or the fluctuations of prices on the world energy market.

However, neither the renewable energy technologies nor new nuclear power plants can compete economically with pipeline natural gas at current prices, wherever it is readily available. In both cases, the initial capital cost is too high.

Thus, radical measures will be needed, if the objective truly is to reduce carbon dioxide emissions. These measures must be undertaken in the context that a moral priority for the coming century will be to help all countries achieve a reasonable standard of living. To do this, the developing countries must industrialize to generate enough wealth to support a higher standard of living, which in the long term will reduce their rate of population growth. This is the only solution that has been demonstrated to stabilize population growth.

Given all these factors, and the global thrust to market economies, the only practical strategies available to governments in their initiative to reduce carbon dioxide emissions are to impose taxes on the emissions, or to provide subsidies for energy produced from non-fossil resources, or a combination of these measures.

Thus, the International Nuclear Societies Council believes that governments should acknowledge the significant impact that nuclear power has played in limiting global carbon dioxide emissions. Furthermore, to minimize future emissions, governments should:

- continue to strive for increased efficiency of energy use
- encourage the use of renewable energies, where they can be shown to be economically beneficial and environmentally acceptable
- strongly encourage the continued operation of existing nuclear power plants and facilitate the extension of their operating life
- support the development and deployment of new, optimized, cost competitive nuclear power plants

1998 Conference of the Canadian Radiation Protection Association

The 1998 CRPA Conference will be held in Ottawa, Ontario, 24 - 28 May 1998

Papers are invited on any area of health physics. A special invitation is extended to students

Summaries of approximately 500 words in French or English (preferably both) should be submitted by 31 January 1998 to:

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Nuclear Energy in the Marketplace of Ideas

by Hugh Segal

Ed. Note: *The invited banquet speaker at the 4th CANDU Maintenance Conference in Toronto, November 17, 1997, was Hugh Segal, one time head of staff for Prime Minister Brian Mulroney and now a Resident Fellow at the School of Policy Studies of Queen's University. Although a full report on the conference will not be available until the next issue, Segal's remarks were timely and well received by his audience. Following is a slightly edited version of his notes for the talk.*

Let me begin by sharing my biases with you.

I was associated with the Ontario government when the decision was made to build Darlington, and to do so without an environmental assessment. I not only agreed with that decision, but enthusiastically believed it was right for Ontario. The net savings to the environment by moving much of our generating capacity into nuclear have been and remain overwhelming. The facts do not allow one to deny how far behind we would be [environmentally], if we had been generating from fossil fuels what we have generated for Canada's industrial and economic heartland from nuclear reactors.

My other bias, and I have held it for a long time, is that the "market place of ideas" is like many others. Vacuums are filled when they are created. They will be filled by other agendas when the main agenda is left by the side of the road. Call it the reality of competitive debate. Call it the reality of the media pendulum. When it swings in one direction, it will always swing back to the other.

Whatever theory one applies, the present construed anxiety about nuclear energy is not just the fault of Ontario Hydro's senior leadership and how they have failed to manage their present circumstance, but also the direct result of the vacuum created by the nuclear industry in Canada which decided some years ago to vacate the field of public communications, advocacy, and public education.

I submit to you that it was not the consultants' report at Ontario Hydro that created the present sense of crisis. It was the mix of that report and the atmosphere into which it was released that combined to produce the official over-reaction and hypersensitivity we now face.

For senior Hydro leadership, there was another choice. Rather than a concerted effort to put the report in some context and indeed reflect in a balanced way on the benefits and costs of nuclear generation (a reflection that could not but emerge on the side of the nuclear option overall), there was a kind of seance - like an embrace of fear for fear's sake. The fact that it [the Ontario Hydro "re-structuring" program] was unjustified by either the technology or the safety record seemed neither here nor there. Irresponsible reference to a 'nuclear cult' diminished the thousands of engineers and employees of both Hydro and the companies that have supplied Hydro over the years, and who are among the very best anywhere in the world.

Hugh Segal

I will set aside my natural scepticism about any consultant whose report produces a permanent job for that consultant in implementing the results of that report. I have always treated people and their work with respect and in good faith. So I am not here tonight to question the results of the consultants' study.

But what I regret and lament is the failure of the Board of Ontario Hydro and its Chairman to put the report, the overall technology, CANDU performance and nuclear generation into some sort of overall context.

The sorts of pillars that would have supported that context are as follows:

- Of the 33 CANDU reactors worldwide, only six are shut down, and they are the oldest.
- CANDU performance ratings outdo all others kinds of reactors. *(Ed. note: Not recently)*
- Almost 20% of all electricity in Canada comes from nuclear power. In Ontario that number is 60%
- To date, the use of non-greenhouse gas emitting nuclear generation has saved Canada's environment from
  - 800 million tonnes of C02 gas,
  - 80 million tonnes of coal ash
  - 32 million tonnes of S02 gas
- The nuclear industry has an annual trade surplus of 500 million dollars, with the only other trade surplus high-tech industry being aerospace.
- Between 1962 and 1994 the nuclear industry contributed 34 billion dollars to our GNP, while the investment in R&D since 1952 has only been 5 billion.

Absent these pillars, plus the sheer reality that no Canadians have ever been killed or injured because of a Canadian nuclear plant's operation, there was no balanced context. It became open season for the anti-nuclear lobby, the solar-panel salesmen and wind-mill proponents. The lack of a framework around issues like efficiency of output, security of supply and environmental benefits only provides a variant playing field for the forces of angst who are free to spread fear everywhere they can.

What is also troubling is the silence of the Canadian Nuclear Association and its supporting industries and suppliers. If it, or they, believe that one can get the lion to go away by feeding it, they are absolutely wrong and, if I may say so, will become part of the problem and not part of the solution.

That a portion of Ontario Hydro's reactors should be sidelined for repair is neither a condemnation of the technology or the energy source. Mechanical systems, however well engineered, need retooling and maintenance and rebuilding. This should be neither surprising nor disquieting.

Changing economics, changing uses of electricity and energy because of miniaturization and information technology should require market-sensitive structural changes in Ontario Hydro. This too is neither a matter of great surprise or great import. It is a mistake to pretend otherwise.

There are other shibboleths that need to be addressed, such as the canard about public subsidy, and the distortions about permanent waste disposal and manageability.

I have examined the multi-disciplinary and international analogue research relative to deep shield disposal. I have seen the plans on both the technology and siting issues. While I am neither a geologist nor scientist, no human being can look at this research and know the men and women who have dedicated much of their professional lives to its objective completion, without concluding that this is a serious, high integrity effort by the best of minds and finest of people to ensure that every possible calculation can and is made in determining the safety and appropriateness of the deep-disposal proposition.

I can think of no industry that has gone about the task of planning for the socially responsible disposal and management of its own waste more thoroughly and more exhaustively.

And all this at a time when the country [was] seized with the fears of a lack of federal leadership relative to greenhouse gases and the Kyoto conference ! The cascading ironies here are almost too much to bear.

Reverting for a moment to my pendulum theory of media and public attitudes, I believe that the present excess of angst about safety and the sad failure of leadership on the part of the Ontario Hydro Board, constitutes not an irrevocable setback but an immense opportunity.

It is at this low point that people begin to look for the other side of the story, the balancing equation. Miss this opportunity, and the nuclear industry will miss an opportunity that may not come along quite this way ever again.

It requires some leadership, focus, resources and courage. But most things of value usually do.

But an integrated program of taking the case of the industry to the public, and the marketplace of ideas is long overdue. The Canadian nuclear industry has been out of the marketplace of ideas now for at least five years if not more. My friends, no industry, however outstanding, can afford that kind of luxury.

The economic case, the case for the superb technology, the safety record, the export and employment case, the environmental and medical research case, have never mattered more. Failure to advance the case for the industry will see the prospects for the industry severely curtailed. This would be a bad thing for Canadian energy requirements, technology, employment and energy security.

Let me summarize my message as succinctly as possible:

The failure of leadership at Ontario Hydro on nuclear power is a symptom of the larger malaise caused in part by the nuclear industry's silence.

Any continuing failure to communicate the compelling public benefits of the industry will only deepen the problem.

On every front: - technology, CANDU safety, relative productivity, economic benefit, environmental benefit and job generation - the story is powerful. But if the industry chooses not to tell it, it simply will not get told.

The rule of the "marketplace of ideas" that determines our democracy's decisions and trends is very simple. Deposits are made in the public goodwill and understanding account, and when crisis strikes, those deposits can be withdrawn to see the crisis through. The recent crisis atmosphere at Ontario Hydro was at least in part because the nuclear industry had stopped making deposits in the account of public understanding and goodwill. When the time to make a withdrawal came, the account went quickly into overdraft.

I believe that this can be reversed. It has happened in the past. It can happen again.

But if the industry does take a serious leadership position, it will not happen, and the result for the industry and Canada may well be unnecessarily discouraging as a result.

Season's Greetings

And apologies.

It had been intended that this issue of the *CNS Bulletin* would be out in mid November. For various reasons that did not happen and then we got entangled with the strike in the Canadian postal system.

The net result will be that some of our readers, especially those in other countries, may not receive the Bulletin until the new year. We regret that but are unable to do anything about it.

Fred Boyd
Editor, *CNS Bulletin*

CNS news

BRANCH NEWS

The problems at the nuclear power stations, especially those of Ontario Hydro, have resulted in limited activity at the associated CNS Branches.

Bruce

The meeting scheduled for September was cancelled as a result of the uncertainty caused by many changes at Ontario Hydro and, particularly, the announcement of the shut down of Bruce A.

On October 23, Neville Fairclough gave an interesting talk on CANDU 9 Design and Constructability. A meeting was planned for November 11 with Joe Kappes, one of the NPAG members from the USA and Maintenance Manager at Bruce.

Eric Williams remains as chairperson of the Branch and is looking for new members for the Branch executive.

Chalk River

The Branch held a seminar on October 23 with Glen MacGillivray of Nray Services Inc. speaking on "Neutron Radiography: Life After Chalk river"

On November 6 the Branch co-sponsored a special commemoration of the 40th anniversary of the start-up of NRU. (See separate article in this issue of the CNS Bulletin.)

Darlington

There has been no activity this fall but chair Richard Murphy hopes to resume a Branch program after things settle down in OHN.

Golden Horseshoe

The Golden Horseshoe Branch, based at McMaster University in Hamilton has a new executive with David Jackson (formerly with the Canadian Fusion Program) as chair and Hassan Basha, Dave Novog, Vladimir Khotylev, Simon Day and Dave Kingdon.

Frank Saundes, manager of the McMaster Nuclear Reactor and Elise Herzig, director of commercial operations, presented a seminar on October 29, entitled "McMaster Nuclear reactor: A Critical Link in Your Chain reaction" The new CNS Membership certificates were handed out to those present.

Manitoba

Branch chair Morgan Brown has been active speaking to the Science Teachers' Association of Manitoba and to the science classes at Pinawa Secondary School.

The Branch has prepared a "Canadian Nuclear History Calendar" for 1998. Anyone wishing copies for distribution or sale should contact Morgan.

New Brunswick

Branch executive member Mark McIntyre reports on recent seminars. On October 14 roger Humphries (formerly with AECL and DND, now president of Candesal Enterprises Ltd.) Provided an interesting look at the CANDESAL process for desalination and the potential for combining it with a CANDU reactor. The process makes use of the waste heat from the turbine condenser to increaser the efficiency of a reverse osmosis process.

On November 4, Doug Borehamof AECL-CRL gave such a interesting talk on the biological effects of radiation that he was booked for two additional talks at Point Lepreau and at UNB.

Ottawa

The Branch plans to have Roger Humphries give his desalination talk on November 20.

The executive, under chairperson Mohamed Lamari have been in office for three years and are becoming discouraged with the low response to meetings. Unfortunately, there are not a large number of CNS members in the Ottawa area and they are very diverse. If efforts this season do not result in greater turnout there is a likelihood that the executive will all resign and the Branch will go dormant.

Pickering

As with the other Branches based at Ontario Hydro plants the Pickering Branch has been inactive this fall

Sheridan Park

Unlike many of the other Branches, the Sheridan Park Branch has been quite active.

On September 10, Professor Albert Reynolds of University of Virginia spoke about the educational program there aimed at high school teachers and about his book "Bluebells and Nuclear energy" which is used as the basic text for the one-week course. (A similar course is planned for McMaster University for the summer of 1998.)

On September 16 Roger Humphries gave his talk on desalination (see above) and on October 10 Professor Sadao Hattori of Japan spoke on the effects of low levels of radiation.

The Branch has an active education program, including the preparation of an education kit and participation in the Sheridan Park career day.

NEWS OF MEMBERS

Stan Hatcher, one time president of Atomic energy of Canada Limited and now a consultant, became president of the 16,000 member American Nuclear Society in June. Stan was chairman of the Pacific Nuclear Council for three years before taking on the ANS post.

Pierre Charlebois, formerly with Ontario Hydro is now associated with Canatom.

Ken Talbot has established a consulting firm, Nuken Services Inc, based in Brooklin, Ontario.

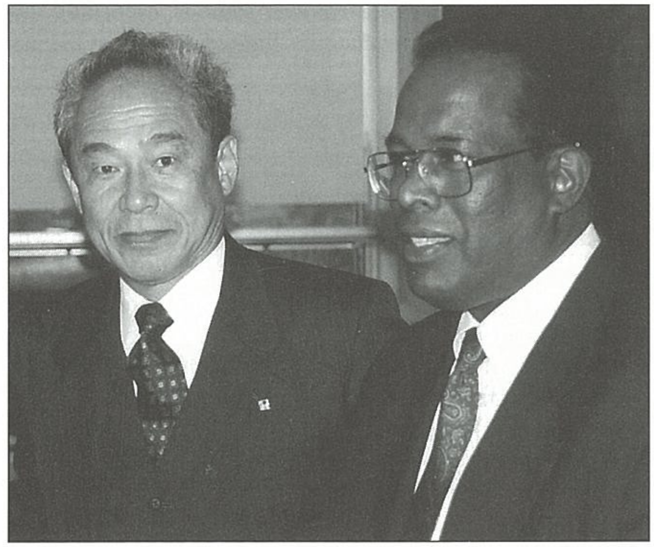
PBNC98 and Retirees

The organizers of PBNC98, the large international event being held in Banff in May 1998 have announced that they will offer a reduced fee to CNS retirees. More information will be n the next issue but those interested, and qualified, should contact the PBNC organization.

New Members

Following are names of new members of the Canadian Nuclear Society since the last issue of the CNS Bulletin.

Fred P. Adams
Xin Bai
Hassan Basha
Denis Robert Boucher
Phillip Bradbury
Adrian Bujor
Gordon R. Burton
Catherine Ann Green
John Handbury
Carol Harley
Sadao Hattori
David P. Jackson
Jaafar Karouni
Muhammad Riaz Khan
Vladimir Alexandrovich Khotylev
Evan Daniel McHugh
James Muckerheide
Hyun Taek Park
J.A. Keith Reid
Jay Sarkar
Douglas Scott
Rayman Sollychin
Lois Susan Stevenson
Asmedi Suripto
David Tregunno
Stan Shih-Tse Yin
Shudong Yu



Dr. Sadao Hattori from Japan poses with Dr. V. Eloqupillai, Director of the newly formed Centre for Low Dose Research at the University of Ottawa pose prior to Dr. Hattori's lecture, October 9. This was the first formal lecture presented by the Centre. Dr. Hattori also gave papers at Chalk River and in the Toronto area during his visit.
The CNS was one of the first sponsors of the new Centre.

Obituaries

Iain Lee

It is with sadness that we note the sudden and unexpected death of Dr. Iain Lee, the senior project officer for the Atomic Energy Control Board at the Point Lepreau NGS. Only 48, Iain collapsed and died suddenly at the Ottawa airport on November 11, 1997, just after deplaning from a flight from Saint John.

Born in the U.K., Iain earned his Ph.D. in chemical engineering at Salford University. He came to Canada in 1981 and joined the AECB shortly thereafter. He served as a project officer at other nuclear plants and spent a period in Korea. Iain was held in high regard by those in the plants he oversaw for his strong technical abilities, pragmatic philosophy, calm demeanor and good sense of humor.

Special memorial services were held at the Hope Cemetery Chapel in Ottawa and at the AECB offices. His ashes will be taken back to England and scattered near his childhood home.

John Stewart

Another early pioneer of the Canadian nuclear program has passed away. Dr. John Stewart died in Ottawa on August 1, at the age of 89. He obtained his undergraduate degrees from Queen's University and his Ph.D. from Cornell University and pursued further studies at Princeton and Leipzig Universities.

After serving as a radar officer with the R.C.A.F. during World War II he joined the early physics group at Chalk River.. John worked on both the practical physics of reactors and theoretical mathematical physics.

After retirement in 1971 he lived mostly in Ottawa where he was active with the local branch of the CNS.

To All CNS Members

At the Annual General Meeting of the Society in June 1997, your Council was authorized to "examine in detail" the incorporation of the Canadian Nuclear Society as an independent, non-profit corporation under federal law. (See Vol. 18 , No. 2, Summer 1997, issue of the CNS Bulletin.) Your Council has responded to that directive and will soon formally recommend to members that incorporation proceed.

As background: when the Society was formed in 1979, the organizers of the fledgling organization felt that it needed the financial and other resources of an established group. Consequently, the CNS was created as *"the technical society of the Canadian Nuclear Association"*, i.e., as a "division" of that organization. That legal structure has continued to the present time. (For more detailed background on the formation and early years of the Society, see the article by Phil Ross-Ross in Vol. 13, No. 1, Spring 1992, issue of the *CNS Bulletin.*)

Over the years the CNS has grown in numbers and in financial strength. The CNS has effectively been administered independently, by its volunteer Council, since the beginning. Financially, we prepare and administer our own budgets and keep separate accounts. The Society now has close to 1,000 members and assets (members' equity) well over $200,000. Given that situation, and recognizing the maturity of the organization, many in the Society have, over the past several years, advocated that the Society make the move to become, legally, a separate entity. At the Annual General Meeting in Toronto, last June, there was total support by those present that Council should examine the advantages and disadvantages of incorporation as a federal, non-profit, organization and, if it judged that incorporation was desirable, to take steps towards that objective. The Council's Executive Committee has examined the question and has concluded that incorporation should indeed be pursued.

This move was NOT motivated by any friction with the CNA, which has been a good "parent". It is instead motivated by the fact (to continue the analogy) that the CNS has now reached the "adult" stage (that it has "grown up"), and that it therefore now can, and should, stand on its own. The Directors of the Canadian Nuclear Association have given their endorsement to the CNS incorporation initiative.

Your Council has, with the assistance of a lawyer, drafted By-Laws as required by the federal corporation law. Council proposes to continue with much of the current logistics arrangement with the CNA, i.e. with the CNS purchasing office services from the CNA, as at present. The "CNS Office" would thus continue to be on Front St. W. in Toronto. A draft of a formal agreement with the CNA for the on-going arrangements has been prepared and discussed with representatives of that organization.

Early in 1998 you will receive a package which will include: the proposed By-Laws, an outline of the proposed agreement with the CNA, and a ballot seeking your vote on this important step in the evolution of the Society.

Assuming a positive vote by CNS members, the CNA Board of Directors has agreed to present the necessary amendments to its constitution (to allow the separation of the CNS) to the members of the Association at its next Annual General Meeting, which will be held in conjunction with the 11th Pacific Basin Nuclear Conference in Banff in May 1998.

If you wish further information contact any member of the CNS Executive.

A tous les membres de la SNC

À l'assemblée générale annuelle de la SNC en juin 1997, votre Conseil a reçu l'autorisation d'examiner en détail le projet d'incorporation de la Société Nucléaire Canadienne comme corporation indépendante sans but lucratif, sous la loi fédérale (voir le vol. 18, no. 2, du Bulletin de la SNC, été 1997). Le Conseil a étudié cette possibilité et recommandera bientôt formellement aux membres que l'incorporation soit approuvée.

Voici un rappel de l'historique de la SNC. Quand la Société fut fondée en 1979, ses fondateurs ont pensé qu'il serait préférable de compter sur les ressources (financières et autres) d'une organisation déjà bien établie. La SNC fut donc créée comme *"la société technique de l'Association Nucléaire Canadienne"*, c'est-à-dire comme une "division" de cette association. Cette structure légale a survécu jusqu'à présent. (Pour plus de détails sur la formation et les premières années d'existence de la SNC, voir l'article de Phil Ross-Ross au vol. 13, no. 1 du *Bulletin de la SNC,* printemps 1992).

Au fil des années, la SNC a grandi, tant en nombre de membres qu'en santé financière . En fait, la SNC a toujours été administrée d'une manière indépendante par son Conseil de bénévoles. La Société prépare et administre son propre budget et maintient sa propre comptabilité. À ce jour, la Société a presque 1 000 membres et des avoirs supérieurs à $200 000. En conséquent, et en raison de la maturité de la Société, plusieurs membres ont suggéré, ces dernières années, que la SNC devrait devenir légalement indépendante. À la réunion générale annuelle de juin dernier à Toronto, tous ceux présents ont fortement appuyé l'examen des avantages et des désavantages de l'incorporation éventuelle de la SNC en organisation sans but lucratif, et de prendre les premiers pas dans cette direction, si elle s'avérait désirable. Après examen, le Comité Exécutif du Conseil a conclu qu'on devrait donner suite à l'idée d'incorporation.

Il est important de noter que cette démarche n'est PAS motivée par une friction quelconque avec l'ANC. Cette dernière a en fait toujours été un excellent "parent". La démarche a plutôt été motivée par le fait (pour poursuivre l'analogie) que la SNC est maintenant "adulte", et qu'elle se doit de voler de ses propres ailes. Les directeurs de l'Association Nucléaire Canadienne souscrivent à cette initiative d'incorporation.

Votre Conseil a préparé, avec l'aide d'un avocat, un texte des règlements proposés, tel que requis par la loi fédérale des corporations. Le Conseil de la SNC se propose de garder les dispositions actuelles de bureau avec l'ANC, c'est-à-dire de continuer de se procurer des services de bureau auprès de l'ANC à un coût mutuellement acceptable. Notre bureau demeurerait donc à la rue Front à Toronto. Une ébauche de l'accord formel avec l'ANC sur l'administration de bureau a été préparée, et les discussions à ce sujet avec le président de l'ANC ont démarré.

Au début de l'année 1998, vous recevrez les règlements proposés, un aperçu de l'accord avec l'ANC, et un bulletin de vote sur cette étape importante dans l'évolution de votre Société.

En supposant un vote positif des membres de la SNC, le Conseil de l'ANC présentera aux membres de l'ANC une proposition de changements à sa constitution pour permettre à la SNC de devenir indépendante. Le Conseil de l'ANC pourrait voter sur ce projet à sa réunion annuelle générale, qui se tiendra en mai prochain au 11e Congrès Nucléaire du Bassin du Pacifique à Banff, en Alberta.

Si vous désirez plus de renseignements sur le projet d'incorporation, nous vous invitons à communiquer avec un membre de l'exécutif de la SNC.

BOOK REVIEW

Affordable Safety by Choice: The Life Quality Method

J. S. Nathwani, N.C. Lind, M. D. Pandey
University of waterloo Press $45 ISBN 0-9696747-9-1

This book is the latest in a series by Neils Lind and Jatin Nathwani, this time with co-author Dr. M. D. Pandey, all of whom are associated with the Institute for Risk Research at the University of Waterloo. It deals with the problems of managing risk on behalf of others. A coherent and unified rationale for managing risk in the public interest is presented in the form of four principles: accountability; maximizing net benefit to society; compensation; and life measure. The method is applied in assessments of U.S. benzene standards, transportation, radiation, health care resource allocation etc. The Life Quality Index is a tool that those in risk management should find helpful.

BOOK REVIEW

History of the International Atomic Energy Agency: The First Forty Years

David Fischer $55 (US)

The author, a long-term senior official at the IAEA, chronicles the history of the agency from U.S. President Eisenhower's proposal to the General Assembly of the United Nations in December 1953 He not only records the events he assesses the achievements and setbacks, including: the role of the IAEA during the Cold War as an instrument of east-west communication and cooperation; the impact of Three Mile Island and Chernobyl accidents, clandestine activities in Iraq, etc.

BOOK REVIEW

The International Atomic Energy Agency: Personal Reflections

several authors $30 (US)

This book contains personal reflections from distinguished scientists and diplomats who were involved in the establishment or subsequent work of the IAEA

Both books are available from the IAEA or in Canada and the USA, contact Bernan Associates, 4611-F Assembly Drive, Lantam, Maryland 20706-4391

Publications available

Annual Report for 1996 - 97: Atomic Energy Control Board

(Free) Available from: Atomic Energy Control Board
280 Slater Street, Ottawa, Ontario K1P 5S9
tel. 1-800-668-5284
e-mail:info@atomcon.gc.ca

1996 Report on Occupational Radiation Exposure in Canada

(Free) Available from: Radiation Protection Bureau
Health Canada
75 Brookfield Road, Ottawa, Ontario K1A 1C1
FAX: 613-957-0960
Web:Website@www.hwc.ca/dataehd

CALENDAR

1997

Dec. 8 - 10

International Conference on Plant Life Management
Prague, Czech Republic
contact: Alan Wagstaff
c/o Nuclear Engineering International
Dartford, Kent, England
Fax: 44-1322-273748
e-mail: energy@wilmington.co.uk

1998

Feb. ?

CNA/CNS Winter Seminar
Ottawa, ON
contact: Sylvie Caron
CNA/CNS Office
Tel: 416-977-7620
Fax: 416-979-8356
e-mail: carons@cna.ca

March 27, 28

CNS/CNA Student Conference
Kingston, ON
contact: Dr. H. Bonin
Royal Military College
Tel: 613-541-6000 ext. 6613
Fax: 613-545-0783

May 3 - 7

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

May 10 - 15

ICONE-6 6th International Conference on Nuclear Engineering
San Diego, California
contact: B. Bigalke
ASME
New York, NY, USA
Fax: 212-705-7056
e-mail: bigalkeb@asme.org

May 24 -28

CRPA Annual Conference
Ottawa, Ontario
Contact: Ms. Cait Maloney
c/o Atomic Energy Control Board
Ottawa, Ontario
Tel: 613-943-8948
Fax: 613-996-2049
e-mail: maloney.c@atomcon.gc.ca

June 7 - 11

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

June 14 - 18

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

June 21 - 24

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

June 22 - 25

Science of Nuclear Energy and Radiation Course for Science Teachers
McMaster University
Hamilton, Ontario
contact: Bill Garland
McMaster University
Tel: 905-525-9140 ext. 24910
Fax: 905-577-9090
e-mail: garlandw@mcmaster.ca

June 28 - July 2
ICENES '98 – 9th International Conference on Emerging Nuclear Energy Systems
Tel Aviv, Israel
contact: Dr. Dan Knassim
POB 1931 Ramat Gan 52118
Tel: 972-3-613-3340
Fax: 972-3-613-3341

October 5 - 8
International Conference on the Physics of Nuclear Science and Technology
Long Island, H.Y., USA
contact: Dr. David Diamond
Brookhaven National Laboratory
Tel: 516-344-2604
Fax: 516-344-5730
Fax: 416-979-8356
e-mail: diamond@bnl.gov

October 11 - 14
International Topical Meeting on Safety of Operating Reactors
San Francisco, California, USA
contact: Dr. Garth Cummings
Danville, California
Tel: 510-422-1264
Fax: 510-423-2224
e-mail: cummingsg@ilni.gov

October 18 - 20
CNS Annual Conference
Toronto, Ontario
contact: Sylvie Caron
CNS Office
Toronto, ON
Tel: 416-977-7620 ext. 18
Fax: 416-979-8356
e-mail: carons@cna.ca

October 25 - 28
ENC '98 International Nuclear Congress and World Exhibition
Nice, France
contact: ENC '98 Secretariat
European Nuclear Society
Berne, Switzerland
Tel: 41-31-320-6111
Fax: 41-31-382-4466
e-mail: carons@cna.ca

Nov. 30 - Dec. 4
Trends in Design and Development of Evolutionary Water-Cooled Reactors
Seoul, Korea
contact: J. Cleveland
IAEA
Vienna, Austria
Fax: 43-1-2060-20607
e-mail:
official.mail@iaea.org

1999

March 26 - 27
CNS / CNA Student Conference
Trent University
Peterborough, Ontario
contact: Dr. Jim Jury
Trent University

October 1999
3rd International Conference on Containment Design and Operation
Toronto, Ontario
contact: K. Weaver
Ontario Hydro
Toronto, ON
Tel: 416-592-4050

October 3 - 8
NURETH-9 - 9th International Meeting on Nuclear Reactor Thermalhydraulics
San Francisco, California, USA
contact: Dr. S. Levy
Levy & Associates
3880 South Beacon Avenue
Suite 112
San Jose, California
USA 95124

?? 1999
International Conference on Effects of Radiation on In-Reactor Corrosion
contact: V. Urbanice
AECL-CRL
Tel: 613-584-4676

CNS Council • Conseil de la SNC

1997-1998
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  Judy Tamm . . . . (204) 753-2311

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Richard Fluke . . . . (416) 592-4110

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1997

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Manitoba	Morgan Brown	(204) 753-2311
New Brunswick	Dave Reeves	(506) 659-2220
Ottawa	Mohamed Lamari	(613) 563-7242
Pickering	Marc Paiment	(905) 839-1151
Québec	Willem Joubert	(514) 871-1116
Saskatchewan	Walter Keyes	(306) 586-9536
Sheridan Park	Mukesh Tayal	(905) 823-9040
Toronto	Ross Rock	(416) 592-4930

CNS WEB Page

For information on CNS activities and other links

http://www.science.mcmaster.ca/cns/www/cns/cns.html