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Editorial

Quiet Moves in the Right Direction

Hardened nuclear engineers have from time to time described commercial nuclear fusion energy systems as the Holy Grail of the energy business, in that like virginity, the objective is pursued with febrile enthusiasm, but has not yet been attained. It is certainly true that despite the rather plentiful supply of hydrogen lying about this place, persuading these bits of hydrogen to get together for long enough to do useful work has only been achieved at nuclear weapons test sites.

It is also true that worldwide this situation is changing. While it's true that commercial fusion power hasn't come above the horizon yet, we are getting a better idea about when that sunrise will actually take place.

Which makes the work of the Canadian Fusion Fuels Technology Project (excerpts from whose annual report appear elsewhere in this issue) particularly interesting. The project, formally launched in 1982 with minimal media hype and an even more minimal budget, has been quietly staking out areas of Canadian expertise in hydrogen energy systems development. Looking at the achievements of the project so far, it's clear that someone, somewhere, is using a bit of intelligence. Canada, with limited resources, must concentrate on what it does best — as was done in the development of the heavy-water reactor. Canadian experience in handling hydrogen (whether in the form of H1, H2 or H3) is second to none. And the prospect of buckets of neutrons available from fusion reactions makes the CANDU concept an extremely plausible contender for *the* energy system to exploit fusion energy during the interregnum between traditional fission systems and pure fusion machines.

The work of the CFFTP will ensure that when fusion systems become a commercial engineering proposition, Canada will have a major part to play and will reap the benefits.

Perspective

CFFTP Activities 1983-84: Highlights

The following update on the Canadian Fusion Fuels Technology Project (CFFTP) is excerpted from its annual report for the period April 1, 1983 to March 31, 1984. Further information is available in the annual report and in the Fusion Fuels Technology Newsletter, both available from CFFTP, 2700 Lakeshore Road W., Mississauga, Ontario, L5J 1K3.

Background

The Canadian Fusion Fuels Technology Project was launched to strengthen Canada's scientific and industrial base in regard to fusion fuels technology and to coordinate the application of that technology to international fusion power development programs.

The project, CFFTP, is a national program backed by funding from the federal and Ontario provincial governments, and by Canada's largest nuclear power utility, Ontario Hydro. The CFFTP project originated in 1981, and was formally launched in 1982. The program is based on the substantial technology developed for the handling of tritium in the CANDU system. It is estimated that of the $20 billion of the capital value of the CANDU system in Ontario, some $2 billion worth of research, development and acquisition activity has been expended by Ontario Hydro and AECL to manage tritium.

CFFTP has a mandate to extend and adapt existing Canadian tritium technology for use in international fusion power development programs. It will execute this mandate through:

- Supporting research and development activities in technical areas related to fusion fuels technology. Activities supported will be those attempting to address identified needs in fusion power development.
- Assisting the fusion community to find solutions for specific problems in particular projects.
- Providing specialist staff for attachment to fusion projects in order to facilitate the exchange of technical information.
- Providing the results of CFFTP development work to the fusion and industrial communities. Providing other fusion related Canadian expertise and assistance from technical institutions and industry.

The program is focussed on five main technical areas:

- Tritium Technology. Emphasis is on problems of fuel systems design, and on processing of waste and coolant streams from fusion reaction chambers and air clean up from reactor vaults.
- Breeder Blanket Technology. The focus is on solid breeder development with major emphasis on neutronics, ceramic fabrication and characterization, materials and engineering aspects, and in-reactor testing.
- Materials Technology. Emphasis is on the effects of tritium and plasma on the first wall, fuel system and breeder system

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materials. Tritium permeability receives special attention.

- Equipment Development. Emphasis is on remote handling and manipulation, and on equipment handling for tritium. Fusion facility maintenance concerns receive special attention.
- Safety and Environment. Emphasis is on tritium monitoring, tritium dosimetry and tritium dispersion.

CFFTP has acted to introduce Canadian industry to these projects and has acted as coordinator and project manager for work that is performed by the various Canadian resource sectors and paid for by the host fusion project in other countries. This work is largely of an engineering nature and is complementary to the R&D program. It provides added direction to the R&D program, clients for the products of the R&D program, thereby giving the overall CFFTP increased relevance to the world's fusion programs.

Project management of CFFTP is carried out by the Fusion Engineering Materials Program (FEMP) of Ontario Hydro.

FEMP provides the key staff for CFFTP. The key staff select technical areas of problems for development, and choose qualified organizations to undertake the research which it funds. The work is then contracted out. CFFTP staff monitor and direct the research and development projects, and administer funds.

During the first two years of the Project, CFFTP managed $3.9 M in funds through 72 contracts with subcontractors. Supplementary funding of approximately $1 M was provided by subcontractors for a total expenditure of $4.9 M. More than 150 people from 22 organizations and consulting companies in Canada participated in technical work related to this Fusion Fuels Project.

For 1984-85 it is estimated that the $4 M budget will be allocated approximately 15% to program management and operation. 17% to industry and consultants, 13% to universities, 25% to Ontario Hydro and 30% to AECL. Commitments resulting from carry-over work started in 1983-84 total approximately $600,000. It is expected that supplementary funding by subcontractors will be offered up to $1.7 M for a total 1984-85 expenditure of $5.7 M.

Recognition of the CFFTP program and value of existing Canadian tritium and remote operations technology has been apparent through broad requests for reports, and via requests for the attachment of Canadian personnel to the Joint European Torus (JET) in England, the Next European Torus (NET) design team in Germany, the Fusion Engineering Design Centre at Oak Ridge (FEDC), Tokamak Fusion Test Reactor (TFTR) at Princeton, UCLA, University of Rochester, EG&G at Idaho Falls and the Tritium Systems Test Assembly (TSTA) at Los Alamos. These assignments have the goal of providing assistance in program planning, performing conceptual and detailed studies and in some cases, providing assistance in the commissioning of tritium and remote operations systems.

Technology Development 1983-84

Some 72 contracts were active in the five major program areas. The programs were characterized by being capable of producing near term results of direct uses to the fusion community and involving a broad spectrum of people from universities, industry and national labs and utilities. In all, more than 150 individuals have had paid involvement in CFFTP contracts to date. The broad range of activities referred to above are represented in these contracts.

Tritium Technology: The main emphasis of work in this area was related to tritium management, purification or recovery from plasma exhaust, coolant streams, waste streams and room atmosphere. Examination of a number of novel processes and ideas were undertaken and some are expected to merit further examination. Highlights of results achieved are as follows:

- A promising new catalyst formulation has been indicated through studies on photochemical dissociation of water.
- The AECL Wet Proof Catalyst has shown initial promise for recovering dilute quantities of gaseous tritium from room air.
- Tritium separation by laser photochemical decomposition has been achieved. There are prospects for a new process.
- The water gas shift reaction has been demonstrated in a model sized to TSTA requirements to be capable of recovering tritium from tritiated water in a low inventory, leak tight device.

Breeder Technology: One major contract was awarded in this area. The purpose was to review world activity and to identify an appropriate breeder program for CFFTP. A major report is in preparation by the 15 member team. Tritium breeder technology will be one of the major new developments required by the 1990's as a part of the continuing development of fusion energy systems.

Materials Technology: Activities in this area have included laboratory work and studies related to the interaction of hydrogen isotopes with first wall materials, with fuel system loop materials and with organic paint formulations for painted structures. Highlights include the following:

- Completion of facilities to simulate plasma edge characteristics for interaction of hydrogen isotopes with first wall materials at UTIAS (University of Toronto).
- Completion of a major study on hydrogen isotope-materials interactions.
- Initiation of programs on tritium sorption to organics, and coated alloys exhibiting assymetric permeation.

Equipment Development: Major activities in this area have included documentation of the status of tritium pump developments, of CANDU nuclear engineering suitable for fusion and of a series of attachments. Highlights include the following:

- Preparation of a vault layout for INTOR (International Tokamak Reactor) based on dose assessment and maintenance requirements.
- Planning and task definition in preparation for remote operation development programs required for TFTR and TFCX (Tokamak Fusion Core Experiment).

Safety and Environment: A broad range of activities have been undertaken in this area ranging from monitor development, a code for tritium dispersion, dosimetry, development of a tritium handling training course and conversion and deposition of tritium in facilities and in the environment. Highlights include the following:

- Development of an industrial version of a compact portable tritium monitor.
- Development of a tritium course for attendance by international fusion personnel.
- Documentation of overall tritium handling experience relevant to fusion.

Staff Assignments: An important activity for CFFTP is to place selected Canadian staff on strategic assignments with other national projects. There must be mutual benefit to both the host project and CFFTP arising from these assignments. Such benefits would include staff training, introduction of Canadian technology where advantageous to the host project, opportunities for broader international collaboration, and improved awareness and overall direction

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Editor / *Rédacteur*
David Mosey (416) 592-3328
Associate Editor / *Rédacteur associé*
Hugues Bonin (613) 545-7613
Production Editor / *Rédacteur, production*
David McArthur (416) 977-6152

of the CFFTP program. A number of such assignments have been successfully carried out in 1983-84. These are summarized below:

TFTR — A four man team of remote operations experts has been at TFTR since October 1983. They are from SPAR Aerospace, Canadian Aviation Electronics and DSMA Atcon Ltd.

Their task is to define needs and design hardware for the TFTR and TFCX experiments.

NET — Two Ontario Hydro staff members (one was a CFFTP member) were assigned to the NET team for the month of February, 1984. They assisted in preparing the NET program plan and budget estimate in the areas of tritium systems and tritium safety requirements.

FEDC — A one month attachment to the Fusion Engineering Design Centre at Oak Ridge was undertaken in December, 1983, by an Ontario Hydro staff member to define work to be undertaken in Canada on optimization of maintenance approach through dose assessment and economic analysis.

UCLA — A two year attachment at UCLA was arranged for a recent Canadian graduate of MIT to work on the FINESSE (Fusion Integrated Nuclear Experiment Strategy Study Effort) program starting in January of 1984. The FINESSE program is required to develop and plan the future U.S. fusion technology program. The attached person has specific responsibility for scaling of solid breeder test blankets with emphasis on tritium transport.

ROCHESTER — A recent graduate from the University of Waterloo has been attached to the University of Rochester Inertial Confinement Fusion program after 9 months service at CFFTP headquarters. The emphasis of this attachment is to review and develop fueling techniques for the preparation of the microsphere pellets. The attachment started in December 1983, is for a one year period.

Technology Application 1983-84

In order to most effectively introduce the existing and newly developed Canadian technologies resulting from the CFFTP program, a directed effort to encourage the application of the technologies to the world's fusion programs is required. Such effort is consistent with overall CFFTP objectives as follows:

- Develop opportunities for involvement by Canadian industry.
- Develop and establish Canadian expertise in science engineering and technology.
- Develop mutually beneficial collaboration with fusion programs.
- Ensure Canadian access to world fusion knowledge for potential application in Canada.

During the first two years of the project there has been increasing opportunity for the involvement of the Canadian nuclear and remote operations industries with fusion projects in other nations. CFFTP has acted to introduce Canadian industry to these projects and has acted as coordinator and project manager for work that is performed by the various Canadian resource sectors and paid for by the host fusion project. This engineering work is complementary to the CFFTP R&D program and will provide added direction to give CFFTP increased relevance to the world's fusion programs.

CFFTP financial committment to these activities is related to project management costs, and to close technical support where required for technology adaptation.

Technology Application Activities in USA

Assessment of Technical Skills and R&D Requirements for a Magnetic Confinement Fusion Fuel System: During the period April 1982 to November 1983, Ontario Hydro participated in an EPRI contract with McDonnell Douglas, Los Alamos National Laboratory and Argonne National Laboratory. The purpose of the contract was to define a method for assessing technological uncertainty and apply it to the more important fuel cycle subsystems. A second purpose was to recommend research and development activities that would minimize technical risks associated with these uncertainties. Results were presented in EPRI Report AP-3283, November 1983.

Planning and Commissioning of TFTR Tritium and Related HVAC Systems: Ontario Hydro through CFFTP was awarded a subcontract in March, 1984, by Grumman Aerospace to provide a commissioning plan for the TFTR Tritium and Related HVAC Systems. The subcontract work has been split between Ontario Hydro, AECL-CRNL, Meikle Engineering Services and Intertech Ltd. The work is being conducted at Princeton.

Tokamak Fusion Core Experiment — Conceptual Design: Ontario Hydro through CFFTP were invited by Grumman Aerospace Corp. to participate as a subcontractor, along with Bechtel, General Dynamics, Brown Boveri and Thomson Ramo Wooldridge Corp. to engineer the conceptual design phase for the tritium and remote handling systems of the Tokamak Fusion Core Experiment. The Phase I work is expected to be completed by December, 1985. The Canadian team will consist of Ontario Hydro, AECL CANDU Operations, SPAR, CAE and DSMA.

Technology Application Activities in Europe

Preliminary Engineering of Emergency Air Clean-Up System and Fuel Purification System for Frascati Tokamak Upgrade: Ontario Hydro through CFFTP was awarded a contract in February 1, 1984, to provide the preliminary design of the Frascati Tokamak Upgrade (FTU) Emergency Air Clean-Up and Fuel Purification System. This work is being undertaken by Ontario Hydro, AECL-CRNL, Spectrum Engineering, Meikle Engineering Services and Systech.

Frascati Tokamak Upgrade — Storage System: A request was received from Frascati to do the detailed design and acquisition of a uranium storage bed for FTU. A bid has been sent based on a submission by AECL. Permission to proceed is pending. Meanwhile, the uranium bed will be included on process flow sheets for the FTU fuel system.

Frascati Accelerator Project: Ontario Hydro through CFFTP have been requested to submit a bid for the preliminary design of the target room and air clean-up system for the Frascati Accelerator Project. A DSMA proposal has been forwarded to Frascati.

Technology Development & Application 1984-85

Interaction with the fusion community from 1983-84 has indicated continued support for the detail and direction of the CFFTP technical program. Consequently, activity in all 5 major technology areas is proposed. Overall program objectives and mandate outlined in the comprehensive agreement governing CFFTP remain particularly relevant to the environment CFFTP has experienced in the developing international fusion programs.

Specific technical objectives have evolved and will help in determining program direction. These are (1) to provide close technical support to fusion facilities in developing data and expertise needed to enable the development of fueling systems and facility requirements for tritium fuelled fusion devices in the next 5 years, (2) to undertake longer term development for second generation machines (NET, TFCX) which will require significant advances in technology, (3) to contribute to the overall advancement of fusion energy systems by conducting generic work addressing critical tritium issues that will be identified in the INTOR, TFCX and NET program activities. These issues are likely to include effects of concentrated tritium on materials, radiobiology and tritium behavior in the environment.

Approximately balanced effort is expected on four of the five major program areas with special emphasis on breeder technology development. This latter area represents the major challenge of the fusion technologies. Canada's CANDU industries and laboratories are most appropriately equipped with skills and technology to undertake this challenge.

Broad representation is again expected among the industrial, university, utility and national laboratory resources in undertaking CFFTP contracts. It is expected that funds will be distributed approximately 17% to industry and consultants, 13% to universities, 25% to Ontario Hydro and 30% to AECL with the remaining 15% allocated to program management and operating costs.

Within the broad program plan the highlight activities are:

- Continued efforts will be undertaken to secure strategic opportunities and staff for assignment to other national fusion projects for mutual Canadian — International benefit. This will provide training, develop opportunities for broader collaboration and assist the application of Canadian technology where advantageous to the host project.
- Starting in 1984-85 greater emphasis will be placed on direct experimentation with tritium and it is expected that four institutions will be conducting R&D with tritium. In addition to AECL and Ontario Hydro these will include McMaster University and the University of Toronto. Specific attention will be given to establishing program and laboratory requirements to undertake experimentation with high level concentrated tritium both in gaseous and oxide forms. This activity will be necessary to develop truly system relevant experience and process verification.
- CFFTP will continue strong efforts to ensure Canadian industrial participation in providing advanced engineering, hardware, services and instrumentation in the direct participation and construction of tritium, remote handling systems, and facilities for existing and planned national projects outside Canada.
- In 1984-85 CFFTP will consummate negotiations underway during the past year leading to longer term institutional commitments for research on tritium technology. It is expected that Chalk River Nuclear Laboratories will indicate their intention to participate in a 3 year (option to extend) program on breeder technology development, and McMaster University through the McMaster Institute for Energy Studies will indicate their intention to participate in a 3 year (option to extend) program on tritium-materials interaction. Both arrangements will involve substantial cost sharing by the institutions.

CFFTP will continue to investigate opportunities in the USA, Europe and Japan for the application of tritium and remote handling technology, as well as nuclear engineering to assist facilities that will undertake or are planning operations with tritium. A number of Phase I activities started in 1983-84 will carry on through 1984-85. Many of these projects will enter Phase II operation in 1984-85 presenting opportunities for the continuation of the Canadian industrial effort.

Tube Failure at Pickering Nuclear Generating Station

This article was originally published in the June issue of McMaster University's Institute of Energy Studies' journal Energy Newsletter. While the information contained in the article has been covered in previous issues of the CNS Bulletin the editors felt it would not be inappropriate to recapitulate the whole G16 story under one heading.

Introduction

On August 1, 1983, Unit 2 at the Pickering Nuclear Generating Station experienced a sudden pressure tube failure. The reactor was shut down in an orderly fashion without invoking any of the special safety systems. Cooling of the fuel was maintained, there were no radioactive releases to the environment and, apart from some water-caused electrical problems in the fuel handling equipment, no consequential reactor damage. Later inspections of pressure tubes in Unit 2 and its sister unit, No. 1 (which was shut down November 15), indicated that a significant number of the 12-year old Zircaloy-2 pressure tubes might fail in a similar manner during subsequent long-term operation. Ontario Hydro therefore decided to immediately prepare for and carry out large-scale pressure tube replacement for both reactors — a project expected to be complete by 1987. This article provides a brief description of the actual August 1 incident and subsequent recovery work as well as an account of inspection and test results and the conclusions reached to date.

Plant Description

The Pickering Nuclear Generating Station is an 8 x 542MW(e) CANDU installation about 30 miles east of Toronto. Six of the units are in service and the remaining two are due to come into service by 1985.

A CANDU-PHW (Pressurized Heavy-Water) reactor essentially comprises a horizontally oriented stainless steel cylindrical vessel (the calandria) containing heavy-water moderator at atmospheric pressure and about 150°F. The natural uranium reactor fuel and high-pressure heavy-water coolant are contained in an array of pressure tubes (390 in the case of Pickering Units 1-4) which run through the calandria. The primary heat transport (PHT) system operates at an outlet pressure and temperature of 1280 psi and 560°F.

In the case of Pickering units 1 and 2 the pressure tubes are made of a zirconium alloy (Zircaloy-2). They are about 20 ft. long x 4 in. ID with a wall thickness of 0.2 in. At each end the tubes are extended through the reactor's end shielding by 8 ft. long stainless steel end fittings which provide connections to coolant feeder piping and contain removable closure plugs to allow remote-controlled on-line refuelling.

Each pressure tube is surrounded by a 5 in. dia. Zircaloy-2 tube (the calandria tube) of 0.06 in. wall thickness, serving to insulate the hot pressure tube from the cool heavy-water moderator. This annular space is filled with an inert gas (nitrogen) which can be circulated and monitored. Two equidistant spacers, known as "garter springs", maintain the spacing between pressure tube and calandria tube.

Sequence of Events

Up to the time of the tube failure, Pickering Unit 2 had operated continuously for 342 days. On August 1 the reactor was operating normally at full power when at 11:10 EST control room alarms indicated a sudden loss of heavy water from the PHT system. The first action of the operating crew was to request a transfer of heavy-water from adjacent units, a process which began at 11:19. However the level of heavy water in the PHT storage tank (part of the PHT make-up system) continued to fall at a rate which was later estimated as indicating a leak rate of about 220 Igpm, so at 11:22 the operating crew began manual reactor power reduction. By 11:24 the reactor was at 71% of full power.

At 11:25 additional heavy-water was requested from Unit 4 at the same time as the fuelling machines were returned and locked back on to the most recently visited fuel channel, an action taken to cover the possibility that this channel had been improperly closed after fuel changing. This, however had no effect on the water loss rate.

Steady, controlled power reduction continued, with reactor power at 52% by 11:26 and 2% by 11:48, at which point the unit's turbine was tripped manually.

At 11:59 the depth of water in the service room sump (the lowest point in the reactor building) was about 20 in., and the sump recovery pump was started to return this water to the PHT system. By 12:38 the heat transport system had been cooled to about 100°F, depressurized to 30 psig and was stable. The leak rate had dropped to about 60 Igpm.

At no time during the event was the heat transport system pressure, temperature or flow outside the normal control band. No active safety system (reactor shutdown, emergency coolant injection or containment) was called for, either automatically or by operator action.

Recovery

With the reactor shut down, and its cooling system below atmospheric boiling point, the next two major tasks were to: (a) provide back-up for the pump recirculating water from the sump to the primary cooling system, and (b) restore the integrity of the primary pressure boundary (ie. stop the leak). A submersible pump was installed in the sump to provide back up recirculation capacity. In parallel with this activity, reactor vault inspection revealed heavy-water escaping from both ends of fuel channel G-16 (1). Before this channel could be isolated from the cooling circuit its 12 highly radioactive fuel bundles had to be removed, a process which was delayed until August 12 as numerous water-caused electrical faults in the remote controlled fuelling machines required repair.

Removal of the fuel bundles from G-16

required significantly higher than normal fuelling machine ram forces, and subsequent inspection of the discharged fuel revealed that bundles 10 and 11 (2) were each missing a single fuel pencil, raising the possibility that the bundles had somehow been snagged in the damaged pressure tube. The fuel channel was isolated on August 14 by blanking off the feeder piping at each end of the channel. With the leak thus stopped, the channel was drained and a miniature television camera was inserted in G-16. Initial results were indeterminate — the nature of the observed damage being highly dependent on the imagination of the observers — but a later attempt on August 20 provided excellent pictures, showing a crack about 0.75 in. wide at its widest, extending about 6 ft. from the eastern (outlet) end of the tube, terminating in a 120° circumferential tear. In the crack, which ran along the bottom of the tube, were the two missing fuel pencils.

Since the two fuel pencils were intensely radioactive it was desirable to remove them from the pressure tube before the tube itself was removed. Initial attempts to poke them free did not work — it was clear that the pencils were tightly jammed in the crack. The tube was therefore cut in half at its mid point and the eastern half (containing the pencils) rotated about 180° to bring the crack to the 12 o'clock position. An hydraulic expander inserted down the tube was used to pry the crack open to release the pencils. Initial attempts were not successful and plans were formulated for tube removal with the pencils *in-situ*. However a final attempt with a modified version of the expander successfully released the pencils which were subsequently pushed out of the tube into a shielded container and shipped to Atomic Energy of Canada's Chalk River Nuclear Laboratories. The two end fittings were cut free and, with the two pressure tube sections, also sent to Chalk River.

Results of Laboratory Examination

Inspection and metallurgical examination of the G-16 pressure tube at Chalk River revealed the following information:

- The crack face was perpendicular to the tube surface over a large portion of the crack length through at least part of the wall thickness — a feature indicating low ductility.
- A 15 in. section, starting about 5 ft. from the eastern end of the tube, had a series of patches identified as "blisters" on the tube OD at the 6 o'clock position, with the crack running through most of them. These circular blisters were about 0.04 in. deep by 0.15 in. diameter and were formed of solid zirconium hydride.
- Examination of the fracture surface showed a 4 in. long crack on the OD, semi-elliptical in shape, and not quite penetrating the tube wall. Centred 11.4 in. from the western end of the crack, it ran through 4 zirconium hydride blisters.
- There were no unusual marks from fuel or foreign material seen on the ID of the tube (3).
- Inspection of the G-16 calandria tube ID showed marks coincident with the hydride blisters on the OD of the pressure tube, suggesting that the pressure tube had contacted its surrounding calandria tube.
- There was evidence that the eastern (outlet) garter spring, which *should* have been positioned at a point close to the circumferential tear in the pressure tube, was in fact about 3 ft. too far west. (Only pieces of garter springs were recovered from G-16).
- Deuterium concentration at the outlet end of the pressure tube was *circa* 200ppm, higher than predicted.

Failure Mechanism

Based on the above data, the most plausible hypothesis for the failure is that:

- The outlet (eastern) garter spring was about 3 ft. west of its design location, probably since reactor construction.
- The pressure tube sagged into contact with its surrounding calandria tube — the time of contact being between 1973 and 1976 (2-5 years after reactor start-up in 1971).
- The outside surface of the pressure tube was cooled where it touched the calandria tube, the calandria tube being surrounded by cool moderator water.
- The deuterium isotope of hydrogen built up in the pressure tube from the inside (ingress from the heavy-water coolant) and the outside (ingress from the insulating annulus gas).
- The deuterium migrated to the cooler contact areas to precipitate as zirconium hydride, forming the hydride blisters.
- A 4 in. crack formed through four of the hydride blisters. Though this crack did not penetrate the tube wall, the thin ductible web on the inside surface later failed and the crack extended to its final 78 in. length.

A major argument in favour of this hypothesis is the coincidence between the pressure tube's hydride blisters and the marks on the inside surface of the calandria tube. Careful analyses of the marks and blisters have been able to relate their relative positions to the history of relative movement between calandria tube and pressure tube. Additionally, the outside surface of the G-16 calandria tube had marks (coincident with the inside marks) suggesting local boiling of the moderator water — an expected consequence of pressure tube-calandria tube contact.

Subsequent Investigations and Operations

A program of selective pressure tube inspection and removal for Unit 2 was instituted immediately following the pressure tube failure. And on November 14, Unit 1 (the only other Ontario Hydro reactor with Zircaloy-2 pressure tubes (4) was shut down for tube checks. Using ultrasonic inspection and eddy current testing 66 tubes were examined for indications of hydride patches and garter spring location and 12 tubes were removed for laboratory examination. About one third of the tubes inspected gave strong ultrasonic indications, suggesting a high probability of the presence of hydride patches. In view of these results it was decided in early March that the quickest way in which units 1 and 2 could be brought back to reliable and economic operation was to commence large scale pressure tube replacement immediately.

Discussion and Implications

Performance of both reactor and operating crew in response to the G-16 failure were good. The G-16 calandria tube, though not designed for full system pressure, withstood it (5), and channelled the escaping heavy water coolant through a narrow and tortuous path (along the annular space between the calandria and pressure tubes, and past the end-fitting bearings), thus reducing water loss rate to that which could be met without invoking the emergency water injection system (thus avoiding downgrading the heavy-water coolant with light water). In fact, the reactor performed as had been anticipated during its design some twenty years ago (6).

The operating crew discharged their duties admirably in following the most fundamental rules of reactor safety during an upset — *control it, cool it down, keep the doors shut*. It is important to notice that throughout the course of the leak — from the instant of detection till the time the reactor was in a cold, shut-down state — efforts were not misdirected towards ascertaining what or where the leak was, but to *maintaining adequate cooling of the fuel*.

The implications of the G-16 failure for Ontario Hydro's nuclear program, and indeed, for the future of the CANDU reactor have been the subject of much speculation, and not all of it in public. Indeed if it were reasonably certain that after a mere 12 years' operation, all CANDU reactors must undergo complete retubing, then the viability of the CANDU system as a commercial power source could require re-evaluation. However this is not the case.

It must be remembered that the G-16 failure resulted from the combination of at least two negative factors: high deuterium concentration in the metal, and local cooling from contact with the calandria tube. The high deuterium concentration combined with normal pressure stresses in the Zircaloy-2 was sufficient to precipitate zirconium hydride platelets in the radial-axial plane at operating temperatures, considerably reducing the fracture toughness of the material. Local cooling of the outer surface of the pressure tube led to precipitation of solid zirconium hydride in the form of large blisters. Since volume expansion occurs on conversion of zirconium metal to hydride, it is postulated that stress levels around the blister areas were considerably increased, thereby initiating the major crack. Contact between a pressure tube with only low deuterium levels and the surrounding calandria tube is not expected to lead to fast fracture of the tube because, (a), there would be insufficient deuterium present in the vicinity of the contact area to produce large local blisters, and (b) reoriented hydrides would not be present at the operating temperature.

As has been mentioned previously, all Ontario Hydro's CANDU reactors built after Pickering Unit 2 use a different material of construction for their pressure tubes — a zirconium-niobium alloy (Zr2.5wt%Nb). This material is somewhat stronger than Zircaloy-2, hence the tubes can have slightly thinner walls (0.16 in. vs. 0.2 in.) with a consequent improvement in reactor neutron economy and hence, fuel economy. Another feature of this newer alloy is that its deuterium uptake rate is very much lower than that of Zircaloy-2. Zirconium-niobium tubes removed from Bruce Unit 2 in 1982 showed very littl deuterium absorption. Further support for this view of zirconium-niobium came recently (last March) when two pressure tubes were removed from the NPD demonstration reactor at Rolphton. One tube was a Zircaloy-2 unit, resident in the reactor since start-up in 1962. The other was zirconium-niobium, installed in 1967. The Zircaloy-2 tube had, as predicted, deuterium concentrations comparable to those found in the Pickering tubes. The zirconium-niobium tube had very low deuterium concentrations — 15 ppm. Both tubes were in sound condition and the garter springs were in the correct position.

On April 20 Unit 3 at Pickering was shut down for scheduled annual maintenance. In the course of this work pressure tube J-09 was removed, and sent to the Chalk River Nuclear Laboratories on May 4. Visual inspection of the tube revealed indications of pressure tube-calandria tube contact, but metallurgical analyses demonstrated relatively low deuterium uptake levels (in the range of 3.3-5 ppm along the tube length).

Unit 3 has been in operation since 1972 and has accumulated 84,000 effective full-power hours of operation. The laboratory results for J-09, together with the evidence accumulated from other zirconium-niobium tubes, provide good grounds for confidence in the long-term performance of zirconium-niobium pressure tubes in the rigorous environment of a commercial power reactor.

Conclusions

Design and operating analyses have confirmed that the sudden pressure tube failure which occurred on August 1, presented no public safety or worker safety concerns. The actual public safety and worker safety consequences on August 1, 1983 were zero. Pressure tubes in Ontario Hydro CANDU reactors constructed after Pickering Unit 2 are of a material which, even given the disadvantageous situation of pressure tube-calandria tube contact, will neither absorb enough deuterium nor develop large enough hydride inclusions to cause fast fracture.

1. *Fuel channels are identified from the west face of the reactor by numbers vertically (1 through 22) and letters horizontally (A through W).*
2. *Bundles are numbered 1 to 12 from the inlet to the outlet end of the fuel channel.*
3. *One informal hypothesis before tube removal and inspection was that some foreign object inside the tube could have scored the surface, providing a starting point for tube failure.*
4. *The 25MWe concept demonstration reactor, NPD, at Rolphton and the 200MWe commercial prototype, Douglas Point, at Bruce, both use Zircaloy-2 pressure tubes, but are owned by Atomic Energy of Canada Ltd.*
5. *Tests of an unirradiated calandria tube at Chalk River showed the tube failing at 1800 psi. A sample of the actual G-16 calandria tube failed at 2100 psi. Primary system pressure is 1280 psi.*
6. *Destructive tests involving full-scale pressure tube/calandria tube assemblies at Chalk River carried out in the early 'seventies suggested that should a pressure tube fail suddenly, its surrounding calandria tube might distort, but would be unlikely to fail.*

David Mosey

FYI

New Ontario Hydro Chairman (Staff)

Ending long-standing speculation, in August Ontario Premier William Davis appointed career civil servant Tom Campbell to the Chairmanship of Canada's largest nuclear reactor operator, Ontario Hydro. The publicly-owned utility, a perennial political target, is arguably one of the world's most successful venturers into the nuclear energy field, achieving outstanding performance with its CANDU units. Ironically enough it is the nuclear program which attracts most critical attention. Described by Hydro insiders as "highly political" and a "bureaucrat's bureaucrat," clearly the provincial government hopes that Campbell's political antennae and contacts will enable the new chairman to defuse issues — or short circuit them — before they become major news items on the floor of the house.

The new chairman is keeping a low profile, declining media interviews as "premature." "Nobody's talking much on the elevators these days" says one Hydro source, "Because we just don't know what he looks like."

Pickering Retubing Progress (Staff)

Decontamination of both units has reduced fields by about 85 percent and all fuel has been removed from both reactors. Heavy water systems have been drained, flushed with ordinary water and vacuum dried. The two reactor buildings have been isolated from the station's vacuum containment system, and preparation is under way to install shielding cabinets. Commissioning manager Ken Talbot noted that work was ahead of schedule and he personally looked forward to seeing both units back in service by 1986.

Unit 4 at Pickering was shut down for annual maintenance August 29 — a week ahead of the originally planned date. The Unit had been operating at 55 percent full power since August 21 when a small heavy-water leak was detected from moderator heat exchanger No. 2. The shut down will last about 7 weeks, during which time pressure tube N-16 will be removed for laboratory examination.

IAEA to Establish International Nuclear Safety Group (Staff)

The International Atomic Energy Agency will establish an international nuclear safety advisory group, the IAEA decided in June. This group will work toward commonly agreed international nuclear safety objectives, but will not produce standards or have regulatory powers. Experts from national regulatory bodies, research organizations and industry are expected to constitute the group, a revised version of a nuclear safety institute proposed earlier.

Neutron Dosimeter Developed (Staff)

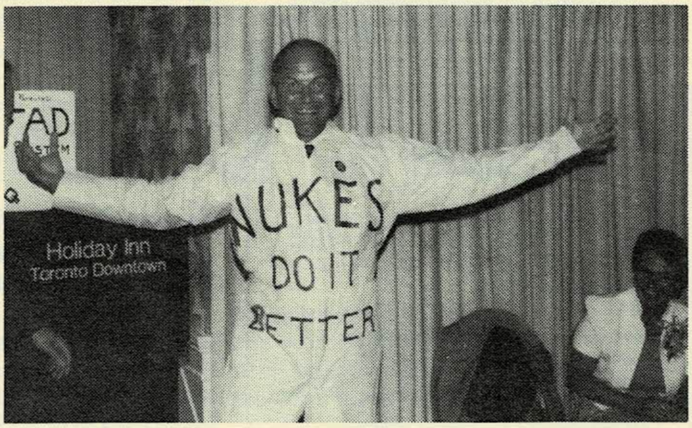
Researchers at AECL's Chalk River Nuclear Laboratories have developed a new type of neutron dosimeter, one capable of detecting neutrons in an intermediate energy range (after penetrating reactor shielding) and one which is small enough to be worn by workers. Neutrons at this energy level contribute to radiation doses but are difficult to detect due to their low energy by traditional dosimeters. The new technique utilizes a solid polymer in which tiny droplets of a liquid have been uniformly dispersed. Neutrons which strike these droplets "explode" them and the resultant gas bubbles are proportional to neutron dose. The sensitivity of the dosimeter can be varied by varying the density of the droplets. Commercial development of the detector is under investigation. The discovery of this versatile neutron dosimeter comes at a time when the radiation risk of neutrons is under re-evaluation and the maximum permissible neutron fluence may be reduced.

Highlights of IAEA Annual Report for 1983 (IAEA)

- The total installed nuclear power-generating capacity in the world reached 191 GW(e) by the end of 1983, with 25 new plants being connected to the grid during the year. Three of the new plants connected to the grid in 1983 were in developing countries; they had a total capacity of 1.4 GW(e). Nuclear power plants accounted for about 12% of the world's total electricity generation during 1983.
- Construction work started on 23 new plants, with a total capacity of 17.5 GW(e), while contracts or firm plans for 12 plants, with a total capacity of 13 GW(e), were cancelled or indefinitely

Off to Academia

(Staff)



*Those CNS members who attended Dan Meneley's farewell party late July, might need to be reminded that they had a good time. One attendee reported to the **Bulletin**: "I think we tripped on low flow at about 21:30 — maybe it was 22:30 — and then I was poisoned out for at least 48 hours." As reported previously, Dan has moved to the University of New Brunswick to take up the newly established chair of Nuclear Engineering. The two accompanying photos show an attentive crowd (and Mrs. Meneley) watching Dan trying out appropriate academic garb for his new post.*

suspended. This was due mainly to the continued low growth in electricity demand and to increasing financing problems in several countries. Three of the new plants were in developing countries.

- Work on several plants now under construction may be delayed or cancelled in the future, and it is now expected that the installed nuclear power-generating capability worldwide in 1985 will be 255-275 GW(e). It is expected that nuclear plants will account for 15% of the world's electricity generation in 1985.
- For the year 2000 a worldwide nuclear capacity of 485-725 GW(e) may now be expected, whereas 720-950 GW(e) were projected in 1982. The projected share of world electricity generation accounted for by nuclear plants in the year 2000 is 20%.
- Nuclear power plant investment costs continued their general strong rise. As they constitute up to 80% of the total costs of nuclear-generated electricity, concern about nuclear power now relates more to the technical and economic performance of nuclear power plants. Accordingly, in addition to the standardization of licensing procedures and the reduction of construction times, nuclear power plant reliability is being emphasized as a key question from the point of view of ensuring the long-term competitiveness of nuclear power.
- The renewed interest in small and medium power reactors, for both electricity and heat generation, may lead to new markets, not only in developing but also in industralized countries, if the economic competitivensss of such reactors can be established.
- There was a continued slowing-down of programs for the development of advanced reactor systems in several countries, especially the United States. However, 1983 was also marked by a trend towards increasing international co-operation — for example, in the development of LMFBRs in Western Europe.

CNS Division Update

CNS Radwaste Conference Postponed to 1986

The CNS Waste Management and Environmental Affairs Division has postponed to 1986 its planned International Conference of Radioactive Waste Management, which was to be held in Winnipeg, September 26-27, 1985. This division sponsored its first such conference September 12-15, 1982, a highly successful event.

Correction

Captions to the adjacent pictures on page 8 of the May-June 1984 CNS Bulletin were inadvertantly interchanged, identifying Eva Rosinger as Gerry Lynch and vice versa.

As well, on the CNS Council and Branch Chairmen list on page 12, Rudi Abel was inadvertantly identified as Ruby Abel. The editors regret these errors and any inconvenience they may have caused.

CNS Branch Programs

Ottawa Branch

The Ottawa Chapter closed its 1983-84 season with an excellent presentation in April by Dr. Brian Cheadle of the Chalk River Nuclear Laboratories on the investigations into the causes of the pressure tube failure that occurred in unit 2 of the Pickering Generation Station in August 1983.

Unravelling a scientific mystery story, Dr. Cheadle led his audience through the various metallurgical tests, analyses and hypotheses to the point where, he stated, the failure in the Zircaloy-2 tube was understood.

The details of the story have been presented elsewhere (e.g. CNS Annual Conference): the mis-located garter spring — allowing the pressure tube to contact the calandria tube, the high concentration of deuterium and hydrogen in the zirconium alloy, the migration of the deuterium and hydrogen to the cooler points where the pressure tube touched the calandria tube, the formation of brittle zirconium hydride blisters, cracking in the blisters, linking of the cracks until a critical crack length developed.

Although Dr. Cheadle felt the course of events was well established he noted that the investigators were still puzzled by the fact that other tubes, which had not failed, had more blisters and higher levels of hydride.

He closed on the optimistic note that the zirconium-niobium alloy used in all CANDU reactors after Pickering 2 showed extremely small propensity for hydrogen pick-up and therefore a similar failure in such tubes was highly unlikely, even if mis-located garter springs allowed contact between the pressure tubes and calandria tubes.

Although a new executive for the Ottawa Chapter had not been elected at the time of writing it is hoped that the Chapter will resume holding similar interesting meetings in the late fall.

Fred Boyd

Conferences & Meetings

International Conference on Occupational Radiation Safety in Mining

(continued on page 8)

CNS Council and Branch Chairmen 1984-85 /
Conseil de la SNC et locaux responsables 1984-85

President / *Président*
Peter Stevens-Guille (416) 592-5211
Vice-President / *Vice-président*
Joe Howieson (613) 995-1118
Immediate Past President / *Président sortant*
John Hewitt (416) 978-6697
CNS International Delegate / *Délégué International de la SNC*
Phil Ross-Ross (613) 584-3311
Secretary-Treasurer / *Secrétaire-trésorier*
(Administrative and Finance Chairman / *Président du Comité administratif et financier)*
John Boulton (416) 823-9040
Communications Chairman / *Président du Comité des communications*
Fred Boyd (613) 996-2843
Membership Chairman / *Président du Comité du sociétariat*
Gerry Lynch (613) 584-3311
Program Chairman / *Président du Comité du programme*
Nabila Yousef (416) 592-5983
Branch Activities Chairman / *Président du Comité des activités des sections locales de la SNC*
Ernie Card (204) 956-0980
CNS Division Chairmen / *Président des divisions de la SNC*
- **Nuclear Science & Engineering / *Science et ingénierie nucléaires***
Riccardo Bonalumi (416) 978-3063
- **Design & Materials / *Conceptions et matériaux***
Nabila Yousef (416) 592-5983
- **Mining, Manufacturing & Operations / *Exploitation minière, fabrication, exploitation des centrales***
Joe Howieson (613) 995-1118
- **Waste Management and Environmental Affairs / *Gestion des déchets radioactifs et environnement***
Eva Rosinger (204) 753-2311

Members-at-Large / *Membres en général*
Richard Bolton (514) 652-8310
Jan-G. Charuk (514) 934-4811
Ex-Officio / *Ex-Officio*
CNS General Manager and CNA Liaison / *Directeur-général de la SNC et agent de liaison de l'ANC*
Jim Weller (416) 977-6152

CNS Branch Chairmen / *Locaux responsables de la SNC*

Chalk River	Al Lane	(613) 687-5581
Quebec	**Contact/Responsable**	(514) 934-4811 x334
Ottawa	Frank McDonnell	(613) 237-3270
Toronto	**Rudi Abel**	(416) 823-9040
Manitoba	Ernie Card	(204) 956-0980

CNS 1985 Annual Conference Chairman / *Président de la conférence annuelle de la SNC (1985)*
Peter French (613) 996-9947

Sponsored jointly by CNA, EMR Canada and AECB; co-sponsored by CNS et al. To be held **October 14-18, 1984** in Toronto, Ontario. For information contact: **R.D. Gillespie, Program Chairman, Radiation in Mining Conference, c/o MacLaren Engineers Inc., 33 Yonge Street, Toronto, Ontario, Canada, M5E 1E7.**

Tritium Safe Handling Course

Sponsored by Canadian Fusion Fuels Technology Project, to be held **November 5-9, 1984** at Toronto and Chalk River, Ontario. For information contact: **CFFTP, 2700 Lakeshore Rd. W., Mississauga, Ontario, L5J 1K3.**

Symposium on New Technologies in Nuclear Power Plant Instrumentation and Control

Sponsored by NRC and EPRI, to be held **November 28-30, 1984** in Washington, DC. For information contact: **J.L. Tylee, EG&G Idaho, Inc., P.O. Box 1625, WCB W-2, Idaho Falls, ID 83415.**

1st International Conference on Fusion Reactor Materials

Sponsored by the Atomic Energy Society of Japan, et al., to be held **December 3-6, 1984** in Tokyo, Japan. For information contact: **R.R. Hasiguti, Science University of Tokyo, Faculty of Engineering, Kagurasaka, Shinjuku-ku, Tokyo 162, Japan.**

International ANS/ENS Topical Meeting on Probabilistic Safety Methods and Applications

Sponsored by the American Nuclear Society, co-sponsored by the Canadian Nuclear Society et al., to be held **February 24-28, 1985**, in San Francisco, California.
For information contact: **Ian B. Wall, Electric Power Research Institute, 3412 Hillview Ave., P.O. Box 10412, Palo Alto, California 94303.**

Symposium on Radioactive Waste Management 85

Sponsored by ANS et al., to be held **March 24-28, 1985** in Tucson, Arizona. For information contact: **R.G. Post, College of Engineering, University of Arizona, Tuscon, AZ 85721.**

Second National Topical Meeting on Tritium Technology in Fission, Fusion and Isotopic Applications

Sponsored by American Nuclear Society and co-sponsored by Canadian Nuclear Society, to be held **April 30 - May 2, 1985** in Dayton Ohio. For information contact: **Program Chairman Michael L. Rogers, Monsanto Research Corporation, P.O. Box 32, Miamisburg, Ohio 45342.**

87th Annual Meeting and Exposition, With Special Session on Fission Product Behaviour in Oxide Fuel

Sponsored by American Ceramic Society, Inc., to be held **May 5-9, 1985** in Cincinnati, Ohio. For information contact: **Dr. I.J. Hastings, AECL CRNL, Chalk River, Ontario, K0J 1J0.**

5th Pacific Basin Nuclear Conference

Sponsored by Korea Nuclear Society et al., to be held **May 19-23, 1985** in Seoul, South Korea. For information contact: **J. Sweeney, General Electric Co., 175 Curtner Ave., MC-873, San Jose, CA 95125.**

25th Annual International Conference of the CNA and 6th Annual Conference of the CNS:

Co-sponsored by Canadian Nuclear Society and Canadian Nuclear Association, to be held **June 2-5, 1985** in Ottawa, Ontario. For information contact: CNS.

The Unfashionable Side

Disposable Reactor Faces Licensing Problems

Efforts by a Crown Corporation to construct and market a disposable heavy water reactor have encountered difficulties with the national Control Board. "Projected costs have risen 1000%" complains one spokesman, "Due to new regulatory requirements ordered by the C.B." The corporation had originally requested a "special dispensation" from the C.B. concerning licencing requirements for the reactor. Now, although industry observers agree the reactor is absolutely harmless, the C.B. has insisted on an exclusion zone of at least one bedroom in size, three independent shutdown systems (SDS1, SDS2 and SDS3) and the necessity of an operator on constant duty, albeit one who would be allowed to watch television.
In addition, a 10 cm thick reinforced plaster (or stucco) containment is now a mandatory requirement, one which would significantly reduce the reactor's portability feature while making observation and feeding of the reactor control system difficult. The C.B. would not rule out the possibility of retrofits in the future or new regulations such as the imminent requirement to register neutrons. "These requirements have effectively shut us out of the $100.00 suburban reactor market," the spokesman added. He also foresaw financial problems for Gecko Solar Laboratories, Inc., the reactor licenser (on behalf of ASLEEP) which recently had difficulties placing a new stock issue.

Chuck Wood