CANADIAN NUCLEAR SOCIETY bulletin DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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- 9th CANDU Fuel Conference
- Manufacturing LVRF Fuel
- OPG Dry Fuel Storage
- New Licencing Directions
- Energy Person of Year
- NWMO Final Report

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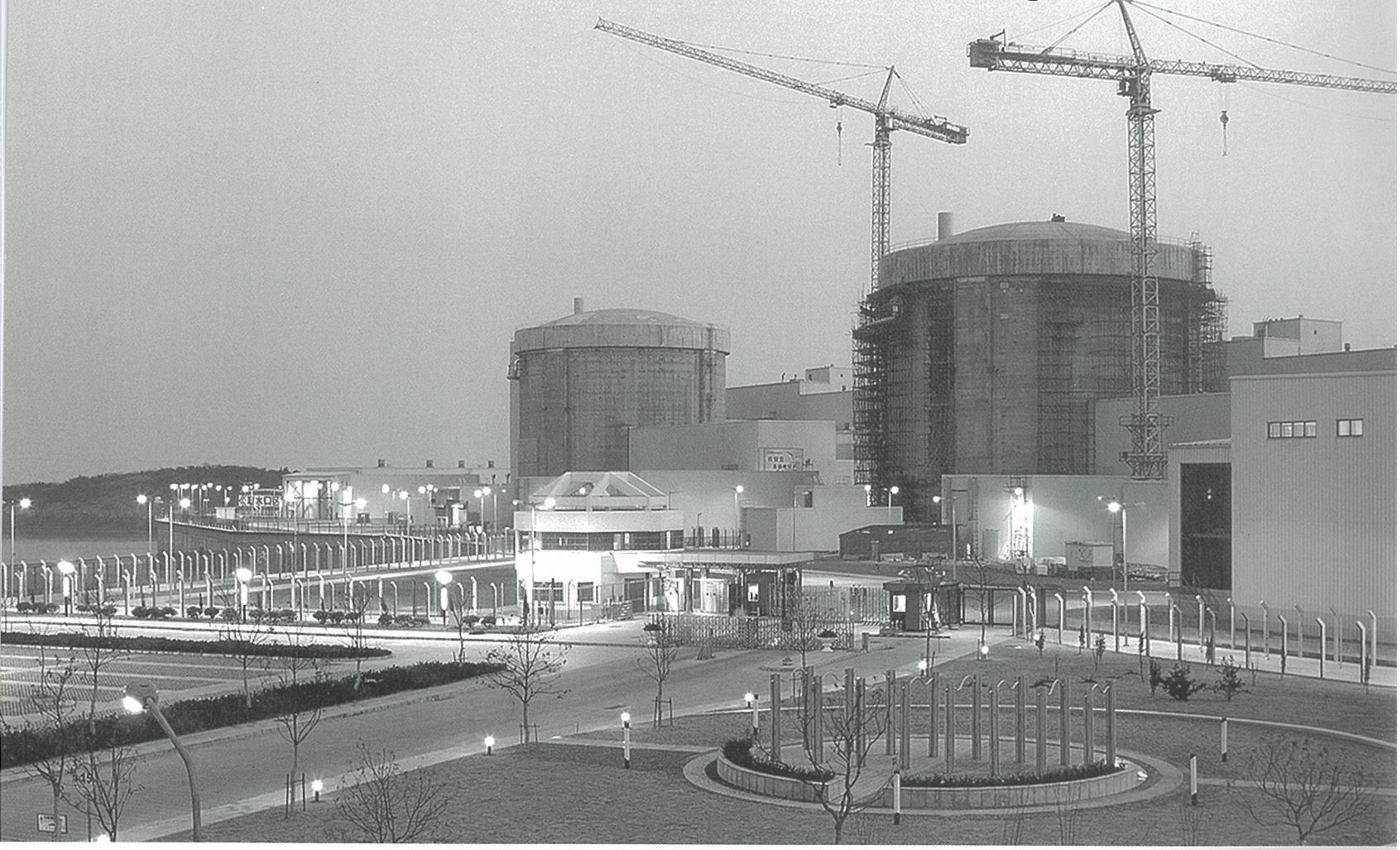

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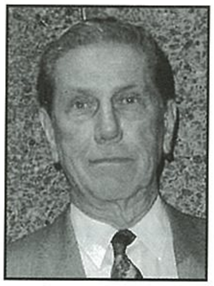
EDITORIAL

Future of CANDU?



As the prospects for "new build" nuclear power plants in Ontario increase, questions are surfacing about whether or not CANDU will be part of that future.

At the CNS CANDU Maintenance Conference in late November, John Coleby, an OPG vice-president, openly expressed what many have been thinking. His comments shocked some in the audience but were accepted by others as confirming their views.

Speaking from his background of restarting units 1 and 4 at Pickering A, Coleby complained that CANDUs are too complicated. PWRs are, he added, "just one big tank". Then he asserted, "If CANDUs do not improve the next Canadian plant will be a PWR."

What he failed to acknowledge is that most of what he is observing with OPG's nuclear plants is due to his predecessors at Ontario Hydro. During the design and construction periods the design organization never spoke to the operations group. Then, in the late 1980s and early 1990s the OH management and Board drastically cut maintenance until the poor state of the plants was so obvious they called in the American "advisers" and shut down eight units.

Because of that background OH plants are more complicated than the CANDU 6 design, which, as the Koreans have shown, can perform well if there is proper operation and maintenance.

As for Coleby's comment about PWRs being just a big tank - their complexity is all inside that tank. Back at the beginning of the CANDU program, when the decision was made to change NPD from a pressure vessel design to pressure tube a major objective was to have a design that could be built in Canada. That involved natural uranium and components within the capability of Canadian manufacturers. If OPG chooses a PWR very little will be built in Canada.

A parallel problem is occurring with the regulator. The CNSC is proposing "international" standards - read USA standards. Their proposals for new plants would exclude CANDU 6 (partially because of its small positive reactivity coefficients). At the beginning of our nuclear power program the then regulator, AECB, deliberately eschewed the prescriptive approach already being adopted in the USA and pursued an independent philosophy based on first principles.

Whether or not AECL's ACR design can overcome the prejudice expressed by Coleby and can meet the CNSC's new standards is yet to be seen. And, according to Jerry Hopwood, AECL does not intend to submit the design to CNSC until at least 2007. By then Ontario may have already made a decision.

Fred Boyd

IN THIS ISSUE

This issue features the 9th CNS CANDU Fuel Conference held in September 2005 but also includes something that has been generally missing, commentaries from readers. These begin with a **Letter** arguing for the need to design CANDU units with the capability to load-follow.

The other two commentaries are in the back section. One is a review, by Archie Robertson, of the large report **"Choosing a Way Forward - The Future Management of Canada's Used Nuclear Fuel - Final Study"** released by the Nuclear Waste Management Organization in early November. The other deals with a video that distorts the history of early uranium mining in the Northwest Territories, **Village of Widows.** We urge you to read these thoughtful pieces.

There is our report on the **9th International Conference on CANDU Fuel** followed by three of the papers presented. First is **LVRF Fuel Bundle Manufacture for Bruce,** which gives a glimpse of the challenge to fuel manufacturers of going to enriched uranium. Next is **CANDU Fuel Long-Term Storage and Used-Fuel Integrity,** a description of the system used by Ontario Power Generation. The third provides an overview of nuclear fuel manufacturing in India, **Manufacture of Fuel and Fuel Channels and their Performance in Indian PHWRs.**

There is a paper from the CNS Annual Conference but which is still relevant and important, **Development Of Licensing Basis For Future Power Reactors In Canada,** by G. Rzentkowski of the Canadian Nuclear Safety Commission.

There is a short account of the ceremony held in late October to honour Duncan Hawthorne as **"Canadian Energy Person of the Year 2005"** and a similarly brief report on the **Annual Meeting of the Organization of CANDU Industries.** A preliminary report is offered on the **7th CNS International Conference on CANDU Maintenance,** which was held in late November just before this issue "went to press".

Another history lesson is provided in the article **The Eldorado Radium Silver Express.**

There are the usual sections on **General News,** with our eclectic selection of items, and **CNS News,** providing a glimpse of the many activities of the Society.

And, of course, there is Jeremy Whitlock's particular view of affairs in **Endpoint.**

Finally, we ask you to look at the advertisements which reflect the renewed activity in the Canadian nuclear scene.

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~ *Cover Photo* ~

The cover photograph shows a view of dry storage containers at the Western Waste Management Facility of Ontario Power Generation at the Bruce site.

– Photograph courtesy of Ontario Power Generaiton.

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Bring Load-following Into Open

by Donald Jones[1]

***Ed. Note:** The following letter has been edited for space.*

Maybe I have missed them but I have not seen any responses in the public domain from the nuclear industry to the subtle message being put out by Energy Probe's Tom Adams that, "renewable energy and nuclear power won't give Ontario the power it needs during periods of peak demand" since "that's a characteristic that neither the nuclear plants nor the renewable energy stations are able to deliver". He is talking about load-following and he is not the only one. The Independent Electricity System Operator (IESO), Professional Engineers Ontario, and the president of the then AECB, back in 1998, have all commented on the lack of flexibility in CANDU.

The nuclear industry is poised for great things and now is not the time to be silent on the load following issue. Although a few papers have been produced on the effect of load-following on fuel in a CANDU reactor, I don't believe there has been a paper putting it all together to include: the reactor physics of power manoeuvring; how ACR will meet the IESO requirements for load-following and grid frequency control; and the cyclic effect on plant components and mechanisms.

Although, as far as I know, the present CANDU plants were not designed for daily load-following, some Ontario and off-shore units have experimented with load-following, but not on a continuous daily basis. Units in the U.S. are mostly run baseload on the theory that if you don't play with them there is less chance of something going wrong. However, with the preponderance of nuclear in France, the French (and German) PWRs have successfully load-followed hourly, daily and weekly for many years and the French units are even used for Automatic Generation Control, that is, the second by second control of grid frequency.

This may not be the best way to utilize nuclear reactors in Ontario but future circumstances may demand it and plants like the ACR must be designed to do it. The plants must have the flexibility to daily load-follow, and possibly even to provide operating reserve and grid frequency control if hydro plants are not available to do so. In some cases a nuclear plant could operate baseload and the unutilized generation exported or used for hydrogen generation, pumped water storage or compressed air storage. This mode of operation could involve the turbine steam bypass system in daily use and it may have to be beefed up as a result.

All power plants are subject to more wear and tear when operated in load-following mode and nuclear plants are no exception. With a nuclear plant it is the fuel that is most highly stressed. Safety dictates that the plant should respond properly to a design basis accident even after years of load following operation. Nuclear fuel that has been subjected to daily power changes must not fail due to higher temperatures after a Loss of Coolant Accident. If analysis and in-core testing show that the ACR fuel can survive daily load-following and the plant can meet the IESO load following specification, where are the rebuttals to the industry's critics?

Can the ACR also meet the IESO requirements for Automatic Generation Control, which puts more stress on the fuel and reactivity control mechanism than load-following? The future Ontario grid could quite possibly be made up of just nuclear and hydro with some significant renewables like wind. This being so, has any thought been given by the designers to increase the robustness of the turbine steam bypass system so that, if it is necessary, it can play a part in mitigating the relatively rapid load fluctuations from the wind portion of the grid? Would a more conservative rated reactor power help?

The IESO 10 Year Outlook mentions that, "Ontario's future generation supply mix will place an increasing reliability value on the flexibility of generating assets to provide load-following capability, operating reserve and automatic generation control". AECL's input last August to the Ontario Power Authority (OPA) on Ontario's future energy mix marketed CANDU into baseload replacement only, with an obscure Figure footnote that said, "Although nuclear generation is typically regarded as a baseload technology, new designs (including those by AECL) incorporate the ability to load-follow, allowing them to increase output to service intermediate demand when called upon".

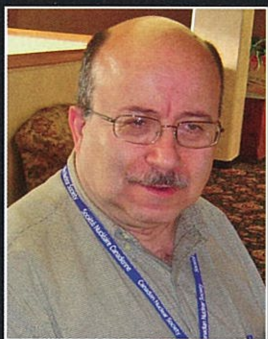
Even though the OPA solicited advice for base, intermediate and peak loads the AECL input did not even theorize on challenging natural gas for the intermediate and peak load segment of the projected demand, which it will have to do eventually. That is not good enough.

The industry must respond to its critics and show potential customers how CANDU can provide more than baseload for Ontario, and elsewhere.

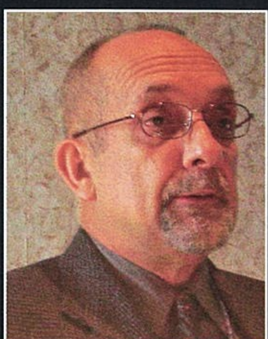
1 Donald Jones, a CNS member, is a retiree of Atomic Energy of Canada Limited who lives in Mississauga, Ontario. His e-mail address is: outrunning@rogers.com

9th CNS CANDU Fuel Conference

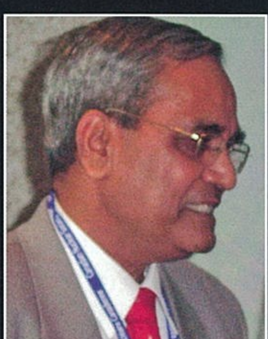
Criticality Safety a Major Topic at This Very Successful Meeting



Engin Özberk



Fernando Iglesias



R. Kalidas

A new issue for the Canadian nuclear scene emerged at the **9th CNS International Conference on CANDU Fuel** in Belleville, Ontario, September 18 - 21, 2005. Over 150 delegates from eight countries attended this well organized, successful meeting

The move to slightly enriched uranium for what has been described as Low Void Reactivity Fuel (LVRF) and the proposal to use similar material in the fuel for the Advanced CANDU Reactor (ACR) has brought new regulatory requirements that are impacting uranium conversion, fuel manufacturing and reactor operation.

Several technical papers by authors from Cameco and Zircatec described the extensive redesign of their facilities needed to meet the new requirements of the Canadian Nuclear Safety Commission (CNSC). A plenary paper provided background and suggestions for utilities using the enriched fuel.

The organizers of the nine CNS conferences on CANDU fuel have typically chosen venues away from the major cities, and it has worked. For the 9th CANDU Fuel Conference they selected a hotel overlooking the Bay of Quinte in Belleville, Ontario, about 120 km east of Toronto. The fact that the location is close to facilities of the three major Canadian players in the Canadian CANDU fuel business, Cameco, GE Canada, Zircatec, was probably just coincidental. They also took advantage of the proximity of Ontario's newest wine region, Prince Edward County, by including a tour of several wineries and dinner at one of them.

An innovation was the offering of two one-day "short courses": *Introduction to Nuclear Criticality Safety* on the Saturday, and *Introduction to Human Factors Engineering in Process Industries,* on the Sunday preceding the conference.

The conference began with a casual reception on the Sunday evening, which allowed delegates to renew acquaintances and meet new ones.

Conference chair **Engin Özberk**, from Cameco Corporation and technical chair **Fernando Iglesia,** of Bruce Power, opened the conference proper on the Monday morning. Iglesia welcomed all delegates and extended a special welcome to the several international representatives. Özberk observed that this was the ninth in the series of biennial conferences on CANDU fuel. Noting that more than 80 papers would be presented he commented that the objective was to learn, share, and "have fun". To help in that last category he reminded everyone of the winery tour and dinner that afternoon and evening.

The first half of the morning was devoted to a plenary session with three overview presentations. **Victor Inozemtsev,** from the International Atomic Energy Agency, began with an outline of some of the activities of the IAEA related to CANDU fuel, including the Technical Working Group on heavy water reactors. He noted the Nuclear Fuel Information System that the IAEA operates. HWR and LWR technologies are beginning to interact, he commented, and mentioned the DUPIC program for recycling PWR fuel in CANDUs.

He was followed by **Jerry Hopwood,** of Atomic Energy of Canada Limited, who gave an overview of the design of the 1,000 MW Advanced CANDU Reactor (ACR - 1000) that AECL is pursuing. The use of slightly enriched uranium will allow increased burnup, he commented, but presents a challenge to fuel designers. The concept requires advances in materials, reactor physics and component design, he added. Operational objectives include 95 per cent capacity factor, three-year maintenance and fuelling shutdown cycle with 25 day planned outages.

Next was **Yearn-Sun Park,** of Korea Hydro and Nuclear Power Company, who spoke on *Current Activities with Respect to Spent Fuel Management in Korea.* Before dealing with the title topic he began with a summary of nuclear power in his country. There are now 20 units operating in the country with a gross capacity of 17.7 GW, which provide approximately 30 per cent of Korea's electricity. Seven more units are planned to be in operation by 2015.

Park spoke primarily about developments in the handling and storage of spent fuel. A search for an underground disposal facility is proceeding. In the meantime spent fuel will be stored on site until 2016, under "Implementation Measures" adopted by the Atomic Energy Commission in late 2004. MACSTOR 400 dry storage units are being built at the Wolsong site.

At the second plenary session, held the first half of the Tuesday morning, **Alex Viktorov** of the Canadian Nuclear Safety Commission led off with a presentation on *Regulatory Activities in the Area of Fuel Safety and Performance.* He began by stating that the regulatory regime is changing. There is an increased demand for accountability, transparency and effectiveness to which the CNSC is responding. Then he turned to the CNSC's long-standing "Generic Action Item" GAI 94G02 on *"Impact of fuel bundle condition on reactor safety",* which, he said has determined the present priorities for regulatory activities related to fuel performance. CANDU licensees were requested to establish a formal program covering: resources, limits of fuel conditions, sheath failure threshold, ageing effects, and an annual review. The CNSC is proposing to issue a guide on fuel design.

He then turned to the CNSC review of LVRF, first from a performance point of view and then the question of criticality. On the latter he mentioned the new CNSC regulatory standard, *S324 Requirements for Nuclear Criticality Safety.*

Fridtjov Øwre, of the Halden Reactor Project, Norway, continued with a presentation *Status and Further Plans for the Halden MMS Activities.* MMS refers to a research project on "man-machine systems". Started in 1958, the Halden reactor continues a number of research programs with membership of a number of countries. Øwre invited Canada to join, noting that they can simulate CANDU conditions. In the MMS project humans are the experiment, he said. Two of the programs deal with human performance and human reliability.

Closing this plenary session was a presentation by **R. Kalidas,** chief executive of the Nuclear Fuel Complex in India, who provided an overview of the extensive programs of his organization. This includes the manufacture of fuel for heavy water reactors, boiling water reactors and fast breeder reactors. NFC also manufactures pressure and calandria tubes and reactivity devices for their PHWRs. The organization makes its own zirconium and zirconium alloys. He mentioned that they had made and used MOX and thorium fuels. *(Kalidas' paper is reprinted in this issue of the* CNS Bulletin.*)*

The final plenary session, on the Wednesday afternoon, focussed primarily on fuel related research but began with a paper *Assessment of Criticality Safety Issues for the Introduction of Enriched Fuel in CANDU Plants* by **Walter Thompson** of Nuclear Safety Solutions. This is an opportunity to paint a new process on a blank canvas, he commented. He referred to an IAEA principle that subcriticality must be ensured even if two independent abnormal events occur simultaneously. With virtually no Canadian utility experience with enriched uranium he proposed using international standards and particularly those of the USA which are the most detailed and recommended following the American ANSI / ANS 8 series of standards. To a question he noted that these standards do not have an enrichment threshold for application and so should be applied for even the slight enrichment of the LVRF.

Brent Lewis provided an overview of fuel engineering chemistry research at the Royal Military College. Extolling the advantages of jointly funded research he noted the following benefits: sharing of resources; visibility for industry; exposure of university people to industry professionals; development of future personnel for industry. He noted that RMC's licensed facilities (including a SLOWPOKE reactor) permits work with radioactive materials. It is all part of a "grander vision", he said, of an industry, university centre of excellence for fuel.

Victor Inozemtsev

Yearn-Sun Park

Delegates at the 9th CANDU Fuel Conference pose for the traditional group photograph.

Rick Holt, who holds the Nu-Tech Industrial Research Chair in Nuclear Materials at Queen's University, spoke about the joint work of the Natural Science and Engineering Research Council (NSERC), Ontario Power Generation (OPG), and CANDU Owners Group (COG). There are now eleven projects underway, he commented.

(John Luxat, of McMaster University, who was scheduled to speak about the NSERC / UNENE Industry Research Program, was unable to attend.)

Most of the conference was devoted to the presentation of technical papers in parallel sessions in four parallel sessions.

Titles of the sessions provide some insight into the scope of the technical papers presented.

- Design and Development
- Fuel Safety
- Fuel Modelling
- Fuel Performance
- Fuel Manufacturing
- Fuel Management
- Thermalhydraulics
- Spent Fuel Management and Criticality

The afternoon sessions on Monday were terminated early to accommodate an arranged tour of three of the new wineries on Prince Edward County followed by dinner at one of them.

At the conference banquet on the Tuesday evening, **Steve Coupland,** of the Canadian Nuclear Association, spoke about the *"Nuclear Communications Challenge"*. He said he would concentrate on the possibility of "new build" in Ontario and referred to a recent speech by Ontario premier Dalton McGuinty in which he opened the possibility of new or refurbished nuclear plants to meet the electricity needs of the province. "Anti-nuclear" groups immediately condemned the idea, Coupland noted, signaling a battle for public opinion. "If we lose that battle in Ontario it will be the end of nuclear in Canada", Coupland asserted. Performance is the most important factor, he stated. Although the CNA has been running a new TV campaign everyone supportive of the nuclear program needs to speak out, he asserted in closing.

The conference was organized by a dedicated group of volunteers headed by Engin Özberk of Cameco and Fernando Iglesias of Bruce Power. Others involved were: Andrew Oliver (Cameco), Dave Ingalls (Cameco), Mark Klintworth (UOIT), Ben Rouben (AECL), Debbie Hoselton (Cameco), Denise Rouben (CNS), Morgan Brown (AECL).

The conference was supported by a number of sponsors: AECL; Bruce Power; Cameco; GE Canada; Hydro Québec; Laker Energy Products; Ontario Power Generation; New Brunswick Power; Stern Laboratories; University of Ontario Institute of Technology; Zircatec Precision Industries.

A CD with full versions of most of the papers is available from the CNS office.

Delegates at one of the wineries visited.

LVRF Fuel Bundle Manufacture for Bruce[1]

by Aniket Pant[2]

Abstract

In response to the Power Uprate program at Bruce Power, Zircatec has committed to introduce, by Spring 2006 a new manufacturing line for the production of 43 element Bruce LVRF bundles containing Slightly Enriched Uranium (SEU) with a centre pin of blended dysprosia/urania (BDU). This is a new fuel design and is the first change in fuel design since the introduction of the current 37 element fuel over 20 years ago.

Introduction of this new line has involved the introduction of significant changes to an environment that is not used to rapid changes with significant impact. At ZPI we have been able to build on our innovative capabilities in new fuel manufacturing, the strength and experience of our core team, and on our prevailing management philosophy of "support the doer". The presentation will discuss some of the novel aspects of this fuel introduction and the mix of innovative and classical project management methods that are being used to ensure that project deliverables are being met. Supporting presentations will highlight some of the issues in more detail.

1. Bruce LVRF Bundle Background

The Bruce Low Void Reactivity Fuel (LVRF) bundle requires two sizes of fuel elements; 8 large diameter (13.5 mm nom. dia.) and 35 small diameter (11.5 mm nom. dia.). In extending the traditional 37 element bundle design the Bruce LVRF development has required the manufacturer to combine what are essentially two separate production lines for the two sizes of fuel into one bundle. The two enrichments in the bundle have compounded the complications. The increased number of sheaths and the addition of the mixer tabs (buttons) have presented an added challenge. The majority of the manufacturing issues have been resolved over the years in various test manufacturing campaigns.

Zircatec Precision Industries (ZPI) has been involved with the manufacturing development of Canflex type fuel since 1986. Early work involved the manufacture of enriched fuel pellets and sheath assemblies for test fuel bundles. During the 1989 -1994 period Zircatec developed tooling and procedures for the manufacture of several (3 - 6) Canflex design (Mk III) bundles for irradiation at CRNL. These bundles were manufactured with 2.26% enriched fuel and also with fuel of mixed enrichment. The uniqueness of this bundle design - two fuel element sizes - required considerable innovation in manufacturing process flow control and tooling design. Due to the small scale of the early work these were not serious issues. However, as the scale of the campaigns increased, so did the attention that was paid to future production level manufacturing issues. As is usual with all new product development activities, the initial campaigns were conducted at a small scale. Most of the early campaigns involved the processing of < 200 kg of UO2 powder (1 - 8 bundle equivalent quantities) and the production of small quantities of tubing. For example, pellet pressing was done in presses which we would consider "laboratory scale"; braze runs were small and brazing was done in a "one off" fashion using a small scale brazing unit; end cap welding was done in a laboratory scale, manually operated welding unit. This early work included development of processes for: control of density and microstructure of Canflex UO2 pellets; small scale manufacture of enriched and natural UO2 pellets and bundles; 26 Canflex bundles for the Point Lepreau Demonstration Irradiation; natural uranium (NU) Bruce style Canflex bundles; and the currently ongoing campaign for Bruce LVRF Demonstration Irradiation. This campaign uses processes that will apply for full core manufacture and the opportunity is being taken to fine tune the processes that will be used during full scale manufacture.

2. Full Scale Production Issues – Bruce LVRF

2.1 New Processes – Quality Built-in

The primary issues with production level scale-up are: the increased number of elements in the fuel as compared with traditional 37/28 element fuel; the fact that the bundle design incorporates two sizes of elements; the fact that the bundle contains both slightly enriched uranium (SEU) and blended dysprosia/urania (BDU) pellets; the thinner sheath wall; the greatly increased number of appendages on the 43 element design; and, the increased number of braze planes. The manufacturing concept is to "build in" quality and this has been a major focus of our efforts.

The different enrichments require the implementation of two distinct manufacturing lines, one for SEU and one for

1 Paper presented at the 9th CNS International Conference on CANDU Fuel, September 2005.

2 Zircatec Precision Industries, Port Hope, Ontario.

BDU. SEU and BDU lines have to be kept segregated from each other and from the NU lines. Further, two additional processes for each size of tube, pellet and end cap need to be incorporated. In addition, each size of pellet stack requires a set of end pellet sizes appropriately designed to provide the degree of control for stack length. The thinner sheath wall requires the introduction of new production level control techniques. Finally, product flow of appendage manufacture, is an issue, since with Canflex twelve different appendage types are required rather than the traditional seven and this complicates process flow and leads to an increased number of unit processes.

2.2 Criticality

Ensuring nuclear criticality safety (NCS) during the manufacture of enriched uranium fuel involves designing the process such that a nuclear reactor is NOT created. It is important to realize that LVRF production cannot be conducted in the same manner as natural uranium production. A robust yet manageable system has to be designed and set up via policies, program structure, process design and operational limits and controls and operator and supervisor training such that an inappropriate assembly of material and moderator cannot be created during the manufacture of the fuel. The fact that such concerns are new to CANDU fuel production, makes it imperative that issues of cultural mindset be addressed at the outset through rigorous involvement and training of all operational levels. The Zircatec NCS program is based on various Industry Standard guidelines (ANS) such as those for administrative practices, processes and operations, and training.

2.3 Fuel segregation

One of the major concerns in introducing enriched fuel into a natural uranium environment is that complete segregation of enriched and natural fuel must be maintained at all times. The design of the Bruce LVRF bundle introduces the added complication of the central BDU element and the added requirement that segregation of BDU/NU and SEU be maintained. The Zircatec strategy is to divide the plant into three physically separate areas for natural, BDU and SEU manufacture. They are physically separated by block walls and each area has its own air extraction and waste system. The BDU area has separate personnel change/shower rooms and entry/exit areas which are some distance from entry/exit areas for SEU and natural. Personnel change/shower rooms for natural and SEU production are common but have separate entry/exit points for the two lines. The SEU area will have coded access for specific qualified personnel who will be identified by color coded coveralls. This physical segregation and color coding will ensure that personnel are continually cognizant of the differences between the lines.

2.4 Project Mandate

As can be seen, implementation of the new fuel will have a significant impact of our current facility. In addition to the introduction of a culture change related to a new fuel design, fuel segregation and criticality safety the project involves the relocation of several existing processes as well as the introduction of some new ones. These changes are, of necessity, accompanied by structural changes to the facility and the associated relocation of people.

The Zircatec Project Mandate is to implement full production (~ 125 bundles/day) of the new fuel by Spring 2006. The project is to be engineered so that any changes to the facility do not interfere with the ongoing delivery of NU fuel to our customers. As can be seen, the changes that we have had to implement to our facility are not trivial and have affected almost everyone at ZPI. It is well known that, if changes are introduced without taking account of the dynamics of people's often unstated fears and anxieties, the enterprise is likely doomed. The balance of this discussion will discuss some of the methods we have used to coalesce people's energies, ensure that this does not happen and meet the project deliverables.

3. Project Structure and Teams

3.1 Language and Culture Change

We recognized that the language that is used in daily practice determines the reality that is created. Einstein made the comment that "you cannot solve a problem using the same language that created it". An extension of this statement is that in order to create sustainable change to an existing order, the language being used needs to change – "if you want a new answer you must use a new language". Cooperidge and Srivastava (1) postulated that since the basis of language is metaphor, it is important to use the correct (appropriately oriented) metaphors in conversations. A "solution" metaphor in contrast to a "problem" metaphor is more likely to result in a synergistic definition of the real issue which, in turn, will lead to a solution that can be implemented and is sustainable. Since the primary response to a stimulus of change is fear and anxiety, we recognized that a traditional problem solving approach – one which started with a metaphor of "what is wrong" – would be more likely to generate barriers and would prevent the airing of the real issues that could impede progress. Instead we attempted to recognize the pride and ownership that our co-workers have brought to the company over many years and utilized the metaphor of "what has been right all these years" and "what do you want to contribute" in each of our discussions. It has been our experience that this allowed fears and anxieties to more easily be brought forward and dealt with.

In the context of the introduction of a new fuel line in a traditional framework – where change has been infrequent – it is important to recognize the subtle barriers to change that may pre-exist in the prevailing language. Elliot (2) postulates that an organization may have a "syntax" – the "..rules of construction and word order..." but a very different "grammar" – "..the larger concept that makes sentences mean what we mean...". In a traditional organization which is not used to routinely engaging in major changes, the temptation is to "change by edict" in order to "get things done quickly". In the above analogy this addresses the issues of "syntax". However, the people who will be implementing and be affected by the change are not used to a "change language" – a language that can easily discuss issues of change without the solution being hampered by the barriers of fear and anxiety - at the daily practice level. Thus, the "grammar" of the language they actually use in daily life remains unchanged and is still rooted in trying to hold on to the security of the old. The end result is that the change can take a lot longer than expected, is full of tensions and anxieties and, worse, is not sustainable.

At ZPI the need to counter these subtle yet far-reaching potential roadblocks to project implementation was recognized and attempts made to develop an environment where people who would be affected by the changes and the process could easily participate in and contribute their energy to the discussions that defined the change. Significant effort was placed in generating appropriate metaphors that were conducive to participation and an attempt was made to use these in daily language so that conversations leading to successful completion of actions became a habit rather than an effort. Team Leaders had to be encouraged to foster such enabling conversations – ones where real issues affecting people could readily be aired and where appropriate actions could be derived and implemented. The fact that "what you talk about in daily practice will define the reality you get" was recognized. One example of this is the introduction of the concept of safety. It became routine to start every conversation in the facility with a safety topic. We deliberately avoided putting out a "edict" on the issue – we just talked about it. Every day. Discussions emanating from the safety topic became enabling, and since every conversation generated actions, the result was that people took ownership of safety enabling actions which were then implemented. The end result has been a general increase in the level of awareness on safety issues, an implementing of safe actions in our daily practice and our safety record has dramatically improved.

It is these concepts that we have used in developing our team and in implementing the new fuel line.

3.2 Project Team and Team Philosophy

The project structure made use of existing available highly skilled and experienced people supplemented by contract personnel. Hiring the right people was an important issue and we used our method of involving affected people in critical hiring decisions – thus, peers and direct reports were part of the hiring teams. Recognizing the fact that the project involved many changes in quality methods, facility, engineering, licensing, human issues and operations we engaged a team with leaders from each of these disciplines to lead the project. The oversight of team activities was at the company senior executive level. "Forming" of the Project Team involved various (minimal) structured training as required including traditional project management methods. An attempt was made to use the Project Management Book of Knowledge (PMBoK) (3) methods but these were found to be excessively planning/reporting/measuring oriented and were either abandoned or modified in favour of what project execution really required which were methods such as "The Last Planner" (4) which are implementation/decision making/consensus generating methods; more in line with the internal "grammar" we had developed.

We also built on our background in new fuel manufacturing development and our process improvement skills. Since this is a major endeavour, we have attempted to retain existing processes and methods for manufacture where possible and develop new processes only where such development was unavoidable due to the complexity of the new fuel design.

The Team Leaders each developed a team Mandate for their area by engaging appropriate team members in the discussions. As the project progressed, particular cross functional teams were struck to deal with particular issues. In all cases the teams had shop floor people at the discussion table.

This project structure, which involved all the affected in a meaningful fashion and inherently encouraged open discussion at all levels resulted in definition of the right actions and encouraged reliable promises from the people who were responsible for executing the actions. The role of the oversight team rapidly devolved to one of removing roadblocks and staying out of the way.

Project coordination was via weekly structured meetings where traditional methods were used to track actions and develop forward plans. These were supplemented by equally important discussions about potential anxieties among our co-workers that may be emerging from the rapidly changing environment. In this manner we attempted to reveal any hidden issues which could delay the project. Each of these very detailed discussions generated specific actions and in the main we were able to either prevent or minimize any detrimental impact on the project and on the normal production that continued unabated. Potential roadblocks requiring either senior management intervention or customer input were discussed at these meetings and were dealt with as the need arose. The team sense was one of agility; issues were dealt with quickly and with care and respect for all co-workers. The overall language was one of consensus and action and individuals challenged themselves to bring forward all relevant information in a timely fashion so that roadblocks could be easily removed.

4. Project Status

4.1 Achievements

Considerable changes have occurred in the ZPI plant since late 2002 when the project was started. The list below describes some of the actions that have been completed.

It should be noted that these milestones were accomplished during a period when the NU productions reached some of the highest levels in ZPI history – we consider this a major achievement from our team and a direct result of the spadework that was done in addressing issues of culture.

- Developed bundle design related manufacturing documentation and obtained approvals
- Prepared supporting Quality, Manufacturing and Criticality documentation and obtained approvals
- Developed, tested and scaled-up new processing methodology for BDU
- Tested and scaled up processing methodology for SEU
- Designed/built, procured and tested LVRF production equipment
- Designed/built, procured and tested LVRF inspection equipment
- Developed, tested, scaled up and made production ready all processes for the subassembly and bundle manufacture of the new 43 element design.
- Moved five non-uranium unit processes off-site
- Restructured plant to accommodate new lines and personnel moves
- Relocated ~ 30% of people to new work areas
- Deployed rigorous criticality safety training for all supervisors and support staff
- Deployed criticality training to specific operators
- Developed cross-functional teams to do the process designs and Criticality Safety Evaluations ~70% of unit process Criticality Safety Evaluations ongoing or completed
- Started DI bundle manufacture

4.2 Current Status

The project is on target. Plant structural work is complete except for two areas where complete definition is still outstanding due to unresolved issues outside of ZPI. All process designs and equipment procurement is substantially complete. Licensing issues are on track.

5. Summary:

The implementation of the LVRF fuel line at ZPI is on track. A Considerable amount of work has been completed. The success of the effort is attributed to a dedicated effort being applied to addressing issues of culture change within the organization.

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CANDU Fuel Long-Term Storage and Used-Fuel Integrity[1]

by Z. Lovasic, P. Gierszewski[2]

Abstract

Technologies for long-term dry storage in helium or air have been developed for used CANDU fuel. Used fuel dry storage facilities are presently in operation or under construction at all Canadian nuclear power stations.

The evaluation of the long-term integrity of stored used fuel started in 1977. Direct examination of fuel stored under water for up to 27 years has indicated that CANDU fuel, defected or not, could be safely stored. The Easily Retrievable Basket and Controlled Environment Experiments have provided information about potential impacts of aging mechanisms during used fuel storage in air for times up to 20 years.

The used fuel aging investigation focused on four mechanisms that are believed could have long term impact on used fuel integrity: Stress Corrosion Cracking (SCC), UO2 oxidation, creep and Hydrogen Assisted Cracking (HAC). As a result it was concluded that under normal dry storage conditions it is unlikely that CANDU fuel will suffer significant degradation during a period of 100 years. Additional investigation is still necessary in the areas where there is a higher uncertainty in the prediction of used fuel condition and for the degradation processes that are potentially more aggressive. Additional work is also necessary to evaluate the possible effects of abnormal/accident conditions on the integrity of fuel.

In 2004 a new program on used fuel integrity was started. The outlines of this program will be discussed. In the first phase of this project, the focus is on a review of the used fuel characteristics at the beginning of dry storage, and on studies of likely stresses that the fuel will be exposed to during handling and transportation after dry storage. In addition, preservation of relevant information (form and content) about the used fuel during a 100 year period is also being studied. In the first phase most of the investigation is carried out by Nuclear Safety Solutions (NSS). After the first phase additional examination and testing of used fuel is planned.

1.0 Introduction

This paper describes the approach to and status of the OPG Used Fuel Integrity (UFI) investigation project in 2005.

1 Paper presented at the 9th CNS International Conference on CANDU Fuel, September 2005.

2 Ontario Power Generation, Toronto, Ontario.

View of dry storage containers at Pickering NGS.

The project started in 2004 and is planned to last five years. The project is also a part of the IAEA Coordinated Research Project (CRP) in "Spent fuel performance assessment and research (SPAR II)".

2.0 CANDU Fuel Design and Life Cycle Conditions Related to Used Fuel Integrity

CANDU fuel bundle design has evolved since the first developments of the CANDU reactor technology. The first fuel bundles used at the Nuclear Power Demonstration (NPD) reactor near Chalk River with natural uranium contained 7 fuel elements. The fuel bundles used at Douglas Point nuclear station consisted of 19 fuel elements. Current CANDU operating stations in Ontario use two types of fuel bundle design. The Pickering station uses a 28-element bundle design, while the Bruce and Darlington nuclear stations use a 37-element bundle design. About 30 % of the fuel bundles currently used is slightly longer (approximately 1 cm). Low void reactivity fuel is also being considered for future use.

A characteristic of all the fuel bundle designs is that fuel elements are held together by means of welds attaching the end-caps of each fuel element to two Zircaloy-4 end plates. This type of assembly, unique to CANDU fuel, makes each fuel element an active component of the bundle structure and mechanically constrains each Zircaloy tube via a rigid attachment of each end cap to an end plate.

The typical burnup of CANDU fuel is about 220 MWh/kgU, with a most fuel between 120 and 320 MWh/kg U. The coolant temperature range is 260 to 300°C at a pressure of 10 MPa. A comparison of some key characteristics of CANDU and LWR nuclear fuel is shown in Table 1.

The fuel cladding is Zircaloy. On the inside of the fuel cladding is the CANLUB layer, a graphite-based lubricant that provides an advantage during fuel manufacturing, and also improves the fuel cladding lifetime by adsorbing some elements like iodine that may act as a catalyst for stress corrosion cracking. During reactor operation, the fuel cladding receives a significant radiation dose and may be subjected to chemical corrosion processes. Typically, CANDU fuel cladding is exposed to high-energy neutron fluence in a range from 6 to 10 x 10^{24} n/m^2. The general effect of fast neutron irradiation on the mechanical properties of Zircaloy is increased brittleness.

The most important chemical effect on a fuel bundle is the incorporation of hydrogen and deuterium in the Zircaloy cladding. The hydrogen content in irradiated fuel results in the precipitation of hydrides, which may in certain cases result in cladding failures during reactor operation.

Following their in-reactor service life, the fuel bundles are removed from the reactor and transferred dry to the irradiated fuel bay. This transfer normally takes less than three minutes, during which time the fuel bundle temperature rises and the fuel cladding reaches temperatures of between 300 and 400°C depending on the bundle irradiation history. Following this transfer, the fuel is cooled off by contact with the water of the fuel bay.

After about 10 years in the fuel bay, the used fuel is transferred to dry storage containers. At OPG, 384 bundles are loaded into a Dry Storage Container (DSC). This is then vacuum dried, welded and refilled with helium. The peak temperature within the DSC with helium has been estimated as less than 180°C, and probably no more than 150°C for average burnup fuel. The temperature then decreases as the radioactive heat decays, and oscillates seasonally.

Table 1: Comparison of CANDU and LWR UO2 Fuel Properties (McMurry et al., 2003)

Fuel Property	CANDU Fuel	LWR Fuel
Uranium processing	Natural UO_2	Enriched UO_2 containing 1-5% U-235
UO_2 density (% of theoretical)	97%	94 - 95 %
Oxygen/Uranium ratio	2.001	2.001
Grain size	5 - 10 μm	2 - 4 μm
Fuel element per bundle	28 - 37	50 - 300
Fuel element length	0.5 m	3 - 5 m
Fuel pellet diameter	12 - 14 mm	8.5 - 11 mm
Burnup range	120 - 320 MWh/kg U	190 - 960 MWh/kgU
Average burnup	220 MWh/kg U	625 MWh/kg U
Linear power range	20 - 55 kW/m	15 -25 kW/m
Centre line temperature	800 - 1700°C	800 - 1200°C

The integrity of the used fuel after an extended period of storage depends in part on the fuel conditions at the start of storage. The amount of fission gas in a fuel element, the neutron damage and hydrogen content of the cladding and, in general, most chemical, thermal and mechanical in-reactor damage to the fuel increases with burnup. (The rate of oxidation of UO_2 to U_3O_8 appears to be lower for fuel with higher burnup.) Burnup varies between bundles, and also within the bundle, with the burnup of the outer fuel elements being about 1.4 times higher than that of fuel elements at the centre of the bundle.

The gas pressure in a fuel element and the resulting net cladding pressure range from 0.41 to 2.4 MPa. The associated localized stresses in the individual fuel elements also vary over a substantial range but under storage conditions remain below 80 MPa for most of the fuel. 100 MPa can be considered the absolute maximum localized stress to which the cladding might be subjected at the assumed high cladding temperature of 180°C.

3.0 Quantities of Used Fuel for Dry Storage

In Ontario there are three nuclear generating stations (Pickering, Bruce and Darlington) with a total of 20 CANDU nuclear reactors. All nuclear fuel will be, after a period of wet storage in the Irradiated Fuel Bays, stored in the dry storage facilities at the site where it is generated.

The quantities of used fuel that will be stored in dry storage facilities depend on the assumed reactor lifetime. A recent reference scenario used by the Nuclear Waste Management Organization assumes that there will be about 3 200 000 fuel bundles in dry storage generated by the OPG nuclear reactors, and a total of about 3,600,000 bundles from all sources in Canada by the year 2033 (NWMO web site, Fact Sheet, Nuclear Fuel Waste in Canada).

4.0 Used Fuel Long Term Management

In 2002, a Nuclear Waste Management Organization (NWMO) was formed as a result of the Nuclear Fuel Waste Act. The mandate of the NWMO is to investigate long-term approaches for managing Canada's used nuclear fuel, and to implement a recommended approach. The draft recommendation of the NWMO for the long-term management of used fuel is the Adaptive Phased Management Approach, (NWMO web site, 2005). This approach is divided into three phases, with flexibility in moving between the different phases. While a deep geologic repository is proposed in the final phase, the approach includes an extended period of continued dry storage at reactor sites, and possibly at a central site, before the repository.

In 2004, as a part of the used fuel long-term management technology program, OPG initiated a 5-year project on Used Fuel Integrity during storage. The project is an extension of the previous used fuel integrity studies that started in Canada as early as 1977.

OPG used fuel dry storage systems and structures are in service at the Pickering Waste Management Facility (PWMF) and the Western Waste Management Facility (WWMF) at Bruce site. A third dry storage facility is being built within the Darlington site. Used fuel is placed in Dry Storage Containers (DSCs), which are arranged above ground in storage buildings.

The other Canadian nuclear stations at Gentilly and Point Lepreau have their own technology for the used fuel long term dry storage. They use Concrete Canisters (CCs) designed by AECL (CANSTOR system). Concrete Canisters are also used for storing used fuel from the shutdown CANDU reactors - Whiteshell Laboratories research reactor (WR-1), Douglas Point and NPD (Frost 1994).

There are differences in storage conditions in DSCs and CCs that will have to be taken into account for used fuel integrity studies. In DSCs, there is a helium atmosphere while in CCs it is air. Also, in DSCs the fuel bundles are stored horizontally, while in CCs fuel is stored vertically, which has an impact on stresses.

5.0 Previous Studies of Potential Degradation Mechanisms of CANDU Fuel

The first formal evaluation of the long-term integrity of used fuel during storage was initiated in 1977 by Ontario Hydro and AECL (Frost 1994).

Examination of fuel stored under water for up to 27 years indicated that neither the cladding nor the UO2 fuel matrix, in any of the undefected elements, had experienced any apparent degradation (Wasywich and Frost, 1991). The cladding of a defected element that had been stored under water for about 21 years also did not experience any apparent deterioration. It was concluded then that CANDU used fuel, defected or not, can be safely stored under water for at least 50 years (Wasywich and Frost, 1991).

In the 1980s, experiments in concrete canisters started at AECL's Whiteshell Laboratories as an investigation of used fuel integrity during dry storage. The concrete canister experiments were known as the Easily Retrievable Basket (ERB) experiment and the Controlled Environment Experiment (CEX-1 and CEX-2) (Frost, 1994). The ERB experiment involved storage in dry air at seasonally varying temperatures. The Controlled Environment Experiment was divided into two phases, one was the storage in dry air at 150°C (CEX-1) and the other was the storage in moisture saturated air at 150°C (CEX-2).

The ERB experiment involved storage of two undefected used fuel bundles from Pickering nuclear station. CEX-1 and CEX-2 involved storage of four undefected used fuel bundles from Pickering nuclear station and four bundles from Bruce nuclear station (Frost, 1994). In 1986 two fuel elements that had developed a through-wall cladding defect in-reactor were introduced into the program to compare the effects of deliberately defected elements and in-reactor defected elements. The defected and undefected fuel elements are separated in the storage canisters.

Subsequent retrieval of fuel elements from ERB, CEX-1and CEX-2 experiments, as well as their inspection and destructive analysis, have provided a data base for this and future investigations of used fuel integrity. The latest retrieval of elements from ERB and CEX-1 occurred in 1997.

The following aging mechanisms have been investigated:

- cladding creep;
- UO2 oxidation;
- stress corrosion cracking of the Zircaloy bundle;
- hydrogen assisted cracking (or delayed hydride cracking) of the Zircaloy bundle.

5.1 Cladding Creep

Cladding creep in CANDU fuel has been evaluated based on extrapolations, mechanistic models and creep correlations mostly developed for LWR fuel. Inspections and testing of fuel from ERB, CEX-1 and CEX-2 experiments also provided some inputs for the creep evaluation.

The cladding creep models developed to predict behaviour of LWR fuel cladding have been applied to the CANDU fuel. The Larson -Miller model and the mechanistic approach with the diffusion controlled cavity growth mechanism used by NRC and DOE, assuming fuel cladding temperature of 180°C were applied. The results from all the models have ruled out creep as a risk to fuel integrity over 100-year dry storage time scales.

However, in CANDU fuel, creep strain can result in changes to the bundle geometry. After irradiation, fuel elements are no longer straight and bundles no longer have a straight cylindrical shape; they are slightly bowed, and the end plates are no longer parallel to each other. The deformation induced on a fuel element during irradiation results from the harsh reactor environment and interactions with the rest of the bundle structure and the reactor pressure tube. Subsequent cooling of the bundle, upon removal from the reactor, results in residual stresses which are reflected in the distortion of the bundle geometry. For CANDU fuel, unlike LWR fuel, the assessment of residual stresses, and therefore subsequent creep strain, must include the effect of interactions between the fuel element and the bundle end-plates via the end-cap to end-plate welds.

In terms of a conventional strain-to-failure criterion for a fuel element, creep is not likely to be a limiting factor for dry storage over a period of 100 years. However, the residual stresses resulting from creep strain on the end plate welding during reactor irradiation and subsequent cooling may present a risk to bundle integrity over long term storage.

5.2 UO_2 Oxidation

Potential oxidation of UO_2 to U_3O_8 in the fuel pellet was considered a concern because the consequent swelling of the pellet would increase stresses on the fuel cladding and may result in cladding deformation or failure.

A model which describes the fundamental data and equations for a detailed model of UO_2 oxidation and provides suggestions for refining and calibrating the model was developed. This model describes the oxidation kinetics of UO_2 pellet fragments by calculating the simultaneous oxidation of grain boundaries, diffusion-controlled oxidation of grains to U_3O_7/U_4O_{9+x}, and further oxidation to U_3O_8 by a nucleation-and-growth process. According to the model results, conditions for detrimental cladding damage from UO_2 oxidation to U_3O_8 are expected to be difficult to reach under a normal storage environment in a DSC (i.e., a conversion yield of 15% to U_3O_8, which would cause cladding diameter increase of 2%).

During the CEX-1 experiment some used fuel elements from Pickering-A and Bruce-A were deliberately punctured to simulate fuel defects and stored in dry air at 150°C. The fuel elements were monitored over a period of 15 years and the fuel bundles were examined four times during this period. Oxidation of UO_2 resulted in U_3O_8 generation only in the vicinity of the defects. No changes in fuel element diameter were observed in the vicinity of defects. This experiment was conducted under harsher conditions (constant temperature of 150°C and presence of air) compared to conditions in DSCs. This further supports the assumption that normally there are no conditions for significant U_3O_8 generation in a DSC.

5.3 Stress Corrosion Cracking of Zircaloy (SCC)

Previous studies have indicated that there are two different types of threat from SCC. One potential threat is cracks in the inner surfaces of cladding or end-cap welds induced by the iodine in the gap of the intact fuel. This is largely prevented by the CANLUB coating in fuel elements (early CANDU fuel did not have Canlub coating). The other threat is that of SCC initiating on the outside surface of a fuel element in cases where the DSC cavity becomes contaminated with SCC agents under some hypothetical accident conditions. This case falls under abnormal storage scenarios. To analyze the risk associated with this scenario, it is necessary to determine the maximum predicted concentration of SCC agents in the DSC cavity due to fuel failure.

The results from the AECL studies provide valuable data on the SCC of CANDU fuel and indicate a path for establishing the risk of fuel failure from SCC. Wood's results indicate a clear dependence of SCC on fast-neutron fluences and on the existence of previous notches or marks on the cladding surface. Since both these parameters can be estimated from fuel statistics using available information from PIE of OPG's fuel, an estimate of the risk of cladding failure from SCC could be largely derived based on existing information.

5.4 Hydrogen Effects on Zircaloy (DHC)

The two major potential effects on the fuel Zircaloy components from hydrogen incorporated during irradiation in the reactor are delayed hydride cracking (DHC) and embrittlement, both of which would increase susceptibility to fuel failure when subjected to impact loads or vibration. These phenomena occur as a result of hydrogen and deuterium precipitation in the Zircaloy and they may constitute the biggest concern for long-term integrity of the fuel. The hydrogen and deuterium precipitate in the form of hydrides. Typical hydrogen/deuterium content is in CANDU fuel cladding is below 100 ppm. The morphology and geometric orientation of the hydrides, as well as their size, have a significant effect on the properties of the material.

Temperature cycling of the fuel in storage induced by ambient temperature oscillations may result in a cycle of dissolution and precipitation of the hydrogen in the fuel Zircaloy components. The slow progressive decrease in fuel temperatures during dry storage will eventually result in precipitation of all dissolved hydrogen in the form of hydrides. Coupled with residual stresses in the cladding and welds, and with the temperature gradients within the DSC, these processes could result in migration of the hydrogen to high stress points and in growth or re-orientation of the hydrides (see EPRI 2002, Part II, and Section 4.3).

A report by Rashid et al. (EPRI 2001) presents an analysis defining five conditions that are needed for DHC to be an active mechanism in LWR fuel during dry storage. Based on this study it was concluded that for CANDU fuel, the stress intensity factor is the key parameter to be evaluated in order to assess the potential effect of DHC on used fuel integrity.

6.0 Temperature Measurements and Thermal Analyses of Used fuel in the DSC

In 1998, one DSC was instrumented with 24 thermocouples at the inner and outer steel liners and temperature was measured over a period of 100 days. The temperature measurement results were used in 2003/2004 for thermal analysis of used fuel in the DSC. Thermal analysis has included scenarios that are a part of the dry storage processes. Thermal analysis was done for various heat sources, under vacuum and different pressures of helium and air.

In the benchmarking part of the thermal analyses, results were compared with the measured temperatures. The results indicated a difference between the computed and measured temperatures. Differences were on the conservative side because the computed temperatures were higher than measured by approximately 10-15°C.

Thermal modeling of the long term dry storage scenarios has shown that the highest temperature of fuel cladding is approximately 140°C, during the process of vacuum drying (ANSYS 2004). The seasonal temperature variations of the hottest fuel element were found to be up to 55°C. The temperatures were in general lower than the originally predicted and used for evaluation of the used fuel deterioration mechanisms.

7.0 Used Fuel Integrity Project

In 2004, a new five-year plan for investigation of used fuel integrity during long-term (100-year) dry storage was started.

The logic of the approach for the next phase of the used fuel integrity investigation is shown on the block diagram in Figure 1. The plan is to evaluate the characteristics of fuel at the beginning of dry storage based on historic data, and in parallel to investigate envelope of stresses and loads that fuel would undergo after the dry storage period. The results of these two investigations would also be the development of a laboratory examination program for fuel characteristics and for behaviour under estimated stresses and loads the fuel would undergo during handling and transport. Fuel stored in ERB, CEX-1 and CEX-2 could be used for some of the examinations. The plans for further used fuel integrity investigations also include additional temperature measurements and thermal analysis.

The results of the program should establish whether used fuel of given characteristics is fit to undergo a certain operation (e.g. transportation). Fuel bundle mechanical integrity is the major concern as it is believed that an occasional pinhole breach of the fuel element is not going to be a major concern during handling and repackaging of the fuel 100 years from now.

The aging processes that will be considered in the Used Fuel Integrity project are those previously noted: cladding creep (including its effect on endplate welds), UO_2 oxidation, SCC and hydrogen effects on Zircaloy-4, as well as mechanical stresses and potential synergistic effects from combinations of these factors. The critical areas of investigation are:

- susceptibility to shock and fatigue failure of Zircaloy components caused by hydrogen mobility and precipitation or re-orientation of hydrides,
- susceptibility to delayed hydride cracking caused by the combined effects of hydrides, residual stresses in the welds and incipient cracks.

Finally, the plan also includes studies of what information that is pertinent to used fuel integrity would have to be preserved for future generations for safe handling and transport of used fuel. The study will also include investigation of the best form to preserve the information.

The specific plan is outlined in more detail below.

7.1 Used Fuel Characteristics at the Beginning of Dry Storage

A project to compile and review all the historic data about the Reference Characteristics of the Used Nuclear Fuel at the beginning of dry storage was started in 2004. The objective of this study is to provide data about fuel characteristics that are pertinent to used fuel integrity, as well as to provide basis for developing further used fuel examination programs.

Preliminary review of data involved categorization of defects that were determined during used fuel inspections. Defects were categorized based on expert experience into moderate and significant risk categories pertinent to losing integrity of the bundle.

Inspection observations were related to the following parameters:

- Residual stress magnitude on the fuel bundle end plate,
- Residual stress magnitude on the weld between the end cap and the end plate,
- Residual stress magnitude on the weld between the end cap and the sheath,
- Residual stress magnitude on the fuel element sheath.

Preliminary data are shown in the Table 2.

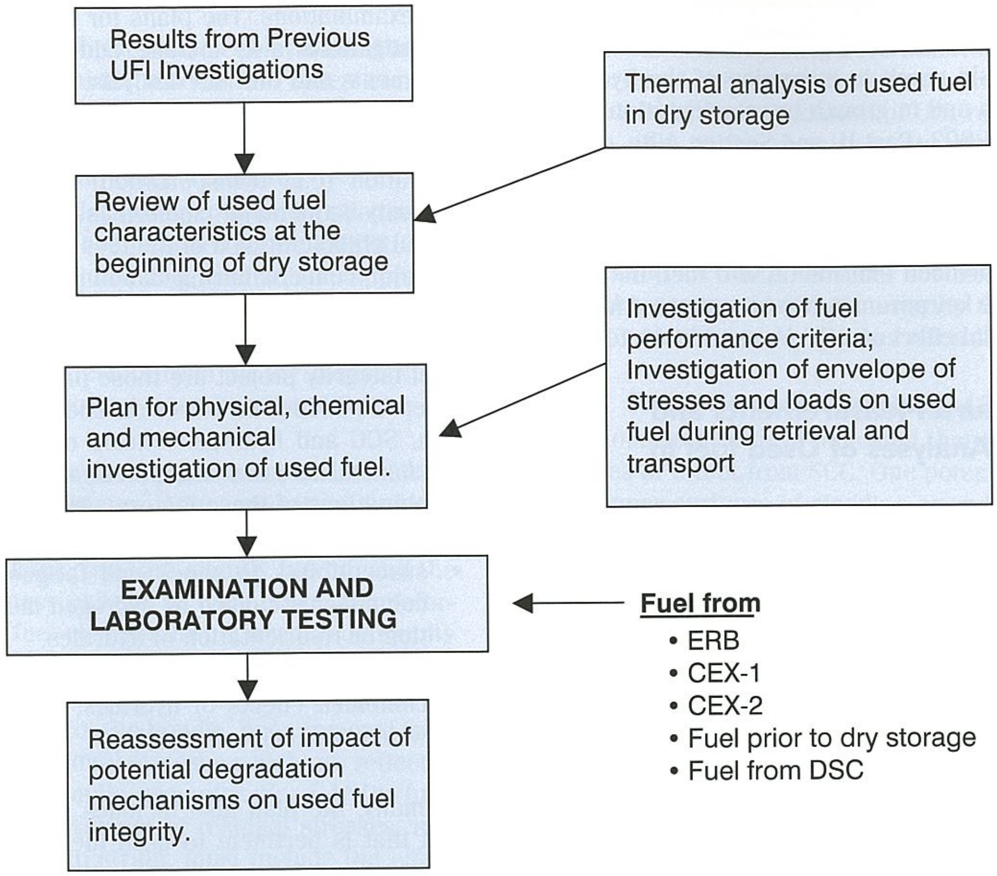


Figure 1: Logic of the approach of the 5-year plan for used fuel integrity investigation.

Table 2: Preliminary Data from Fuel Characteristics Evaluation

Total number of used fuel bundles	1,500,000
Number of bundles inspected	9,000
Number of bundles undergone PIE*	~ 300
Estimated % of all bundles with potential loss of integrity	0.02-3.6 (%)

* PIE= Post Irradiation Examination

The wide range of percentage bundles with potential loss of integrity is due to uncertainty in how representative the inspected fuel bundles are of the general population. The range covers from random selection of fuel bundles to targeted inspection based on some incident indications.

7.2 Expected Stresses and Loads during Handling and Transportation

A need to determine the envelope of possible loads and vibrations used fuel may be exposed to during handling and transport after long term storage was identified, and a project to define this envelope was started at the end of 2004. The work will involve review of the current practices and procedures for handling and transport of used fuel. The results of this investigation would enable determination of the acceptable physical characteristics of used fuel that would ensure their integrity during handling and transport.

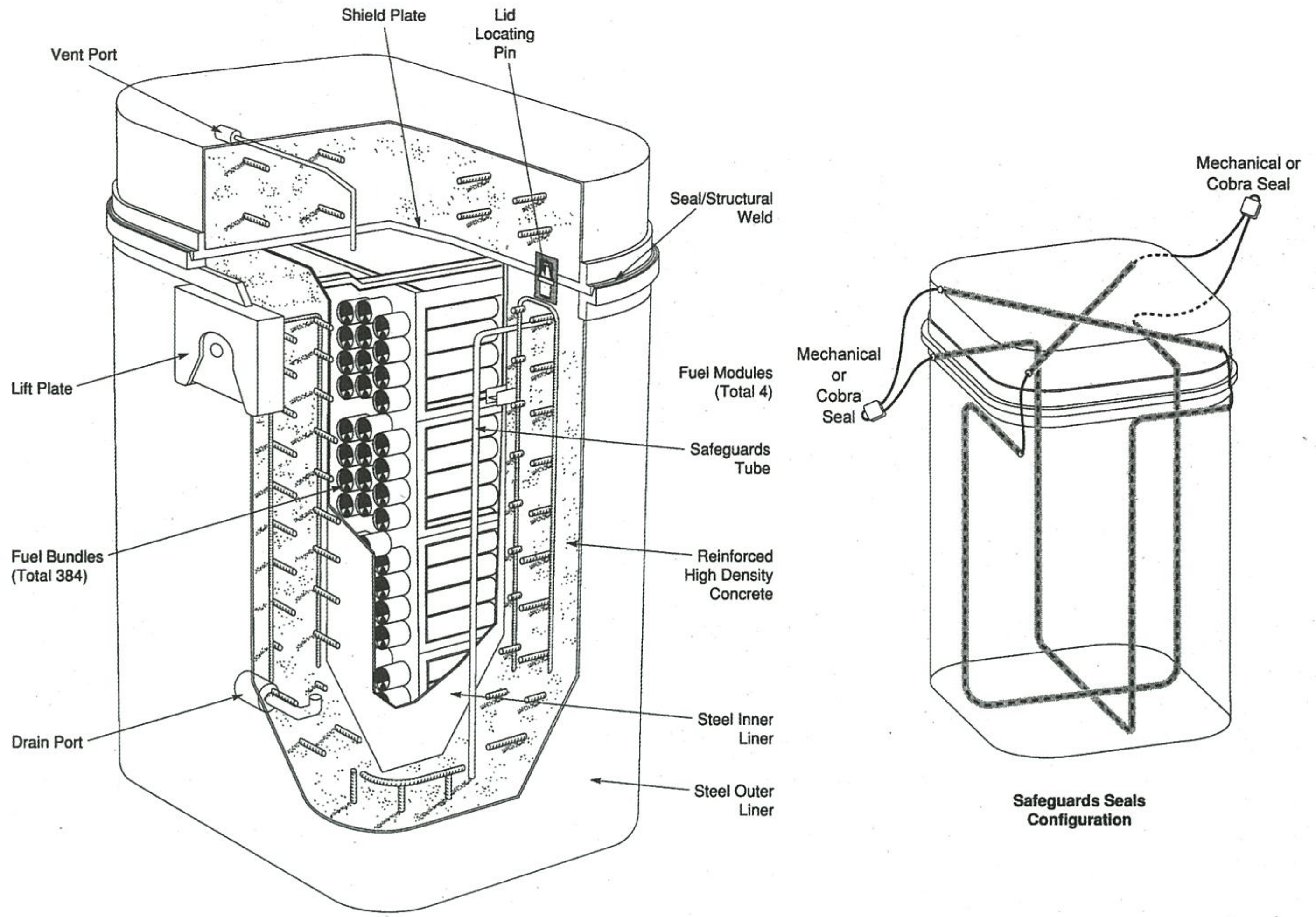
7.3 Development of a Plan for Examination and Testing of Used Fuel

The examination programs will consider tests and analyses of used fuel that could provide information on stressors and parameters affecting deterioration mechanisms of used fuel. The program will be based on previous examinations and on the identified data gaps for used fuel deterioration modeling. Furthermore, the program will consider testing and examination of used fuel behaviour under the envelope of defined loads and vibrations.

8.0 Summary and Path Forward

Based on the review of technical information on phenomena relevant to fuel integrity and previous investigation and research of CANDU fuel, there are some major conclusions that could be made:

- Under normal storage conditions it is unlikely that CANDU fuel will suffer significant degradation during a



Schematic of a Dry Storage Container.

period of about 100 years of dry storage. Therefore it should be possible to retrieve, re-package and transport used fuel as required using methods and systems similar to those used today.

- To provide increased confidence regarding the first conclusion, additional investigation will be conducted in areas where there is a higher uncertainty in the prediction of fuel condition and on some degradation processes to which the fuel appears to be more vulnerable.
- Additional work will also be conducted to evaluate the possible effects of abnormal and/or accidental conditions on the integrity of fuel.

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Manufacture of Fuel & Fuel Channels and Their Performance in Indian PHWRs[1]

by R. Kalidas[2]

Abstract

Nuclear Fuel Complex (NFC) at Hyderabad is a conglomeration of chemical, metallurgical and mechanical plants, processing uranium and zirconium in two separate streams and culminating in the fuel assembly plant. Apart from manufacturing fuel for Pressurised Heavy Water Reactors (PHWRs) and Boiling Water Reactors (BWRs), NFC is also engaged in the manufacture of reactor core structurals for these reactors.

NFC has carried out several technological developments over the years and implemented them for the manufacture of fuel, calandria tubes and pressure tubes for PHWRs. Keeping in pace with the Nuclear Power Programme envisaged by the Department of Atomic Energy, NFC had augmented its production capacities in all these areas.

The paper highlights several actions initiated in the areas of fuel design, fuel manufacturing, manufacturing of zirconium alloy core structurals, fuel clad tubes & components and their performance in Indian PHWRs.

1.0 Introduction

Nuclear Fuel Complex (NFC) at Hyderabad, India is an industrial facility of the Department of Atomic Energy for manufacture of fuel assemblies and core structurals for all the power reactors in the country. Uranium and Zirconium are processed in two separate streams of plants engaged in chemical, metallurgical and mechanical operations and finally culminating in PHWR fuel assembly plant. The production capacities of various plants have been significantly enhanced to meet the increased fuel demand for the growth of nuclear power generation programme in India. Several technological developments carried out in production processes have resulted in improved quality of the fuel and productivity of the plants at NFC. Backed by more than three decades of fuel manufacturing experience at NFC, fuel for the first 540 MWe PHWR at Tarapur has been successfully manufactured and supplied.

In the areas of reactor core structurals too, NFC has developed unique technology for the manufacture of large diameter thin - wall calandria tubes through seamless route instead of conventional welded route. Likewise, several process improvements have been carried out for the manufacture of Zr - 2.5% Nb pressure tubes and zirconium alloy clad tubes & components resulting in improved quality.

With continual improvements in production processes coupled with strict quality assurance system in place at NFC, the performance of fuel and fuel channels in the reactors has been quite satisfactory.

The subsequent sections of the paper highlight the improvements made in the manufacture of fuel and fuel channels for PHWRs.

2.0 Nuclear Power Generation in India

Presently, 12 PHWRs and 2 BWRs are in commercial operation in India with a total installed capacity of 2720 MWe. Two of these units viz. RAPS-II at Rajasthan and MAPS-II at Kalpakkam are operating successfully after en-masse coolant channel replacement. The first of the higher capacity 540 MWe PHWR units at Tarapur (TAPP-IV) has been successfully commissioned in March, 2005. Construction of the second 540 MWe PHWR unit at Tarapur (TAPP-III) and four additional PHWR 220 units at Kaiga (KAIGA - III & IV) and Rawatbhatta (RAPP - V & VI) is progressing well. These units, which are in various stages of construction, are expected to go into commercial operation during the next couple of years. Kakrapar-I surpassed record of 272 days of uninterrupted operation on June 15, 2005. Table 1 summarizes the nuclear power programme in India based on PHWRs.

The performance of the Indian Nuclear Power Plants has been continuously improving over the years. So far, 70 full power (FP) years of PHWRs and 40 FP years of BWRs have been clocked.

3.0 PHWR fuel production in India

3.1 Fuel manufacturing activities at NFC

Keeping pace with the nuclear power generation profile as projected by Nuclear Power Corporation of India Ltd (NPCIL) and the consequent increase in the requirement of yellow cake, the mining and milling activities have been intensified by Uranium Corporation of India Ltd (UCIL). Likewise, the production capacities of various plants at NFC have also been significantly enhanced to ensure the supply of required quantities of fuel in time.

1 A plenary presentation at the 9th CNS International Conference on CANDU Fuel, September 2005.

2 Chairman & Chief Executive, Nuclear Fuel Complex, Department of Atomic Energy, Hyderabad, India.

Table I : Nuclear Power Programme Based On PHWRs

PLANT	RE-RATED CAPACITY	COMMERCIAL OPERATION SINCE
PLANTS UNDER OPERATION		
RAPS - 1	1 x 100 MWe	December 16, 1973
RAPS - 2	1 x 200 MWe	April 01, 1981
MAPS - 1	1 x 220 MWe	January 27, 1984
MAPS - 2	1x 220 MWe	March 21, 1986 (Uprated to 220 MWe)
NAPS - 1 & 2	2 x 220 MWe	January 01, 1991 and July 01, 1992
KAPS - 1 & 2	2 x 220 MWe	May 06, 1993 and Sept 01, 1995
KAIGA - 2	1 x 220 MWe	March 16, 2000
RAPS - 3	1 x 220 MWe	June 01, 2000
KAIGA - 1	1 x 220 MWe	November 16, 2000
RAPS - 4	1 x 220 MWe	December 23, 2000
TAP - 4	1 x 540 MWe	Became critical in March 2005
SUB TOTAL	**3040 MWe**	
PLANTS UNDER CONSTRUCTION		
TAP - 3	1 X 540 MWe	
KAIGA - 3 & 4	2 X 220 MWe	
RAPP - 5 & 6	2 X 220 MWe	
SUB TOTAL	**1420 MWe**	
TOTAL	**4460 MWe**	

High density natural uranium dioxide pellets are required as fuel for PHWRs. The as - received magnesium diuranate (MDU) concentrate from UCIL is processed by dissolution in nitric acid, purification by solvent extraction using Tributyl Phosphate and precipitation of ammonium di-uranate (ADU) by ammonium hydroxide. ADU is subjected to controlled calcination, hydrogen-reduction and stabilization treatments to obtain sinterable grade UO2 powder. High density UO2 pellets are manufactured through classical "powder-pellet " route involving granulation of fine UO2 powder, pelletisation, high temperature sintering in pusher-type continuous sintering furnace in reducing atmosphere and centreless grinding. The ground pellets are subjected to quality control checks and the accepted UO2 pellets are encapsulated in zirconium alloy-4 clad tubes which are finally assembled in the form of 19-element or 37-element fuel bundles for PHWR-220 and PHWR-540 units respectively.

NFC has been expanding its fuel production capacities over the years to meet the continuously increasing fuel demand. The cumulative production of PHWR fuel bundles manufactured at NFC since its inception is given in Figure 1 below:

During the year 2004, NFC has crossed yet another milestone of manufacturing 300,000 PHWR fuel bundles which include natural uranium dioxide, depleted uranium dioxide and thoria as fuel. While the depleted uranium dioxide and thoria bundles have been used mostly for neutron flux flattening of the initial core of PHWRs during start up, the depleted uranium dioxide bundles are also envisaged to be used in equilibrium cores of PHWRs that enables closing of the fuel cycle and also conserving natural uranium resources.

3.2 Fabrication of fuel for PHWR 540 units

Process flow sheets for manufacture of smaller dia UO2 pellets, smaller dia clad tubes, appendage welding and assembly required for the first 540 MWe PHWR at Tarapur were standardized incorporating necessary quality checks at

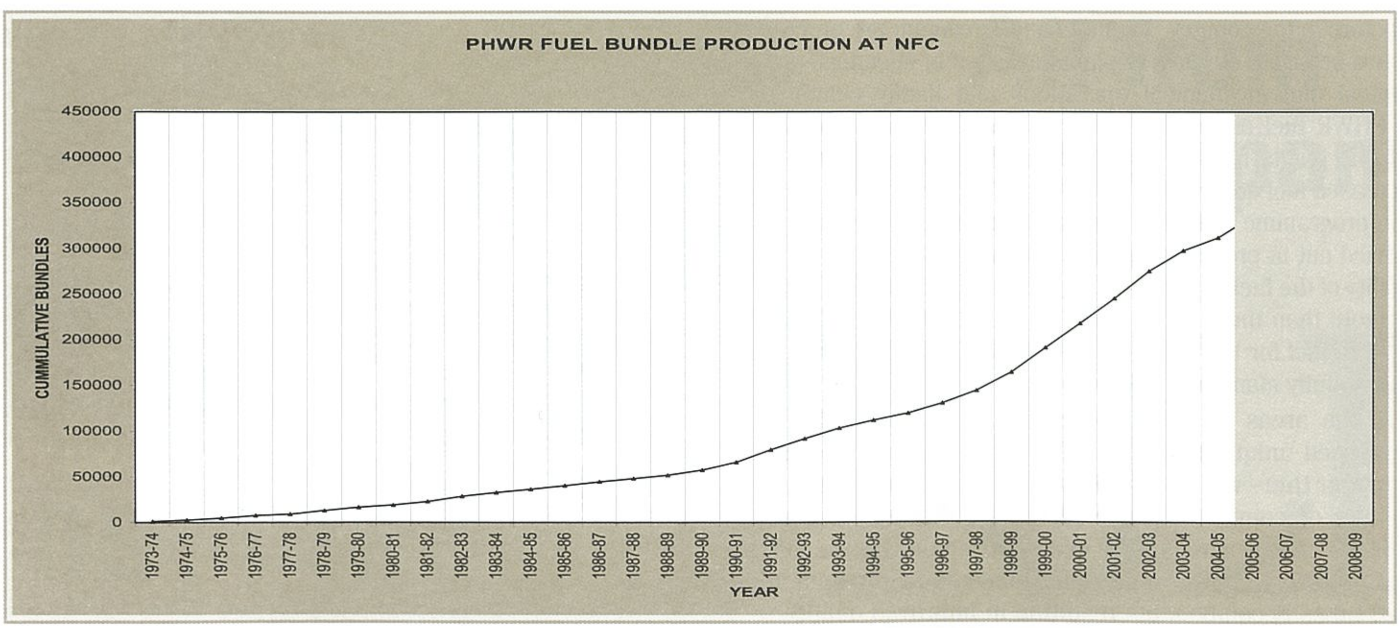


Figure I: Cummulative Production of PHWR Fuel Bundles at NFC

Figure 2: 37-Element Fuel Bundles for 540 MWe PHWRs.

various stages of fuel manufacturing. More than 5000 37-element fuel bundles were successfully manufactured and supplied towards the initial core requirement of TAPP-IV which was commissioned during March, 2005. The in-reactor performance of these bundles during this period is reported to be quite satisfactory by which NFC has been accredited for manufacturing of new type of fuel "Right First Time".

Compared to 19-element fuel bundle, 37-element fuel bundle has more types of elements and requires more number of precision components. Several innovative techniques, as detailed below, were adopted while manufacturing fuel for 540 MWe PHWR.

a) A noteworthy feature of these bundles is that the spacer pads and bearing pads are resistance welded on to the fuel tubes prior to loading of UO2 pellets. This operation of attaching appendages by resistance welding is unique to India and has the distinct advantage of maintaining the integrity of the pellets during fuel bundle assembly. This process is also advantageous in that it allows easy retrieval of the pellets from rejected pins, if any, thus improving the recovery.

b) The pelletisation operations were standardized for the production of UO2 pellets having double dish and chamfer on both edges, which were used for manufacturing fuel bundles required for initial charge of TAPP-IV. These pellets are expected to minimize "pellet-clad mechanical interaction" thus improving the performance of fuel in the reactor.

3.3 Improvements in production processes

A number of technological innovations were carried out in the production of UO2 powder, pelletisation and assembly operations. In the UO2 powder production process, Uranyl Nitrate Raffinite (UNR) is a liquid effluent generated in the purification steps which contains valuable residual uranium. A new process was developed that results in avoidance of UNRC generation, which is demonstrated successfully at plant scale. After optimization of design parameters in consultation with fuel design group, regular production of UO2 pellets, having double dish and chamfer on both edges, was carried out both for 19-element and 37-element fuel bundles.Likewise, in the fuel assembly manufacturing lines one of the most important development works carried out and implemented on industrial scale production is the introduction of curved bearing pads.

As against the conventional bearing pads, these pads do not require milling operation to be carried out for achieving the required radius on the outer profile. All the 37-element fuel bundles manufactured for the initial core of TAPP-IV contained these curved bearing pads.

4.0 Quality Assurance

Quality Management System and QA Programme at NFC have been effectively synchronized to meet the enhanced production targets. Several innovative techniques adopted in different streams of fuel production have resulted in the manufacture of 37-element fuel bundles of high quality.

Fig 3: Integrated Spacer and Bearing Pad Welding Machine

Increased number of components and welds meant enhanced defect opportunities, hence emphasis was laid on capability studies for new process and development of inspection equipment. Hence Quality Assurance Systems for 37-element fuel manufacturing had to be redesigned.

In order to ameliorate operator fatigue while handling 37 element fuel bundle during dimensional check, helium leak testing and final visual inspection, material handling system based on zero gravity air balancers have been indigenously developed and put into use. Machine Vision System for inspection of fuel tube inner surface after appendage welding was developed for checking the weld defects. An accepting sampling was evolved and templates were made to facilitate random selection of pellets. Testing methods and procedures were finalised to suit the needs of new process flow sheet. Integration of process control with systematic inspection has resulted in obtaining Cp value more than 1.67.

Ultrasonic test results of end-closure welds showed the defect echo less than the specified limit of 70%. UO2 content was also maintained above the specification limit. On-site inspections like helium leak testing on sampling basis, kinked tube and visual check on 100% basis by the customer revealed no defects.

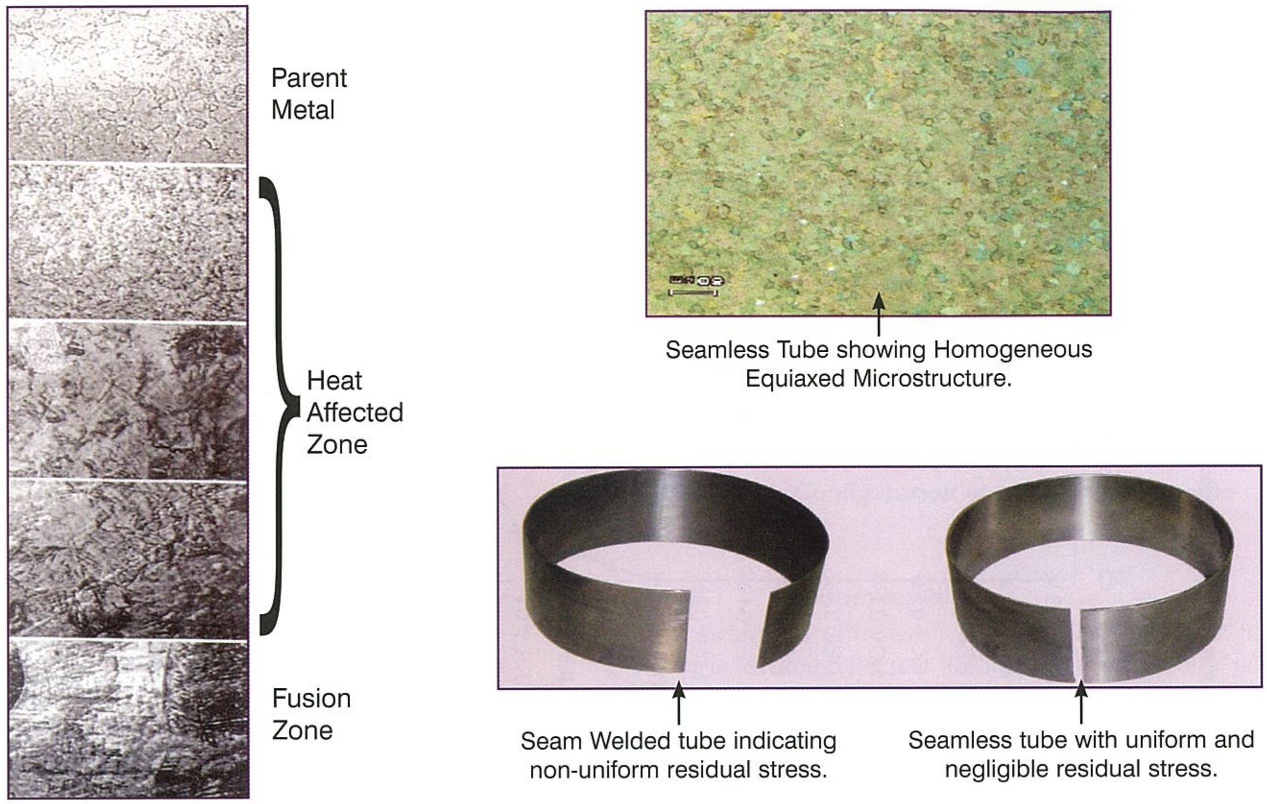
Many advances were made in eddy current and ultrasonic evaluation to meet the stringent quality control requirement and locate the micro flaws for manufacturing of fuel clad tubing and bar for end caps. Special defect standards were developed to identify and eliminate micro-flaws and thereby ensure consistent quality product.

Ultrasonic Testing equipment for evaluating quality of fuel tubes was successfully developed indigenously and put into regular use on the shop floor.

5.0 Development of special purpose equipment

Several special purpose equipment for welding of spacer pads and bearing pads have been successfully designed and developed at NFC, which are employed for the fabrication of 37-element fuel bundles. An Integrated Spacer and Bearing-pad Welding machine, developed for welding the appendages on empty fuel tubes, has special features like capability to weld both spacer pads and bearing pads for all the five types of fuel elements; replaceable magazines for all the appendages; integrated tube loading-and-unloading system for ease of operation; automatic selection of the optimum welding parameters for the two spacer pads and bearing pads of different thickness and provision of a 'weld sentry' for 'on-line' assessment of the quality of welds. In addition, equipment like appendage weld-strength testing units, graphite coating units and baking furnaces were also designed and developed at NFC.

Several other critical process equipment were indigenously developed with the help of Indian industry which include



Welded tubes showing non-homogeneous microstructure (3 distinct zones).

Fig 3 : Comparison of seam welded and seamless calandria tubes

end cap welding machine, fuel tube/fuel element machining centers, fuel element degreasing/cleaning stations, centreless grinding machines for UO2 pellets and final assembly & end plate welding machine. In addition, high temperature sintering furnace having advanced features like automatic charging/discharging of charge carriers, data acquisition systems and controls through SCADA was also indigenously built and put into regular operation.

6.0 Manufacture of reactor core structurals

6.1 Calandria Tubes

During the last couple of years, NFC has put in a lot of developmental efforts that has resulted in standardizing manufacture of thin-wall calandria tubes through seamless route for the first time in the world. The zirconium alloy-4 calandria tubes for 540 MWe PHWR, though of larger diameter as compared to the one for 220 MWe PHWR, were successfully manufactured through this innovative route. Unlike the calandria tubes produced through the conventional welding route, these seamless calandria tubes have uniform micro-structure, homogeneous mechanical properties, negligible residual stresses, favourable texture and superior dimensional stability. This apart, fewer production steps, higher productivity and better recovery are the other distinct advantages of this route.

6.2 Coolant Tubes

Similarly, full core of Zr-2.5% Nb pressure tubes required for PHWR 540 units (TAPP-IV) were also successfully manufactured and supplied. These pressure tubes are produced through the process route of multiple vacuum arc melting followed by extrusion and two-pass pilgering. Quadruple melted Zr-2.5% Nb alloy ingots are expanded, beta-quenched and extruded to suitable blanks. The concentration of gaseous impurities is reduced to extremely low values due to quadruple melting (maximum of hydrogen - 5 ppm ; phosphorous - 10 ppm; chlorine 0.5 ppm and carbon 125 ppm). The fracture toughness of the tubes is more than doubled due to the control of chemical composition as a result of multiple vacuum arc melting. The fabrication process has been designed to eliminate pick-up of hydrogen during manufacturing.

The extruded blanks are finished in two cold pilger passes. The adoption of Pilgering process enabled control of texture in the finished product. The dislocation density was also closely controlled. Large reduction is employed in the initial breakdown pass to improve homogeneity and dimensional

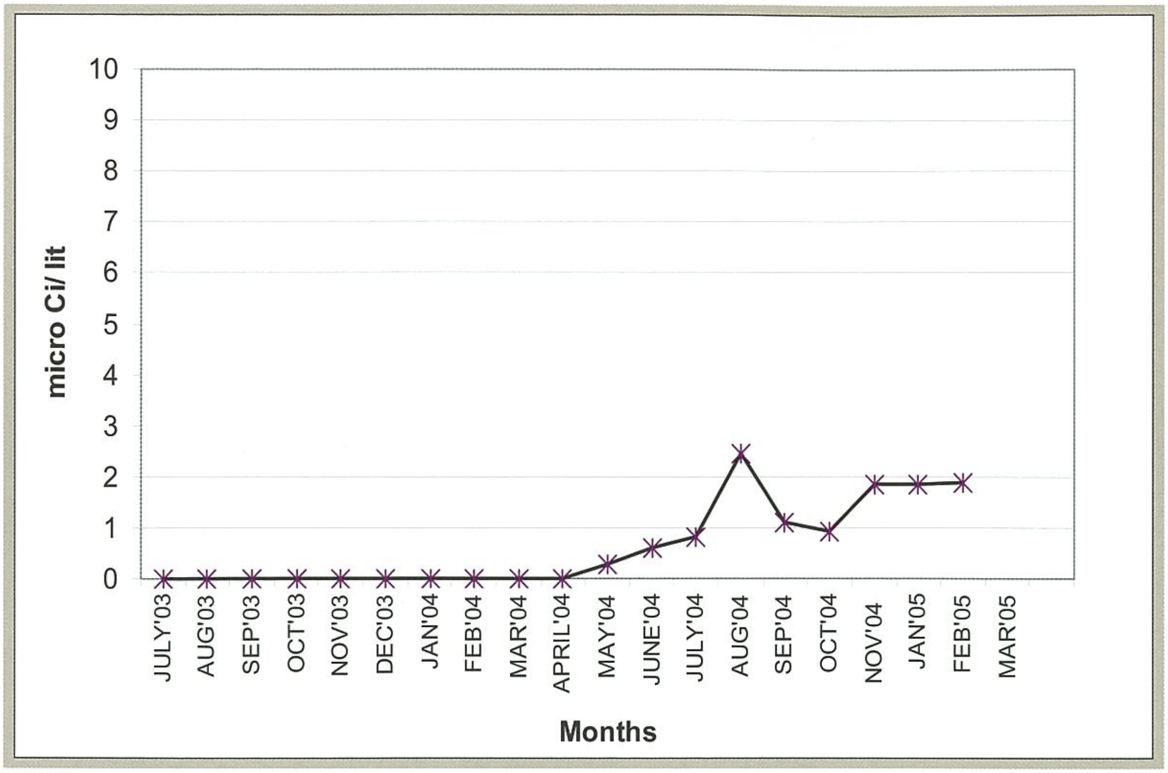


Figure 5: Iodine activities in PHT system of MAPS-II

tolerances. The final pass is designed with high Q-factor and 20-25% cold work. These large size coolant tubes meant for PHWR 540 units were manufactured for the first time meeting all the stringent specifications in terms of mechanical properties and dimensional tolerances. A very high recovery of about 98% by numbers was achieved.

6.3 Reactivity and shut-off devices

Assemblies for reactivity and shut-off mechanisms for the PHWR 540 units are more complicated than PHWR 220 units, both from design and fabrication point of view. A variety of assemblies, totaling 95 include horizontal and vertical flux units , liquid zone control, liquid poison injection tube and guide tubes consisting of adjusted rod, shut-off rod and control rod assemblies. After freezing the design aspects in consultation with the design group of NPCIL, NFC took up fabricability studies, manufacture, mock-up testing and finally supply of these intricate assemblies. High level of accuracy in manufacturing and assembling in a length of 13 m was needed to achieve zero leaks. All the welds were subjected to radiography and helium leak testing to ensure integrity.

7.0 Zirconium Alloy Fuel Cladding and components

Quality of Zirconium Alloy Fuel Cladding and components has a direct bearing on the performance of fuel bundles. Many sophisticated and intricate processes such as vacuum arc melting, extrusion, hot working and cold working process with intermediate annealing are employed in the production of zirconium alloy fuel cladding and components. Emphasis was laid for achieving high recoveries at minimum cost.

NFC has developed necessary expertise and sophisticated manufacturing facility to meet the stringent specifications imposed by the customer in the production of zirconium alloy fuel cladding. Several creative and innovative processes were adopted particularly in the fabrication of spacers for 37 element fuel bundles. The spacers were produced through the wire route and subsequently parting them into tiny spacers, which is entirely different from the conventional route of fabricating the sheets followed by blanking and coining. While manufacturing bars for end caps, specifications and testing procedures were tightened at various stages of production starting from melting of ingots and subsequent extrusion and swaging.

8.0 Fuel performance

The fuel performance in Indian reactors has progressively improved over the years. So far, more than 280,000 fuel bundles have been irradiated and discharged from the 12 PHWRs. Efforts have been put to improve the fuel bundle utilization by increasing the fuel discharge burn-up of the natural uranium bundles. The discharge burn-up of all the reactors have increased in the last 3 years. The present average fuel discharge burn-ups are in the range of 7500

- 8000 MWD/TeU. This is against the design discharge burn-up of 6,300 MWD/TeU.

Fuel Performance can be gauged by the fuel failure rate and also by the iodine activities in the coolant. Close monitoring of the Iodine activity in coolant system is done in operating stations. The iodine activities in coolant circuits are usually less than 5 microCi/litre. Typical iodine activity values in MAPS-II, since restarting of the reactor after coolant channel replacement in the year 2003, are shown in Fig.5.

The fuel failure rate has been in the range of 1 bundle per 1000 bundles discharged. The fuel failure rates in the year 2003-04 and 2004-05 are 0.05 and 0.136 respectively. Efforts are underway to bring down further the fuel failures. The fuel failures are random in nature as seen by the operational history of suspected / failed bundle burn-up and power.

9.0 Performance of Fuel Channels

The pilgered coolant tubes are superior to drawn tubes in terms of wall thickness variation, homogeneity, texture etc. The coolant tubes made of Zirconium-2 are performing satisfactorily and these reactors have completed more than 10 full power-years of operation. Up to about 15 years of operation, the hydrogen concentration in Zirconium-2.5% Niobium pressure tubes has been found to be low (21 ppm at tube center) and most of the hydrides are found to be circumferential. It is also known that up to 63 ppm of hydrogen, the hydrides being circumferential, in the reactor operating range, hydrogen concentration had little effect on fracture toughness.

KAPS is the first Indian Reactor with Zirconium-2.5% Niobium alloy. This reactor has also been fitted with 4 Nos. of tight fit garter springs, which do not move from their installed positions. Hence these channels would not come into contact with calandria tubes at least till 40 years. The hydrogen pick up rate in this material is also very low with the result hydrogen embrittlement problems are expected only in the late life of the reactor. Regular examinations reveal that there are no life limiting or safety issues in any of the coolant channels in the near future. There has been no failure of any coolant tube.

10.0 Alternative fuel concepts for PHWRs

Taking advantage of the flexibility to use variety of fuel loading patterns with different fuel types in PHWRs, fuel bundles are designed and irradiated on specific requirement/situation. This enabled the designers to evolve alternative fuel concepts that can be employed in Indian PHWRs.

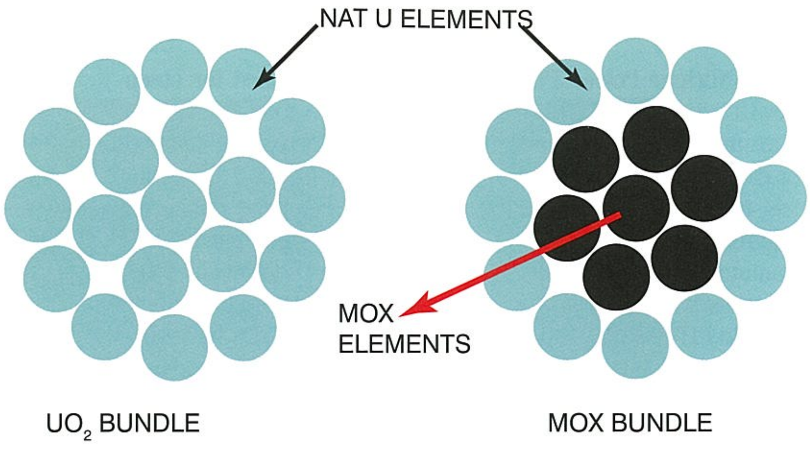


Figure 6: Configuration of MOX-7 Fuel Bundle

10.1 Thorium bundles

Bestowed with vast deposits of thorium, India has a long term strategy for use of thorium in its nuclear power programme. To gain experience in irradiation of thorium in power reactors, fuel designs with thorium were optimized for use in the initial cores of PHWRs for the purpose of flux flattening. The design aspects included suitably specifying the axial and radial gaps in the fuel elements and incorporating some minor modification in bearing pad positions to enable proper identification of these bundles. As per the reactor physics calculations, 35 thorium bundles have been used as a part of initial charge fuel in the 220 MWe PHWRs which are distributed in the high power and low power channels of the core. The use of these thorium fuel bundles in the initial cores was successfully demonstrated in Kakrapara Atomic Power Stations (KAPS I and II), Kaiga Atomic Power Stations (KGS I and II) and Rajasthan Atomic Power Stations (RAPS III and IV). The fabrication and irradiation of thorium bundles have provided valuable experience that can be utilized for the Advanced Heavy Water Reactor (AHWR) and Fast Breeder Reactors (FBRs).

10.2 MOX-7 bundles

19-element bundles with inner seven elements having MOX pellets, consisting of plutonium dioxide mixed in natural uranium dioxide, and outer twelve elements having natural uranium dioxide pellets was evolved to conserve natural uranium resources. Fuel loading pattern and refueling schemes were optimized for establishing the use of these bundles in one of the operating PHWRs. As part of initial trial irradiation programme, some 50 MOX-7 bundles have been fabricated by BARC and NFC and were loaded in the KAPS-I unit in the year 2004. The performance of these bundles in the reactor is quite satisfactory.

More details about the alternative fuel concepts for PHWRs and their performance are discussed in the technical paper being presented during this Conference.

11.0 Concluding Remarks

The Nuclear Power Programme in India is poised for steep growth with five PHWRs currently under construction and many more under consideration to meet the ever increasing demand for electricity. Being the only manufacturer of fuel and fuel channels in the country, NFC is gearing up to meet the enhanced requirements. In addition to conventional fuels containing natural uranium dioxide, alternative fuel concepts with Thorium and MOX materials were also developed and irradiated to establish their usage in PHWRs. Several developmental efforts at NFC have successfully established the techniques of attachment of appendages on tubes by resistance welding and manufacture of calandria tubes through seamless route, which are unique to India.

12.0 Acknowledgements

The author is grateful to Dr. Anil Kakodkar, Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy, Government of India, for the encouragement and guidance given in presenting this paper. The author would like to thank his colleagues at NFC, Mr. R.N. Jayaraj, N. Saibaba, G.V.S. Hemantha Rao, and M. Narayana Rao for preparation of this paper. The valuable contribution made by colleagues in different units of Department of Atomic Energy is highly acknowledged.

First Announcement

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December 16, 2005	Authors' notice of intent to present a paper
March 15, 2006	Submission of full papers to conference
April 10, 2006	Notification of paper acceptance to authors
May 01, 2006	Deadline for early registration benefits

For More Information

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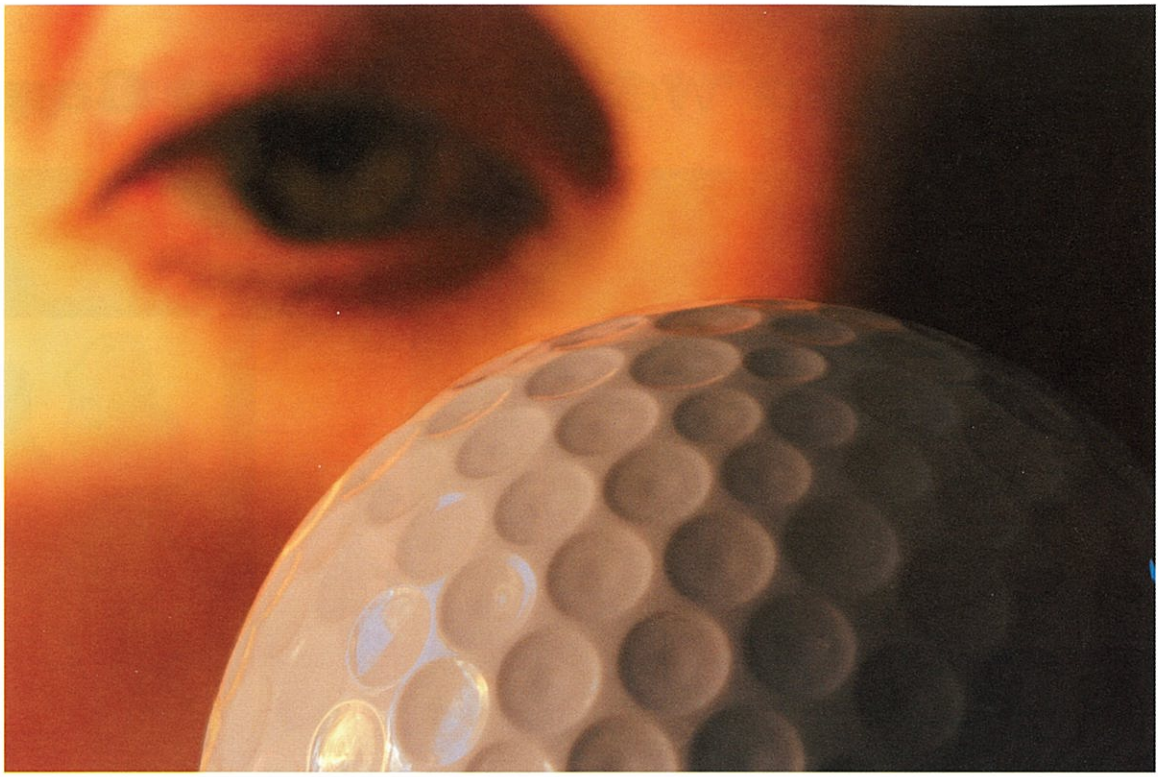

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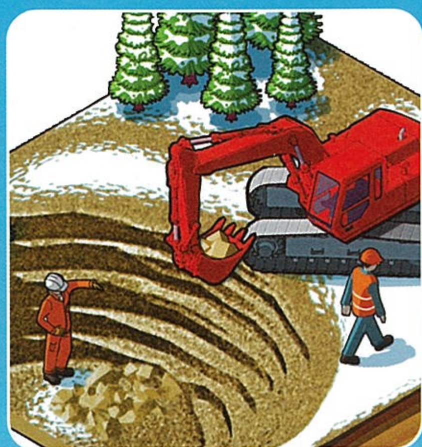
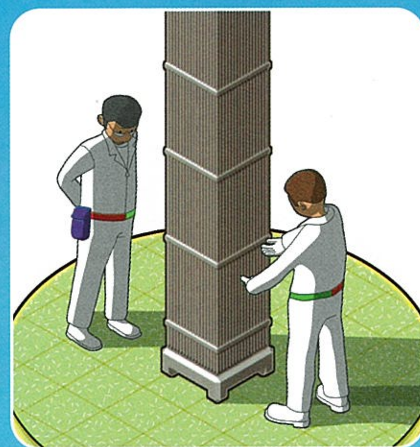
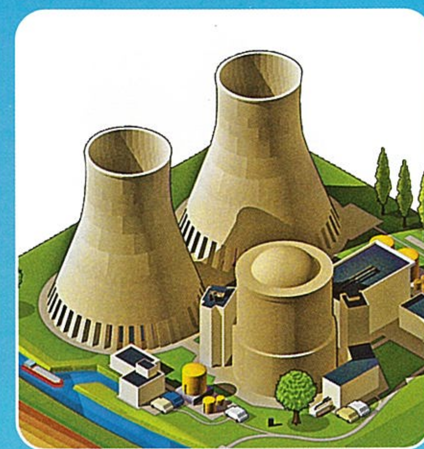


Uranium mining



Nuclear fuel manufacturing



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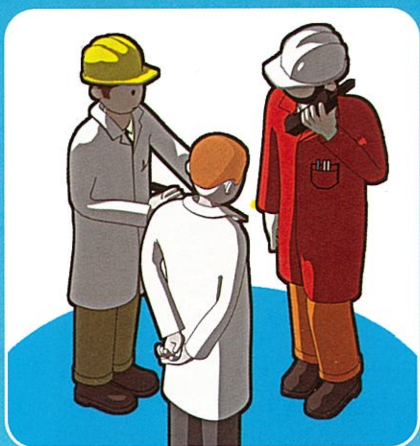

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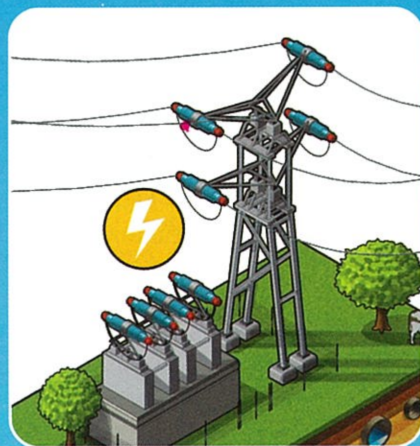

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Development of Licensing Basis for Future Power Reactors in Canada

by G. Rzentkowski, I. Grant and T. Viglasky[1]

Ed. Note: *The following paper was presented at the 26th CNS Annual Conference in Toronto, Ontario, June 2005. Dr. Rzentkowski states that, although the development of a new licensing basis is continuing, this paper is still relevant.*

Abstract

In response to the renewed interest in a nuclear energy option in Canada, the CNSC must ensure that a clear and pragmatic regulatory framework is implemented to achieve its commitment to effectiveness, transparency and efficiency. Consequently, the regulatory framework for licensing new nuclear power reactors is currently under review, and its applicability to advanced reactor designs is being examined. This work includes the review of the licensing process and the development of comprehensive regulatory requirements for design, siting, construction and operation which will form the licensing basis for future power reactors in Canada.

The revised licensing basis will introduce a risk-informed set of regulatory requirements which are intended to be consistent with currently accepted international practice and Canadian regulatory experience. At the same time, the new licensing basis will enhance the overall level of reactor safety. The first step in updating the licensing basis is the revision of the requirements for the design of nuclear power reactors. These requirements have recently been issued for pre-consultation and trail use.

This paper describes the overall framework for the development of licensing basis, and the general approach to the development of the design requirements for new power reactors, including the description of safety goals and the defence-in-depth concept.

1. Background

There are prospects for new power reactors to be built in Canada, and in particular in Ontario, arising from increased electricity demands associated with expected economic growth. In response to this renewed interest in a nuclear energy option, the CNSC is reviewing the regulatory framework for licensing new nuclear power reactors, and is also assessing its applicability to advanced reactor designs. The need for this review stems from following factors:

- any new power reactor would be the first to be built in Canada in over 25 years;
- the current regulatory requirements for power reactors have not been systematically reviewed for many years;
- a formal and comprehensive set of regulatory requirements is desirable to add more certainty to the licensing process;
- the basis for current requirements was developed about forty years ago to meet general risk guidelines; and
- the risk-informed approach has been further refined at an international level and should be adapted as appropriate into the Canadian regulatory approach for the licensing of power reactors.

The intention underlying this work is to develop the licensing basis for future power reactors; namely, a set of comprehensive requirements for design, siting, construction and operation of power reactors which are risk-informed and closely aligned with accepted international practices.

In assessing the options for the development of the licensing basis, the following general objectives were set:

- enhance safety in comparison to existing plants;
- harmonize licensing requirements with international practices;
- apply extensive experience with operating CANDU plants;
- use a technology-neutral approach to the extent possible; and
- consider a risk perspective to the extent practical and prudent.

As an initial step, CNSC staff has updated and modernized the current requirements for the design of power reactors. The new design requirements, [1], recently issued for trial use and comments, are intended to be applied to the licensing of new nuclear power plants in Canada. The IAEA Safety Standard NS-R-1 [2] was selected as the underlying template for the development of these requirements which, in general, are technology neutral. The CANDU specific requirements are incorporated into a technology neutral framework, where required, in accordance with industry and regulatory experience.

Subsequent work in the development of the licensing basis will include the preparation of regulatory requirements for siting, construction and operation of new power

1 Canadian Nuclear Safety Commission, Ottawa, Ontario.

reactors. The review of licensing process is also underway with the objective to assess CNSC's readiness for facing challenges associated with licensing new power plants. In addition, CNSC staff is evaluating the options for simplifying and streamlining the licensing process in an effort to enhance and modernize the existing regulatory framework.

2. Framework for the Development of Licensing Basis

The overall framework for the development of the licensing basis for new power plants is depicted in Figure 1. In essence, this framework describes the logic which links the licensing requirements for power reactor siting, design, construction and operation (licensing basis) with the CNSC Mission Statement and Safety Objectives.

The CNSC Mission Statement, as defined in the *Nuclear Safety and Control Act,* mandates the CNSC to regulate the use of nuclear energy and materials to protect health, safety, security and the environment, and to respect Canada's international commitments on the peaceful use of nuclear energy.

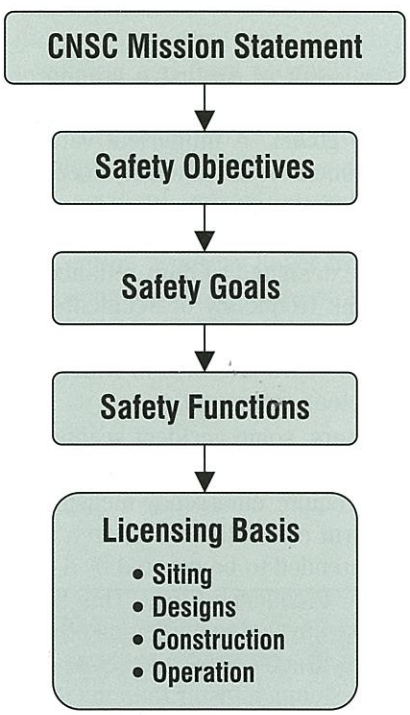

Figure 1: Overall Framework for the Development of Licensing Basis for New Power Reactors

The fundamental Safety Objectives are defined as:

- ensure that in all operational states public and station staff exposures to radiation are kept below prescribed limits and as low as reasonably achievable;
- take all reasonably practical measures to prevent accidents and to mitigate their consequences should they occur;
- ensure with high level of confidence that, for all possible accidents taken into account in the design of the power reactor, including those of very low probability, any radiological consequences would be minor or below prescribed limits; and
- ensure that the likelihood of accidents with serious radiological consequences is extremely low.

In many jurisdictions Safety Goals have been established for effective implementation of the fundamental Safety Objectives, and for clear demonstration that power plant operation will not pose any significant additional risk to the public health, safety, security and the environment in comparison with other risks to which the public is normally exposed. Consequently, Safety Goals consist of numerical limits or targets for the public, the worker and the land contamination.

Successful achievement of Safety Goals can be ensured by meeting an adequate set of expectations (fundamental safety functions) for nuclear power reactor siting, design, construction and operation. These expectations must, in turn, be reflected in a comprehensive set of regulatory requirements which will form the licensing basis for future power reactors in Canada.

3. Approach to the Development of Design Requirements

The general approach to the development of the design requirements starts from the formulation of Safety Goals. Safety Goals are formulated in addition to deterministic design requirements so that risk to the public that originates from accidents outside the design basis is considered. Quantitative goals are linked to potential health effects to people in the vicinity of the plant. These goals are expressed in terms of the risk of a fatality caused by the operation of the nuclear power plant being a small percentage (typically less than 1%) of the risk posed by other industrial activities and societal risks. The main tool for demonstrating that the proposed design meets Safety Goals is the Probabilistic Safety Assessment (PSA).

The implementation of Safety Goals is supported by the fundamental safety functions for the design phase which can be expressed as:

- CONTROL - control reactivity;
- COOL - remove heat from the core; and
- CONTAIN - confine radioactivity and shield radiation

A defence-in-depth strategy provides a conceptual platform for effective implementation of safety functions. There are five levels to the defence in depth:

- prevention of abnormal operation and failures;
- control of abnormal operation and detection of failures;
- control of accidents within the design basis;

Table I: Levels of Defence in Depth

Level	Objective	Essential Means	Supporting Analysis
1	Prevention of abnormal operation and failures	• High-quality design, materials, construction and operation; proven equipment, • Quality Assurance Program; • Control Systems to keep plant within design limits	Design analysis to show plant controlled within normal operating limits
2	Control of abnormal operation and detection of failures	• Control systems capable of protecting against most AOOs, • Other surveillance features	Conservative analysis to demonstrate continued plant operation allowed after AOOs
3	Control of accidents within the design basis and minimizing their consequences	• Engineered safety features (e.g. safety system) with prescribed on-demand reliability; • Defined mission time of ECCS and containment; • Maximum rate of containment leakage, • Emergency procedures	Conservative deterministic analysis to demonstrae all AOOs and Design Basis Accidents meet prescribed limits
4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	• Plant design features to mitigate severe accidents, • Complementary measures to protect confinement function, • Accident management	Best-estimate deterministic analysis
5	Mitigation of radiological consequences of significant releases of radioactive materials	• Off-site Emergency Response Planning	

- control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents; and
- mitigation of radiological consequences of significant releases of radioactive materials.

The defence-in-depth concept is further supported by emphasis on inherent safety characteristics of the reactor, and insights from deterministic and probabilistic safety analyses. Since the current regulatory framework has been largely constrained to the design basis accidents, particular emphasis is placed on systematic application of this approach to severe accidents.

This approach is consistent with user requirements for innovative nuclear reactors, as recommended by IAEA, [3].

3.1 Safety Goals

There are two fundamental Safety Goals; one relating to early fatalities and the other relating to late or delayed fatalities. Early fatalities are linked to accident rates (e.g. industrial, traffic, etc.) while late fatalities are linked to cancer rates. The actual numerical safety goal limits that are typically used in the nuclear power industry are conservative surrogates of these goals to simplify their calculation. For this purpose, the CNSC is adopting three Safety Goals:

- the Large Release Frequency Goal,
- the Severe Core Damage Frequency Goal, and
- the Small Release Frequency Goal.

The Large Release Frequency Goal refers to the frequency of an off-site release that would result in the need for long-term, or even permanent, evacuation of the surrounding population as a result of extensive ground contamination. This requirement is more restrictive than that needed to meet the fatality goals. A numerical value of once every million years for such events is widely accepted in the international nuclear community.

The Severe Core Damage Frequency Goal is a defence-in-depth measure designed to limit reliance on the containment system. The frequency of accidents that could lead to severe damage is very low, i.e., less than once every hundred thousand years and also is widely accepted in the international nuclear community.

In CANDU reactors, some accident scenarios may result in limited core damage, leading to small but significant releases. These accidents require emergency measures such as sheltering or short-term evacuation of an area around the plant. This concern is intended to be covered by a third Safety Goal, the Small Release Frequency Goal. This Safety Goal is not expected to impose any undue burden on other types of nuclear power plants in which severe accidents would typically be expected to progress much faster than in CANDU plants.

3.2 Defence-in-Depth Concept

The concept of defence-in-depth -- as applied to all safety activities, whether organizational, behavioural or design related -- ensures that these activities are subject to overlapping provisions so that if a failure were to occur it would be detected and compensated for, or corrected, by appropriate measures. Application of the concept of defence in depth throughout plant design provides a graded protection against a wide variety of transients, anticipated operational occurrences (AOOs) and accidents, including those resulting from equipment failure or human action within the plant, and events that originate outside the plant. The objectives of each level of defence in depth, along with the essential means of addressing them in the plant design, are summarized in Table 1.

A relevant aspect of the implementation of defence in depth is the provision in the design of a series of physical barriers to confine the radioactive material at specified locations. The number of physical barriers that will be necessary will depend on the potential internal and external hazards, and the potential consequences of failures. For water-cooled reactors, the barriers may typically be in the form of the fuel matrix, the fuel cladding, the reactor coolant system pressure boundary and the containment.

The risk perspective, gained from PSA, is used to evaluate and optimize the overall defence-in-depth strategy by identifying the design basis challenges to physical barriers and by judging their acceptability based on the derived acceptance criteria. A high level of independence of the different levels of protection is a prerequisite for avoiding cascading failure propagation from higher to lower level of defense-in-depth.

This strategy is further strengthened by a systematic application of anticipated accident scenarios, and by incorporation of risk insights fully in the original deterministic defence-in-depth framework. The first includes identification of initiating events, strategies to prevent initiating events from occurring and from progressing to accidents, and strategies to mitigate the consequences of events and accidents should they occur. The second, supported by a comprehensive plant specific PSA, is essential in balancing strategies of accident prevention and mitigation; that is, higher frequency initiating events and event sequences rely more on prevention, whereas lower frequency initiating events and event sequences rely more on mitigation.

4. Summary and Future Work

In response to the renewed interest in a nuclear energy option, the CNSC is currently developing the licensing basis for future power reactors: a set of comprehensive requirements for siting, design, construction and operation of power reactors. As the first step, the requirements for the design of new power reactors have been revised and issued for pre-consultation and trial use.

The revised licensing basis will introduce a risk-informed set of regulatory requirements which are intended to be consistent with currently accepted international practice and Canadian regulatory experience. At the same time, the licensing basis will enhance the overall level of reactor safety.

The review of licensing process is also underway with the objective to assess CNSC's readiness for facing challenges associated with licensing new power reactors. In addition, CNSC staff is evaluating the options for simplifying and streamlining the licensing process in an effort to enhance and modernize the existing regulatory framework.

References

[1] CNSC Pre-consultative Draft Document, *"Requirements for Design of Nuclear Power Plants"*, March 2005

[2] IAEA Safety Standard Series No. NS-R-1, *"Safety of Nuclear Power Plants: Design"*, IAEA, Vienna, 2000

[3] IAEA Report, *"Guidance for the Evaluation of Innovative Nuclear Reactors and Fuel Cycles"*, IAEA-TECDOC-1362, June 2003.

Canadian Nuclear Achievement Awards

Call for 2006 Nominations

The Canadian Nuclear Society and the Canadian Nuclear Association jointly announce a call for nominations for the Canadian Nuclear Achievement Awards for 2006

The deadline for all nominations is 2006 March 31

See the brochure enclosed with this issue of the CNS Bulletin

Energy Person of the Year

Canadian energy community honours Duncan Hawthorne

Despite the high profile of the oil and gas industry in the Canadian energy picture, the Energy Council of Canada chose a prominent and popular champion of nuclear energy as "Canadian Energy Person of the Year for 2005".

Duncan Hawthorne, president and CEO of Bruce Power, was presented with the honour at a special dinner held in Toronto, October 25, 2005. Over 300 senior representatives of the many companies and organizations across Canada involved or associated with the Canadian energy scene assembled at the elegant Liberty Hall building at Exhibition Park for the ceremony.

In a somewhat unusual format the presentation was made prior to the meal. Murray Stewart, president of the ECC (and one-time president of the Canadian Nuclear Association), served as master of ceremonies. Oskar Sigvaldason, chairman of the Energy Council of Canada, welcomed everyone and outlined briefly the role of the Council. He noted that Canada would be hosting the 2010 World Energy Congress in Montreal.

James Gillis, Deputy Minister of Energy, Ontario, spoke about the electricity situation in the province as background to the recent agreement for the refurbishment of Bruce units 1 and 2. He commented however that he "hoped the project would work out better than nuclear projects in the past".

For his introduction of Hawthorne, Doug Annable, president of the energy and Mining division of AMEC Americas Limited, showed a video of interviews with Hawthorne and some of the people at Bruce Power.

In his acceptance Hawthorne emphasized the great support he had from the staff at Bruce Power. He stated that he believed the refurbishment of Bruce units 1 and 2 is the right thing for Ontario. We must help governments think "long term" he emphasized. Speaking proudly of his staff he stated, "if we can not restart [the units] on time and on budget, nobody can". "I am proud to be recognized", he said in closing.

The Energy Council of Canada is the Canadian national member of the World Energy Council, and is made up of representatives from all facets of Canada's energy sector. The Council established the Canadian Energy Person of the Year award in 2001. Sectorial energy associations of Canada also support the award. Recipients of the award are selected based on significant accomplishments in the energy and business or government sectors, as well as the community at large. An important factor is a strong sense of social responsibility and belief in giving back to the community by focusing on environmental and social issues, and economic development.

Duncan Hawthorne (R) receives the plaque honouring him as the Canadian Energy Person of the Year 2005 from Oskar Sigvaldason, chairman of the Energy Council of Canada, at a special dinner October 25, 2005.

Duncan Hawthorne began his career as an apprentice in a power plant in Scotland 30 years ago. He subsequently obtained a degree in control engineering and an MBA from Strathclyde University.

Between 1978 and 1997 he held various engineering and management positions with British Energy at nuclear power stations in the UK. In 1998 he was appointed Chief Operating Officer for British Energy in the United States where he was responsible for several acquisitions of nuclear plants.

He was appointed President and CEO of Bruce Power in 2000 when British Power acquired the lease to operate the plant. With the collapse of British Energy he took the lead in the creation of the current Bruce Power partnership.

In 2001 he announced the plan to restart two of the laid-up Bruce A units. Unit 4 restarted in October 2003 and Unit 3 in January 2004.

He is chair of the Board of Governors of the World Association of Nuclear Operators and chair of the Canadian Nuclear Association.

He is a Fellow of both the Institution of electrical engineers and the Institution of Mechanical Engineers, both based in the UK.


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OCI Annual Meeting

Organization of CANDU Industries adds interesting speakers to AGM

Shyamala Cowsik

Reflecting its focus this year to the domestic nuclear market, the **Organization of CANDU Industries** augmented its Annual General Meeting in Toronto, November 16, 2005, by including a mini symposium with five interesting speakers. The event drew close to 100 attendees of representatives of the 70 member companies and invited guests.

The actual AGM was a concise affair with reports from General Manager, **Martyn Wash** and Chairman, **Rae Watson** and election of the Board of Directors for 2006.

Leading off the presentations was **Shyamala Cowsik,** High Commissioner for India, who began by commenting that she had studied some nuclear science but not worked in the field.

After describing India's ambitious nuclear program, which includes all aspects of the nuclear fuel cycle, she referred to the country's plans for fast breeder reactors and thorium fuelled reactors. India's reserve of uranium is modest, she noted, but the country has considerable thorium. Most of the nuclear power program is based on pressurized heavy water reactors (PHWR) using designs that India has evolved from the first CANDUs, similar to the Douglas Point plant, built in the 1970s. Given the Indian development of the design she quipped that they are sometimes described as INDUs.

Her most pointed remarks were on the need for Canada and India to renew nuclear relations. A positive step, she noted, resulted from a meeting between Canada's Minister of Foreign Affairs, Pierre Pettigrew and India's Minister of External Affairs, Natwar Singh, in Ottawa in September 2005, when they agreed to enhance nuclear safety collaboration and pursue exchanges in nuclear science and technology.

Next was **Rob Buguski,** recently appointed vice-president Supply Chain at Ontario Power Generation. After briefly outlining his varied background in the brewing, petroleum and other industries he commented that utilities, in general, were behind other industries in the procurement process. By a requested show of hands he learned that those in the room had mixed opinions of their dealings with OPG. He closed by inviting suggestions for improvement.

Canada's nuclear policy was the topic of **Sylvan Guindon,** Director, Nuclear Energy, at Natural Resources Canada. She referred to NRCan's energy science and technology panel and mentioned a review underway on "national nuclear laboratory and infrastructure". In that context she noted that the federal government contributes $100 million to research at the Chalk River Laboratories, with Atomic Energy of Canada Limited funding the balance of the $270 million annual operating cost from its commercial revenue.

Jerry Hopwood, of AECL, began by commenting that in addition to the refurbishments already announced, all CANDU owners are planning or considering it. "New build" is expected, he said, with negotiations on Cernavoda 3 in Romania underway and possible decisions in Ontario. China continues to be interested in CANDU, he claimed.

The design of ACR 1000 is proceeding with formal application to the Canadian Nuclear Safety Commission expected in 2007 or 2008. To a question of when the design would be completed he replied that it was being "phased" and would depend on Ontario's decision.

Sean Russell, of the Nuclear Waste Management Organization, provided a brief outline of NWMO's final report and recommendation, issued in early November 2005, which calls for an "adaptive phased management" approach. The next step, he said, is implementation, assuming the government accepts the recommendation.

Gerry Waterhouse announced that OCI had created a bursary program in the name of **Jack Howett,** long-time General Manager of OCI. The program will award a $500 bursary to a student pursuing nuclear studies at University of Ontario Institute of Technology or McMaster University.

In addition, this year the OCI set up an endowment for the UOIT with matching funds from the Government of Ontario under the OTSS program (Ontario Trust for Student Support). This endowment will provide an annual award of approximately $1,000 starting in 2009, which will replace the annual $500 bursary and will exist in perpetuity. As OCI revenues permit, similar endowments will be set up in other universities and colleges.

After the closing of the formal meeting, **Walter Thompson,** of Nuclear Safety Solutions, gave an impromptu outline of the organization of the new company AMEC-NCL *(see General News section).*

Following are the members (reappointments or new) of the OCI Board of Directors for the next two years.

Rae Watson (IST), Bob Goel (3L Filters), Glen Crawford (NEL), Doug Filker (Sulzer), Dorine Duquet (Brent), Gerry Waterhouse (NLI Canada), Richard Barnes (Anric), John Deacon (Western Valve), Neil Alexander (RCM Technology), Yvette Amor (B&W Canada), Art Birchenough (AMEC), Ken Carrier (Cintube), Hany Michael (Wardrop), Doug Hink (SNC Lavalin Nuclear).

7th CNS International Conference on CANDU Maintenance

A preliminary report

***Ed. Note:** The 7th CNS International conference on CANDU Maintenance took place November 20 - 22, 2005, just days before this issue of the CNS Bulletin went to the printers. Following is a preliminary report, the next issue will contain full coverage and some of the papers presented.*

Warren Macdonald

More than 350 delegates registered for the 7th CNS International Conference on CANDU Maintenance, held in Toronto, Ontario, November 20 to 22, 2005. surprising the organizers and straining the resources of the hotel.

Augmenting the presentations was an exhibition by a score of companies offering products and services to aid maintainers of CANDU plants in Canada and abroad. The opening reception on the Sunday evening and the one preceding the dinner on the Monday evening were held in the exhibition area.

The guest speaker at the dinner was Warren Macdonald, an Australian adventurer who lost both of his legs in a mountain climbing accident. He overcame that tragedy and achieved climbing Mount Kilimanjaro using special artificial prostheses.

There were also speakers at the two luncheons; Cmdr. Marcel Hallé, of the Royal Canadian Navy, spoke during the Monday lunch and CNS past-president Bill Schneider, recently retired from Babcock & Wilcox Canada, at the Tuesday lunch.

The conference began with a short plenary session on the Monday morning. Brent Murchie, conference chair welcomed delegates and introduced honorary chair, John Coleby, vice-president, Pickering A, Ontario Power Generation.

Coleby said he had four key messages: achieving a reliable plant; Pickering A advantages; Pickering A report card; process efficiency. After expanding on these topics he offered some "lessons" learned. CANDU has too many moving parts, he said, making it difficult to maintain. He shocked some in the audience by commenting that if the design is not improved the next Canadian nuclear plant would likely be a PWR.

Mark Elliott, director of station engineering, Pickering B, OPG, noted the decline of performance of his station beginning in the 1990s and continuing into this decade. There was a long list of problems, he said, but many are now corrected. The target is to achieve 85% capacity factor and less than 5% forced outage rate by 2007

Ken Ellis, vice-president maintenance at Bruce Power, continued the theme with the phrase "exotic technology leads to exotic problems". He added the phrase "need to do right maintenance and do maintenance right". Maintenance staff need to understand and have better interaction with operators, he said in closing.

The final plenary speaker was Bill Pilkington, former manager and site director at the Point Lepreau station in New Brunswick, now in NB Power's corporate office. He provided some background leading up to the decision to refurbish Point Lepreau. Much of the planning has already been done, he noted. The plan calls for the plant to be shutdown in 2008 and restarted in 2009.

Over 60 technical papers were presented over the balance of the two days, in four parallel sessions. The organizers had allowed ample time for questions and discussion at the presentations and extended break periods where delegates shared their experiences.

This was a very well organized and run meeting.

View of reception.

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- *the Globe & Mail*

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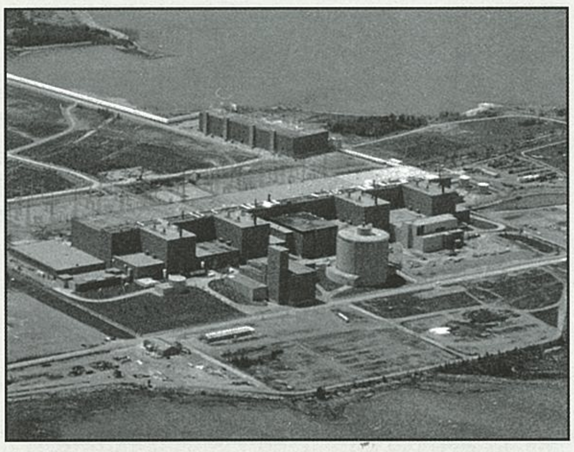
GENERAL news

Bruce Power awards major contracts for units 1 and 2

In mid October 2005, Bruce Power reached a definitive agreement with the Ontario Power Authority and launched a $4.25 billion investment program that will begin with the restart of Bruce A Units 1 and 2. When those units are restarted the site's total output will be more than 6,200 MW. Under terms of this long-term agreement Bruce Power will also refurbish Unit 3 with new fuel channels and steam generators when required and install new steam generators on Unit 4.



Following the agreement for the refurbishment of units 1 and 2 of the Bruce A nuclear generating station, Bruce Power announced contracts for major portions of the project.

AMEC NCL to be project manager for Bruce 1 and 2

The new company AMEC NNC Canada Limited (AMEC NCL) has been awarded a contract for project management, contract management and construction management for the refurbishment of Bruce units 1 and 2. The contract is reportedly worth up to $510 million.

Kevin Routledge, who is best known in Canada as president of Nuclear Safety Solutions Ltd. (NSS) has been named president of AMEC NCL and is serving as project director for the Bruce task.

AMEC is an international project management and services company with headquarters in London, England. It has over 44,000 employees in more than 40 countries. Although the name AMEC was introduced in 1982 the origins of the companies from which it evolved go back to the 1840s; Societé de Construction des Batignottes in France and the Matthew Hall Group in the UK.

AMEC claims almost 100 years experience in Canada since it acquired AGRA in 2000, which, in turn, had acquired Monenco in 1992, and Monenco was formed in 1907.

AMEC acquired NNC Holdings Ltd. in mid 2005, thereby obtaining NNC Canada Ltd. and its subsidiary, NNS.

Kevin Routledge, a director of NNC Holdings Ltd., came to Canada in 2001 to set up the Canadian subsidiary and subsequently was involved in the purchase of Ontario Power Generation's Nuclear Safety Analysis Division to form NSS. NNC Canada Ltd. purchased the nuclear waste management company Monserco in 2003. Routledge continues to serve as president of all three companies. .

AECL awarded contract for retubing Bruce A Units 1 and 2

Atomic Energy of Canada Limited (AECL) has been awarded a contract by Bruce Power for the retubing of the Bruce A Units 1 and 2 reactors.

AECL's scope of the project is expected to take approximately 41 months to complete and includes the removal and replacement of 480 pressure tubes and 480 calandria tubes in each of the two reactors, along with the associated hardware.

The retubing project will also involve the removal of radioactive components already present within the reactors and moving them to safe storage within the Western Waste Management Facility on the Bruce Power site. This will be followed by the installation of new components that meet current and improved specifications.

SNC-Lavalin Nuclear to replace steam generators at Bruce 1 and 2

SNC-Lavalin Nuclear Inc. has been awarded a contract for engineering, procurement and construction to replace the steam generators at Units 1 and 2 of Bruce Power's Bruce A nuclear power station.

The removal of the generators will be segregated from the ongoing operations at Units 3 and 4. The pipes will be cut to separate the generators from the steam drum and the generators will be sealed so they will be self-contained units when removed. Work is now underway, with an expected completion date of June 2008.

NWMO issues "Final Study"

Elizabeth Dowdeswell, president of the Nuclear Waste Management Organization used a breakfast gathering at the National Press Club in Ottawa to formally release the NWMO's "Final Study" report on November 3, 2005.

Before tabling the 451 page "Final Study" document titled "Choosing a Way Forward" she recalled that the NWMO had been created just three years previously with the mission to develop, collaboratively with the citizens of Canada, a management approach for the long-term care of Canada's used nuclear fuel.

She noted that the subject had been studied for a long time. But, as the environmental assessment panel chaired by Blair Seaborn found after eight years of hearings in the 1990s, the challenge was not a technical one but an issue of values and ethics. Over the past three years the NWMO has met with or heard from thousands of Canadians.

Three basic goals emerged from the consultations:

- assume responsibility now
- do not make any arrangement irreversible
- safety and security must be pre-eminent

The NWMO final recommendation is for a program it calls "Adaptive Phased Management" which entails continued storage at reactor sites while studying a possible central storage facility and planning for a deep geological repository. The design of the last must ensure retrievability, at least for the first several decades. .

To questions, Ms. Dowdeswell stated that the next step is for the government to formally accept the NWMO recommendation and charge the organization with the next part of its mission - implementation of the plan. A major factor in the implementation, she said, would be to find a knowledgeable and willing host community for deep geological repository.

An extensive review of the NWMO report by J. A. L. Robertson is printed elsewhere in this issue of the CNS Bulletin.

Van Adel reappointed as President and CEO of AECL

The Minister of National Revenue and Minister of Natural Resources, John McCallum, announced in late November 2005 the reappointment of Mr. Robert G. Van Adel as President and Chief Executive Officer of Atomic Energy of Canada Limited (AECL). Mr. Van Adel was first appointed to the position in February 2001. His reappointment was confirmed following a parliamentary review process.

Mr. Van Adel has a broad base of experience in both private and public sectors. Prior to his appointment at AECL, he held a number of key executive positions in the AGRA group of companies, including President of AGRA Engineering Inc. He also served for several years in top executive positions with Export Development Corporation (EDC).

He sits on a number of boards, including the Nuclear Energy Institute, Energy Council of Canada, Canadian Nuclear Association, Canada China Business Council and Junior Achievement of Canada.

At the same time McCallum announced the appointment of Jean-Pierre Soublière as Acting Chairman to the AECL Board of Directors.

Mr. Soublière appointment was effective October 20, 2005 and is for a term of three years or until a new chairman is appointed. He replaces Raymond Frenette who completed his term as Chairman in September. Mr. Soublière has been a member of the AECL Board of Directors since October 1998.

Mr. Soublière is President of Anderson Soublière Inc., an executive-focused consulting corporation. He is also a member of several councils and boards including the University of Ottawa, International DataCasting Corporation, Med-Eng Systems Inc., Positron Public Safety Systems Inc., Provance Technologies Inc., E-Witness Inc, United Way of Canada, the City of Gatineau's Strategic Planning Committee, and the Harmony Foundation.

Licence for MAPLE Reactors renewed

Canadian Nuclear Safety Commission (CNSC) announced, November 24, 2005, its decisions:

- to renew the Non-Power Reactor Operating Licence for Atomic Energy of Canada Limited's (AECL) MAPLE 1 and 2 medical isotopes reactors. The renewed licence will permit the completion of the commissioning activities and the operation of the MAPLE reactors.
- to renew the Nuclear Substance Processing Facility Operating Licence for Atomic Energy of Canada Limited's (AECL) New Processing Facility. The renewed licence will permit the completion of the commissioning activities and the operation of the New Processing Facility.

Both of these licences are valid until November 30, 2007.

The CNSC also decided to amend the Nuclear Research and Test Establishment Operating Licence for AECL's Chalk River Laboratories to permit the National Reactor Universal (NRU) reactor to operate until July 31, 2006, seven months beyond its previously scheduled shutdown on December 31, 2005.

Transcripts of the hearing are available on the CNSC web site at www.nuclearsafety.gc.ca, or by contacting the CNSC.

Cameco looking to acquire Zircatec

Cameco Corporation openly announced in October that it is negotiating to acquire Zircatec Precision Industries, Inc.

Zircatec's primary business is manufacturing CANDU nuclear fuel bundles. Zircatec has one plant in Cobourg, Ontario that produces metal components for fuel bundles and other reactor components. A second plant in Port Hope, Ontario handles nuclear materials and completes the fuel bundle fabrication process.

Cameco's review of Zircatec will determine if it meets the company's investment criteria. Cameco will provide an update on the status of this project once negotiations have proceeded to a point where the company has made an investment decision, which is expected by year-end.

Zircatec president Lloyd Jones, who owns the private company with four persons, was quoted as saying that a large number of details need to be negotiated.

Pickering Unit 1 "in-service"

On November 3, 2005 Ontario Power Generation's Pickering 'A' Unit 1 was reconnected to the grid. The unit is now commercially in-service and its electrical output is being dispatched under the direction of the Independent Electricity System Operator.

The Ontario government approved OPG's plan to restart Pickering 1 in July 2004. Major construction on the Pickering A Unit 1 project was completed in July 2005 and at the end of that month the Canadian Nuclear Safety Commission granted permission to begin the process of starting up the reactor.

On August 2, 2005, the reactor went critical for the first time since the unit was laid up in December 1997. On September 9, the heat transport system was warmed up to an operating temperature of 265 degrees Celsius and a series of power ramp ups was underway. The production of first electricity from the unit and its synchronization to the provincial power grid occurred on September 26. This was followed by further testing until the unit was declared in service on November 3.

Total costs incurred up to November 3, 2005 were $996 million, excluding the impact on costs of feeder inspections and replacement of $20 million, which were not included in the original scope of the project.

MDS Nordion buys Cobalt-60 from Russia

In late November 2005, MDS Nordion announced a long-term agreement and Rosenergoatom, Russia for the supply of cobalt-60. The company stated that this agreement is to ensure the continued supply of cobalt-60 for use in medical sterilization devices and related applications.

Rosenergoatom was established in September 1992 as the operating utility of Russia's nuclear power plants. Rosenergoatom operates all 10 state-owned Russian nuclear power facilities with a total of 31 nuclear reactors and an installed electrical capacity 23,242 Megawatts. Rosenergoatom has recently commissioned two new power reactors; Volgodonsk-1 and Kalinin-3. More information may be found at http://eng.rosatom.ru/.

Unlike some reactors that produce cobalt-60, the design of the Leningrad nuclear power plant's reactors allows cobalt-60 to be harvested while the reactor is in operation. This will allow MDS Nordion to more closely match cobalt-60 supply to customer demand.

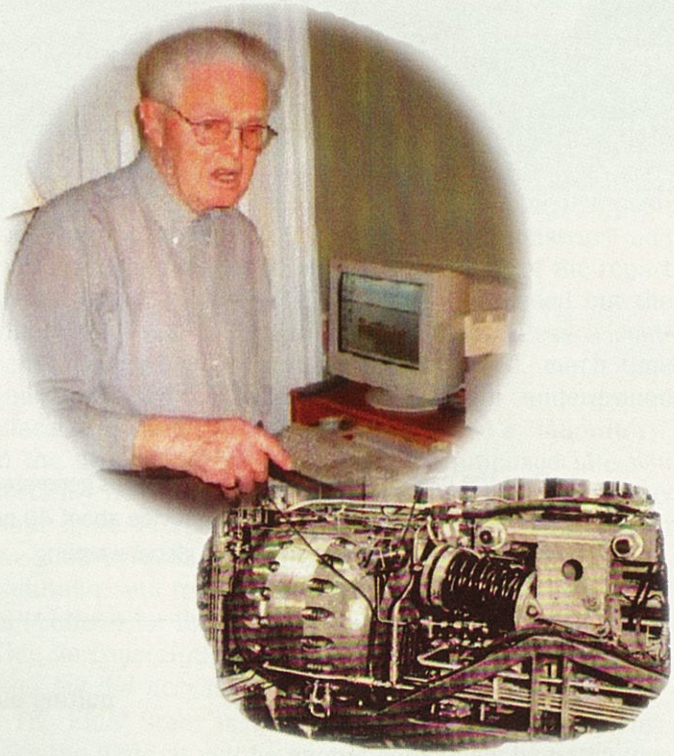
MDS Nordion is the world's largest supplier of radiation facilities usingcobalt-60. They are used to sterilize disposable medical devices and supplies such as surgeon's gloves, syringes, sutures and catheters, as well as pharmaceuticals, implants and tissue.

Fuelling machine designer turns 100

The September 2004, Vol. 25, No. 3, issue of the CNS Bulletin contained an article by Bill Jackson, one of the key designers of the original fuelling machine for the first CANDU reactor, NPD.

On November 17, 2005, Bill celebrated his 100th birthday in Cobourg, his present residence. Relatives and friends, including CNS former president Jow Howieson and CNA former general manager Jim Weller, joined the celebration.

The illustration is from a special card presented to Bill.



Bruce partnership restructured

Following Cameco's decision to not take part in the refurbishment of the Bruce A units a new Bruce Power A Limited Partnership has been created between the other members of the existing Bruce Power Limited Partnership (BPLP): TransCanada Corporation, BPC Generation Infrastructure Trust (BPC), Power workers Union and the Society of Energy Professionals.

As part of the restructuring, BPLP paid a distribution to its limited partners. Cameco's share was $200 million but the company states that it will show a loss of $63 million its investment.

Cameco will maintain its 31.6% interest in BPLP, which is responsible for the overall management of the site and will continue to hold a 31.6% interest in the four Bruce B reactors. It will also continue to be the fuel procurement manager for all the Bruce units (A and B) but will no longer have obligations to procure or supply uranium for the Bruce A reactors.

Cameco officials state that the company supports the Bruce A investment program as an important initiative for Ontario's nuclear industry but has concluded that the agreement with Ontario does not meet its investment criteria.

More information is available at Cameco's website: www.cameco.com.

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ONTARIO POWER GENERATION

Review and Comment

"Choosing a Way Forward"

The Future Management of Canada's Used Nuclear Fuel

Final Study

Nuclear Waste Management Organization, 2005, 451pp.

by. J. A. L. Robertson

Ed. Note: *"Archie" Robertson, a retired senior researcher at the Chalk River Laboratories, has followed closely the various panels and reviews of Canada's nuclear "waste" including the eight-year long "Seaborn panel" in the 1990s. Although he called the following note a "book review" it is more than that - so our reference above to a "review and comment".*

The Nuclear Waste Management Organization (NWMO), charged by the Federal Government to recommend an appropriate long-term management approach for used nuclear fuel, has submitted its Final Study. This opens with "Three short years ago the NWMO took on the mission ...." However, the essential recommendation, eventual containment and isolation of nuclear fuel wastes in a deep geological repository, is what the nuclear industry has been recommending for three long decades. This concept was endorsed by the Hare Committee (1977), Ontario's Royal Commission on Electric Power Planning (1978), the Federal and Ontario Governments (1978), the Parliamentary Committee on Energy Mines and Resources (1987) and the Blair Seaborn (Seaborn) Panel's Scientific Review Group (1998).

The NWMO confirmed that each of the three options that it was required to examine, deep geological disposal, storage at reactor sites and centralized storage, is "credible and could be designed to be safe for the near term" at least. However, as a result of its assessments it recommended a fourth option that included many of the advantages of the other three while minimizing their limitations. This consisted of initial on-site storage and eventual deep geological disposal with the option of interim centralized storage.

Where the NWMO offers originality is in the means to reach the end, presented in a manner to achieve public acceptance. It proposes an Adaptive Phased Management (APM) approach that would "build on sequential decision-making which would preserve flexibility during implementation ..." to allow for any new developments. To those familiar with major engineering projects this seems like normal practice, e.g., the decision to change the NPD reactor design from pressure-vessel to pressure-tube in the light of zirconium developments. However, the terminology is worthwhile if it reassures members of the public that they are not writing a blank cheque but that they will have the opportunity for further input along the way.

From its start the NWMO has stressed the need for ethics in any assessment, initially as a separate issue. Over its life it has come to realize that ethics, like safety, must be embedded in every decision. Documents show that this has been the industry's position since at least 1975. The 1994 Environmental Impact Statement submitted to the Seaborn Panel included a 263-page volume on "Public Involvement and Social Aspects" that had a chapter on "Ethical Considerations".

In view of the Seaborn Panel's rejection of the deep geological concept on the unreasonable grounds that "broad public support" for it had not been demonstrated (see www.magma.ca/jalrober/Blundera.htm), the NWMO devoted much effort to engaging the public, emphasizing "Dialogue". Although it is difficult to imagine what more could have been done, the response was disappointing: the report refers to "thousands" involved, out of more than 30 million Canadians. This apparently negative result is reassuring in that the vast majority of Canadians are not sufficiently concerned by nuclear wastes to take the trouble to participate.

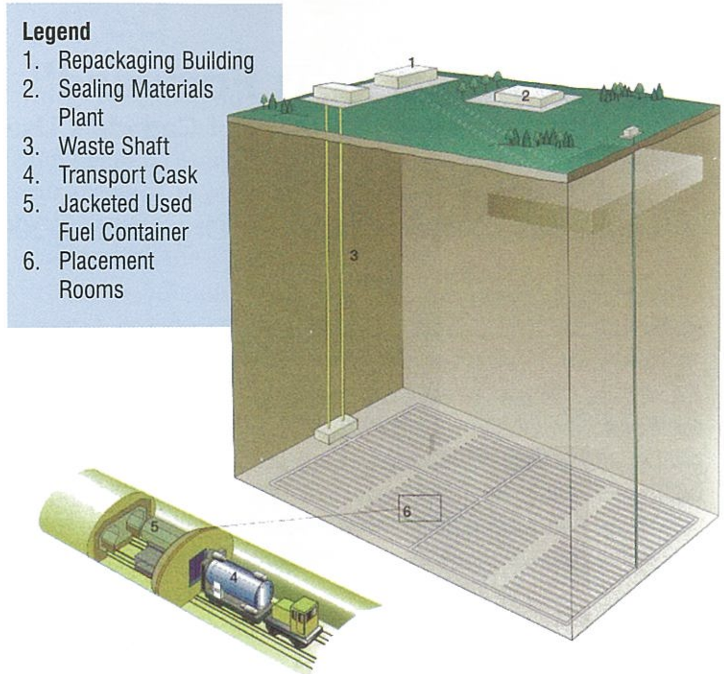
The NWMO has implicitly retained the separation of concept acceptance and siting introduced in 1977 to address the Not In My BackYard (NIMBY) effect that was impeding field studies.

The NWMO proposes a very conservative, i.e., extended, schedule of 30 years for siting and preparing for a central storage facility (CSF); 30 years for operating the facility and preparing for a deep geological repository; and a further indefinite period to construct and emplace used fuel in the repository. A draft of the report simply assumed that the CSF would be needed but the Final Study states that it is "optional". Unless a cost-benefit assessment demonstrates the need, much time and money could be saved. Similarly for an "underground characterization facility" that was termed a "laboratory" in the draft. Work to characterize a proposed site will certainly be needed but the NWMO will have to identify what more is required beyond what is available from the Underground Research Laboratory at Whiteshell, Manitoba, and from international cooperative programs. APM allows for these where justified. To adapt Mackenzie King on conscription in WW-II: *"Facilities where necessary but not necessarily facilities."*

The Final Study is weightier than most family bibles. Like the bible, it will be quoted selectively by both sides in an argument. I suggest that the Canadian nuclear industry should endorse and support the "NWMO's Recommendation", *as worded in point form* on page 44 of the report.

What next? It is now up to the Federal Government to approve implementation of the NWMO Recommendation. Past governments have dodged what was considered to be an unpopular decision by calling for further inquiries. Whatever is decided, a vociferous minority will continue to oppose nuclear energy. However, politicians should be encouraged by public opinion polls showing a majority in favour of nuclear energy and the NWMO's finding that most of those who expressed interest want us to get on with safe and responsible management of the wastes. CNS members should urge their MPs to implement the recommendation.

The NWMO should take advantage of the wait to develop an approach to siting, learning from the experience of the Low Level Radioactive Wastes Task Forces. Prior to implementation the NWMO should increase its staff: the present staff is strong on social sciences, appropriate to its past mission, but weak on physical sciences and engineering. At least one senior engineer, experienced in the design and construction of a major project is essential even if the actual work is to be contracted out.



An illustration from "Choosing a Way Forward" showing a possible concept of "Phase 3, Long Term Containment, Isolation and Monitoring")

NWMO's Recommendation

Our recommendation for the long-term management of used nuclear fuel in Canada has as its primary objectives safety - the protection of humans and the environment -and fairness to this and future generations.

Therefore we recommend to the Government of Canada Adaptive Phased Management, a risk management approach with the following characteristics:

- Centralized containment and isolation of the used fuel in a deep geological repository in a suitable rock formation, such as the crystalline rock of the Canadian Shield or Ordovician sedimentary rock;
- Flexibility in the pace and manner of implementation through a phased decision-making process, supported by a program of continuous learning, research and development;
- Provision for an optional step in the implementation process in the form of shallow underground storage of used fuel at the central site, prior to final placement in a deep repository;
- Continuous monitoring of the used fuel to support data collection and confirmation of the safety and performance of the repository; and
- Potential for retrievability of the used fuel for an extended period, until such time as a future society makes a determination on the final closure, and the appropriate form and duration of postclosure monitoring.

Errata

Glace Bay HWP

Howard Rae, AECL retiree and one-time head of heavy water programs, informed about an error in the Obituary for Don Nazzer, p. 54, Vol. 26, No. 3, September 2005, as follows:

> *I was surprised to see on page 54 of the September issue of the Canadian Nuclear Society Bulletin that the rehabilitated Glace Bay Heavy Water Plant never operated. In 1968 the original Glace Bay plant was declared inoperable. After prolonged negotiations the plant was purchased by the Federal Government and in 1971 AECL was directed to oversee its rehabilitation and to operate the plant. CANATOM MHG was hired to redesign and rebuild the plant. It started operation in 1976 and was shut down in 1985, along with the Port Hawkesbury plant, since a large surplus of heavy water had been accumulated. The Glace Bay plant produced about 1500 Mg. of heavy water between 1976 and 1985.*

Emergency response

Leslie Shemilt, co-author of the paper Emergency Response to a Nuclear Power Accident, p. 42, Vol. 26, No. 2, June 2005, sent in the following correction.

Thanks to a sharp-eyed reader we find an inexcusable error (actually it occurred twice!) in our note. In case you wish to publish an errata it occurs on P42 and again on P.44 where we note the average dose as being 30 msv per year. It should read "about 3 msv a year". We do apologize.

Another Commentary

A Review of the Video "Village of Widows"

A lesson of how much more powerful emotions can be than facts

by. Walter Keyes

Several years ago a Canadian filmmaker, Peter Blow, produced a sensational video called **A Village of Widows.** The project started when members of the Deline Uranium Committee from Deline, NWT, invited him to make a film about the Sahtu Dene's "tragic involvement with the world's first atomic bombs." Blow notes it was not intended to be an investigative or journalistic effort, but rather, "I wanted to make an intimate film from the perspective of the community".

> *The film purports to show the disastrous consequences to native people from the community of Deline, NT. People who worked for the Eldorado uranium mine at Port Radium on Great Bear Lake between the 1930s to1960 when the project ended. It tells the tale of how unwitting native workers and their families were exposed to high levels of radioactivity and how the product of the mine was used to make the bombs that were used in Japan. It even shows a delegation traveling to Japan to apologize and seek forgiveness for their involvement in the event.*

Blow's film is powerful. Interviews with elders provide sad litanies and frightening anecdotes, tents made from used gunnysacks dusty with uranium, children playing in "sandboxes" filled with tailings, the decimation of entire families by cancer. The visual imagery, camerawork and editing are all put to the service of the Deline Uranium Committee's desire to tell a story. Archival footage locates the story in history and lends a factual context to the film while the clever juxtapositioning of fact with fiction weaves a seamless story in a documentary style format.

It's a powerful formula for such a film and it is difficult not to be affected by its emotional impact. It's a good film, even if it isn't true. But this is not an objective report on what was once known as Port Radium. Rather, it is a brilliant piece of propaganda art and a lesson of how much more powerful emotions can be than facts.

The first factual flaw in *Village of Widows* is its title. According to StatsCan, there are more men in Deline than women, but somehow the name Village of Widowers wouldn't work quite as well. The next factual flaw is in its opening scene, a mournful image of lovely old women at a funeral, burying 'another' of the former mine workers who died of cancer. In fact the funeral was for a young man who died in a truck accident. But again, safe driving in a village with six kilometers of all weather road is not as good story material, so why not invent?

About the same time the film was being shot, the Deline Uranium Committee got the attention of the federal government. They met with three federal Cabinet Ministers, Alan Rock, Ralph Goodale and Jane Stewart, and they had their camera along to record the meeting. They wanted both compensation and recognition of past wrongdoing by the federal government.

The ministers took the matter seriously. Both Stewart and Goodale wanted to see some facts. "We need to work together . . . to get clear a common set of historical facts," Stewart told the Deline delegation.

To make it happen, Ottawa put up six million dollars and created a working group called the Canada Deline Uranium Team (CDUT). The Team consisted of Deline members appointed by the Deline Band Council and federal government officials. The CDUT investigation lasted five years and cost close to seven million dollars. Its report was released in mid September 2005. In a way, it too was a bombshell. But it got almost no media coverage.

The report concluded that perhaps the largest health threat to the community was the fear that had been created by scary news reports and fictional events like those contained in Blow's video *Village of Widows.*

The report concluded that no Dene people ever worked at the mine site, not one, ever, in the 28 years the project was in operation. A few Dene worked as part-time seasonal stevedores for about two months each summer, loading and unloading barges at three of eight sites on the river system. It found that the Dene were treated no differently from any of the other transportation workers.

With regard to radiological effects, the report found that at an absolute *maximum,* the most additional cancer deaths that could even theoretically be attributed to all such exposures was 1.6 but that the *likely* additional deaths was below any statistical detectable levels.

The finding from five years of research and six million dollars of taxpayers money was that the community of Deline, which is about 200 miles away from the mine, had hardly been affected by the mine, in any way, environmentally or individually.

Vision TV helped spread the message

The belief patterns illustrated in *Village of Widows* are likely to be much more widespread and persistent than the findings of the CDUT study. The film illustrates how people and organizations that set themselves up as ethical and rational authorities can be so easily drawn in, and be so wrong.

In Canada, Vision TV has aired this video a number of times without ever warning the audience that events have been dramatized in a documentary format. The film won a joint Vision TV /CAW sponsored HUMANITARIAN AWARD at the Hot Docs

Festival in Toronto. The award was for the *Canadian documentary that best explores humanitarian issues.* That's right, documentary! Despite the producer, Peter Blow's acknowledgement that it was not a documentary, it won in the documentary film category. An award sponsored by Vision TV and the Canadian Auto Workers Union, two credible Canadian organizations!

Effect spreads

The culture of self-deception and herd instinct goes far beyond the film award and Vision TV. *Village of Widows* has been incorporated into educational materials in our school systems. One example is from south of the border. The University of Washington and Western Washington University produce a series called K-12 Study Canada. This educational series is designed to teach American students about Canada by making links between the histories of the two countries. According to the program outline, *"Village of Widows* is designed to point out an important historical event that links our two countries".

That project is funded by the U.S. Department of Education with the mandate to provide education to students, educators and the community about Canada. Additional funding for outreach is from an annual Program Enhancement Grant from the Canadian Embassy in Washington, DC.

It's not just in the US school system that this stuff is being promoted. The same thing is taking place in Canada as well. For the past two years a high school teacher in Saskatoon Saskatchewan has been propagandizing her students with study sessions on the tragedy at Deline. She maintained she was teaching the students to be discerning, to judge for themselves, what the merits of the case were. How enlightened, except for the fact that all the time she was feeding them fiction dressed up to promote a cause. She failed to distinguish that it was not different opinions or interpretations of the facts that were involved but in this case but a difference between facts and fantasy.

Breathtaking isn't it? A work of fiction is awarded a prize for best documentary film. The fiction is next turned into an historical event and taught in our schools. And, the Canadian Embassy in Washington helps finance the event at the same time the Canadian Government in Ottawa and the Dene of Deline are working hard to establish a common set of historical facts - facts for which few people seem to have an appetite.

Walter Keyes is a member of the Saskatchewan Branch of the CNS. Over his career he has worked as a Deputy Minister in the Saskatchewan Government regulating many aspects of the uranium industry in Saskatchewan and has also been involved in many national and international consulting projects on energy and resources issues.

"Badge-Draw" Winners at CNS Fuel Conference 2005

At the end of the 9th International CNS Conference on CANDU Fuel, on September 21, 2005, 9 prizes were awarded by random draw from among badges returned by Conference attendees.

The winners:

- Laurence Leung (AECL) and Zvonko Lovasic (OPG) each won a CNS silk tie
- Mukesh Tayal (AECL) won a CNS multitool
- Faramarz Akbari (Royal Military College of Canada) won a copy of the book "Unlocking the Atom"
- Aniket Pant (Zircatec Precision Industries) won a copy of the book "Canada Enters the Nuclear Age"
- Raghavapudi Kalidas (Nuclear Fuel Complex, Hyderabad, India) and Guoping Zhang (AECL) each won a CNS sweatshirt
- Emily Corcoran (Royal Military College) won a CNS memory stick
- Raheel Hameed (Zircatec Precision Industries) won a free 2006 CNS membership.

Congratulations to all the winners!

Gagnants de prix au tirage des porte-insigne à la Conférence sur le Combustible CANDU

À la fin de la 9ième Conférence internationale de la SNC sur le Combustible CANDU, le 21 septembre 2005, 9 prix ont été tirés au sort parmi les porte-insigne retournés par les participants à la conférence.

Voici les gagnants des prix:

- Laurence Leung (EACL) et Zvonko Lovasic (OPG) ont chacun gagné une cravate en soie de la SNC
- Mukesh Tayal (EACL) a gagné un " outil multiple " de la SNC
- Faramarz Akbari (Collège Militaire Royal du Canada) a gagné une copie du livre "Unlocking the Atom"
- Aniket Pant (Zircatec Precision Industries) a gagné une copie du livre "Canada Enters the Nuclear Age"
- Raghavapudi Kalidas (Nuclear Fuel Complex, Hyderabad, Inde) et Guoping Zhang (EACL) ont chacun gagné un chandail de sport de la SNC
- Emily Corcoran (CollËge Militaire Royal du Canada) a gagné un b,ton de mémoire électronique de poche de la SNC
- Raheel Hameed (Zircatec Precision Industries) a gagné une adhésion gratuite à la SNC pour 2006.

Félicitations à tous les gagnants!

The *Eldorado Radium Silver Express*

by J.E. Arsenault

***Ed. Note:** A CNS member, Jim Arsenault is a retired reliability engineer living in Stittsville, Ontario, who has developed an interest in the early days of Canada's involvement in radiation and nuclear energy. As well as the following bit of history he has been pursuing the papers generated at the Montreal Laboratory during the Second World War.*

Introduction

Preserving cultural artifacts has a long tradition in Canada, especially with respect to the arts. However, with few exceptions, science and technology have until recently received little attention in this regard. The situation is improving and there are a number of efforts now underway, particularly related to the nuclear field, aimed at preserving the scientific and technical accomplishments of the past.

A case in point is the work of the Western Canada Aviation Museum (WCAM) at Winnipeg, Manitoba, which is engaged in the restoration of an aircraft, the *Eldorado Radium Silver Express,* owned originally by Eldorado Gold Mines Limited, that was linked directly to the mining of uranium.

Eldorado Gold Mines Limited

Eldorado Gold Mines Limited was incorporated in 1926 but with the doubtful value of its claims associated with its mine at Long Lake, Manitoba, and the discovery in 1930 of pitchblende (uranium oxide) at Great Bear Lake, Northwest Territories, the company changed direction completely. The point of land where the discovery was made by the company's Managing Director, Gilbert LaBine (1890-1977), became known as Port Radium. The ore consisted of both uranium oxide and silver in significant amounts. At the time, the mining economics were driven by the world price of radium, which was extracted from uranium oxide and sold on the world market for US$50,000 per gram or, taking inflation into account, about US$500,000 today.

With these considerations in mind, Eldorado set plans in motion to bring in a mine and mill operation at Port Radium, and a refinery at Port Hope, Ontario for radium. The refining of the silver concentrates was to be contracted out. One of the stark challenges was the great distance between the mine and the Port Hope refinery; the route that evolved was a water and railway combination of nearly 4000 miles. The uranium concentrates were ferried westward across Great Bear Lake and down the Great Bear River, up the Mackenzie River, eastward across Great Slave Lake, then southward up the Slave and Athabaska Rivers, to the railhead at Waterways, a short distance up the Clearwater River from Fort McMurray, Alberta - a total of about 1450 miles.

The waterborne segment of the route was limited in capacity and was restricted to the short open-water season at those latitudes. Consequently, an additional all-season transportation mode was developed quite early on, to bridge the gap between mine and railhead, during the bulk of the year when the lakes and rivers were frozen.

The *Eldorado Radium Silver Express*

In the 1920s, exploration in the north began to open up rapidly with the use of bush planes, which were capable of flying great distances and landing on both water and ice. It was the use of a bush plane by geologists and others, including Gilbert LaBine, that led to the Great Bear Lake mining rush around 1930, which seemed like the only game in town in the depths of the depression. In the early days at Port Radium, the uranium oxide concentrates were sufficiently rich to justify the use of aircraft to supplement the water route, and to fly in personnel and supplies. For this purpose the Bellanca Aircruiser was selected [see Table 1].

This aircraft was designed in 1928 by Giuseppe Bellanca, to fly non-stop from New York to Rome - which it never did - but the essential design survived as a passenger and freight aircraft. A total of 23 aircraft were built. It was originally powered by a water-cooled engine but this was changed to a more reliable, air-cooled engine. The final version of the Aircruiser was the most efficient aircraft of its day and with the air-cooled, supercharged engine it could carry 4000-lb payloads at speeds up to 155 mph. The version that likely came to the attention of Eldorado was the floatplane which operated around New York City, as a ferry service between Wall Street and the East River.

CF-AWR was built in 1935 by the Bellanca Aircraft Corporation of New Castle, Delaware, and was the first of five of its type used in Canada. It was operated for Eldorado by Mackenzie Air Service Limited of Edmonton, Alberta, and it was the second largest aircraft operating in Canada at that time. Mackenzie was formed in 1932 by Leigh Britnell (1895-1971), coincidentally the pilot who first landed Gilbert LaBine on Great Bear Lake in 1929. The aircraft was named the *Eldorado Radium Silver Express* but it was nicknamed 'The Big Bellanca' or 'The Flying W'. It was identified easily by the characteristic W appearance, derived from the aerodynamically shaped, triangular lifting struts, which extend down from the bottom of the fuselage

Table 1: Some characteristics of CF-AWR Eldorado Radium Silver Express (Bellanca Model 66-70 , sn 719)

General

Wingspan	19.81 m (65 feet)
Wing area	61.32 sq.m (660 sq. feet)
Length:	13.16 m (43 feet 2 inches)
Height	4.04 m (13 feet 3 inches)
Engine	700 hp Wright Cyclone SGR 1820F-32
Maximum speed	216 km/h (135 mph); Cruise: 200 km/h (125 mph)
Maximum range	1690 km (1050 miles)

Typical Weight Schedules (all in lbs.)

	Land plane	Seaplane	Ski plane
Gross	11400	11700	11700
Empty	6300	7176	6821
Disposable	5100	4524	4879

Typical load (for ski plane):	
Pilot	160
Engineer	140
Gas	700
Oil	90
Equipment	200
Total:	1290
Disposable	4879
Typical load	1290
Available cargo:	3589

then up to a point outboard of the main wing.

The first load of concentrates was flown out on 19 March 1935 and was landed at Fort McMurray [see Figure 1]. In the winter of 1936 a rail carload of 34 tons of concentrates was airlifted to the railhead at Waterways from the Port Radium mine, a distance of 710 air miles, and an additional 20 tons was flown to Fort Rae on Great Slave Lake to take advantage of the earlier ice break-up there. Fort Rae, at that time, was an important fuel stop for planes on the route between Waterways and Port Radium.

Based on the fact that 130 mg of radium is usually found in a single ton of pitchblende containing 50% uranium oxide, and assuming the Port Radium concentrates were such in 1935, it would take about 8 tons of concentrates to produce 1 g of radium. Allowing for two flights a week and 50% cargo space, enough concentrates to produce 1 g of radium per month was feasible, theoretically. Due to downtime caused by freeze-up and break-up, only 10 months would be available annually for flight operations, thus limiting radium production to about 10 g per year from concentrates carried over the air route.

The Port Hope refinery produced 2.8 g of radium in 1934, 8.5 g in 1935, 15.5 g in 1936 and 23.8 g in 1937. As Eldorado was interested in producing a steadily increasing output of radium, the economics demanded improvements in the less expensive but slower water route. Plans were implemented to stockpile enough uranium concentrates at Port Radium, which could be moved by the water and rail route to Port Hope, to keep the refinery going for a year. In 1936 Eldorado created a water-based shipping subsidiary by purchasing the Northern Transportation Company, and by 1938 it had cut the 1934 shipping rate by half.

The Eldorado and Bellanca Legacy

The Port Radium mine was closed in 1940 during radium market saturation and disruptions caused by the Second World War, then it was reopened in 1942 to supply uranium oxide for the Manhattan Project. In 1943, Eldorado was renamed Eldorado Mining and Refining Limited, in recognition that gold mining was no longer the main business of the company. Uranium had by this time become a strategic material and Eldorado Mining and Refining became a Crown Corporation in 1944 and it was renamed Eldorado Mining and Refining (1944) Limited in 1945. The mine ceased production of uranium oxide in 1960 due to economic considerations and by that time Eldorado had gone on to other developments. The company became Eldorado Nuclear Limited in 1968, Eldorado Resources Limited in 1982, and later still it was merged with the Saskatchewan Mining and Development Corporation (in 1988) to form Cameco, now the largest uranium producer in the world, headquartered in Saskatoon, Saskatchewan.

Today nothing much more than a plaque exists at the Port Radium mine site. It says, in part, "In order to supply this remote northern community and to transport the mine's products, the mining companies pioneered aviation, marine and winter road transportation in northern Canada. ...pro-

*The **Eldorado Uranium Silver Express** with Leigh Britnell (left) and Stan McMillan (right).* (WCAM PHOTO) duction from the Eldorado...mines included 13,700,000 lbs [6850 tons] of uranium oxide."

The Waterways dock and railhead property has been rehabilitated and forms part of the Fort McMurray public park system. Along the edge of the Clearwater River only a few piles provide a physical link to an era long past but nearby at the Heritage Park in Fort McMurray, a 48-foot yard vessel built in 1946, the *MV Radium Scout*, has been preserved and is on display in the open.

The Port Hope refinery now produces fuel for heavy water CANDU reactors and products for the export market, which are used to manufacture fuel for light water reactors.

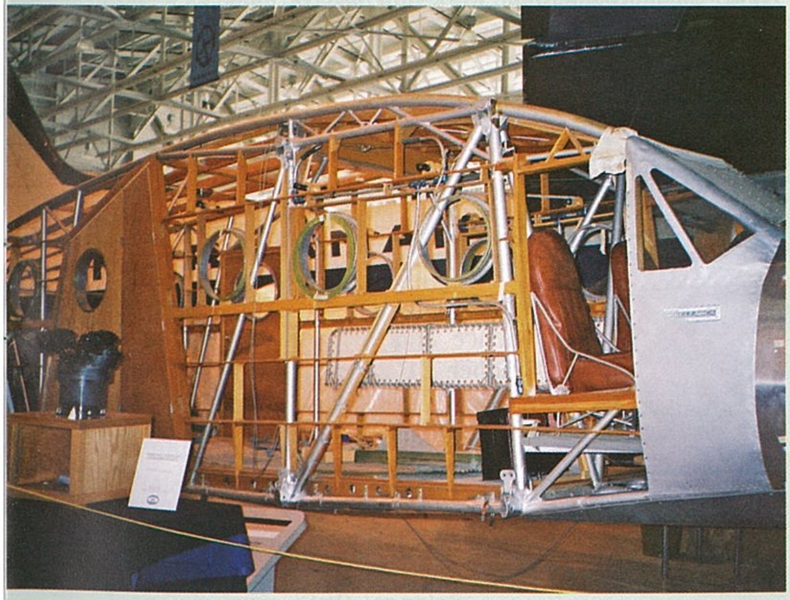
By the late 1930s, Eldorado became less dependent on the Bellanca and increasingly dependent on the water route to move concentrates to the Port Hope refinery. In August 1939, ownership of the Eldorado Radium Silver Express passed to Canadian Airways Ltd., of Winnipeg, Manitoba. It remained in the service of Eldorado until the mine was closed in 1940. CF-AWR served on floats and skis with Canadian Pacific Airlines, after it was formed in 1942 and took over the bush-plane operations of Canadian Airways Limited.

In January 1947, CF-AWR crashed and was damaged beyond economic repair, at the edge of Upturned Root Lake, about 130 miles northeast of Sioux Lookout, Ontario, as a result of fuel starvation. It lay abandoned until 1973, when it was retrieved by the WCAM.

WCAM Restoration Project

After 26 years, volunteers from WCAM, assisted by a helicopter from the Canadian Forces, recovered the remains of CF-AWR from the bush. At that time, most of the woodwork had rotted away, steel parts were badly rusted and trees had grown up through the skeletal remains.

The restoration was initially contracted out to an experienced mechanic who had worked on Bellancas for many years. The fuselage frame was rebuilt from scratch, which required making everything back from the rear of the cabin, including much of the floor and wood framing, before it was brought back to the museum for completion. New wooden spars were fabricated for the wings and all the stainless steel ribs were rebuilt one by one. From 1990 to 1998 restoration work was limited but since then steady progress has been made. All major structures have been rebuilt and a trial erection was made in 1998. At present work is concentrated on the instrument panel, the engine and powerplant controls, the propeller and its controls, and fabric work [see Figure 2].



CF-AWR undergoing restoration at WCAM (author photo)

CF-AWR is one of only two aircraft of this type known to exist today. The second aircraft, CF-BTW, also of Canadian registry, served into the 1970s and is presently located in a museum in the United States.

Conclusion

The Canadian nuclear legacy is only emerging slowly in the nations' museums and archives but there is the appearance of an accelerating trend. The Bellanca Restoration Project by the Western Canadian Aircraft Museum is part of that trend and Canadians can undoubtedly look forward to other fine examples of historical preservation.

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Tel (204) 786-5503 Fax (204) 775-4761
web site: wcam.mb.ca email: info@wcam.mb.ca

Acknowledgements

Thanks are due to John Clearwater for drawing my attention to the WCAM, to Fred Boyd for encouragement with this article, to Carl and Elizabeth Vincent for Bellanca background material and to Brian Watson of WCAM for restoration details.

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CNS news

Meet the President

John Luxat brings to the position of President of the Canadian Nuclear Society over thirty years of professional and academic nuclear background.

Originally from South Africa he obtained his bachelor and masters degrees from the University of Cape Town. After coming to Canada he completed his studies with a Ph.D. from the University of Windsor in 1972. All of these were in electrical engineering.

He immediately became involved with the Canadian nuclear program with a consulting firm, DCF Systems, where he worked on design studies on overall plant control for Bruce NGS A. In 1974 he moved to another consulting firm, Gellman, Hayward & Partners, where he developed spatial reactor control approaches for the conceptual design of the proposed CANDU-1250 and the reactor kinetics code SMOKIN.

In 1977 he moved to Ontario Hydro where he remained for the next 24 years, including its transformation to Ontario Power Generation, rising to become Manager of Nuclear Safety Technology.

When the Nuclear Safety Analysis Division was sold to become Nuclear Safety Solutions Ltd. in 2002, he was appointed vice-president of the new company and a member of its Board of Directors.

Two years later, 2004, he received a call to move to academia and accepted his current position of Professor and holder of the Industrial Research Chair in Nuclear Safety Analysis in the Department of Engineering Physics at McMaster University, Hamilton, Ontario. The Chair is jointly funded by the Natural Sciences and Engineering Research Council (NSERC) of Canada and by the University Network of Excellence in Nuclear Engineering (UNENE).

During his earlier years at Ontario Hydro John performed advanced analyses, developed complex codes, and conducted design reviews. By 1988 he was manager of group of 50 involved in the Darlington design and safety analysis. In 1998 he was appointed Manager, Nuclear Safety Technology at OPG, the position he held until the department became part of NSS.

Concurrent with that he was a member of several technical committees and working groups of the Nuclear Energy Agency and the International Atomic Energy Agency and, through CANDU Owners Group, worked on the globalization of CANDU safety research and development.

Despite the challenges of his increasingly senior positions John managed to author or co-author 80 technical papers.

At the CNS he has been quick to volunteer for several challenging tasks, including being chairman of the organizing committee for the 2005 CNS Annual conference. He conducts Council (and other) meetings in a professional manner, respecting those attending while ensuring that the business is conducted effectively.

Divisions

Nuclear Science and Engineering - Dorin Nichita

The NSED CANDU Reactor Safety Course held in Kincardine in September was attended by 36 participants, of whom 30 were from Bruce. The 13 presenters and the course organizers are to be congratulated for this successful event.

Design and Materials - Prabhu Kundurpi

The Design and Materials Division is organizing the Second Canadian Workshop on Engineering Structural Integrity (CWESI-2) to be held in Toronto, Ontario April 3rd & 4th, 2006. Submissions to the workshop must be made as a short abstract by December 1st, 2005 and an extended abstract or full paper or presentation material by February 28th, 2006.

Committees

World Year of PHYSICS 2005 · 2005 Année Mondiale PHYSIQUE

Education and Communications

The official opening of the ZEEP reactor display at the Canadian Science and Technology Museum on October 21 was attended by Jeremy Whitlock. The display was opened to the public on October 22. *(See photo)*

visions OF SCIENCE Network for Learning

CNS Council has supported an ECC proposal to become a financial sponsor of Visions of Science (VoS, www.visionsofscience.ca) - an organization dedicated to promoting science and technology in the black, African-Canadian and Caribbean community, and encouraging the next generation to pursue those fields. This organization participates in the Science and Technology Awareness Network. VoS are particularly interested in recruiting individuals who share their heritage and who may be able to inspire youth to pursue careers in science and technology.

Racial minorities now equal more than 50 percent of the Greater Toronto Area population with Blacks and African Canadians accounting for 25 percent and South Asians 21 percent. By the year 2006, 5.6 million people or 18 percent of a projected 30.6 million Canadians will belong to visible minorities.

Visions of Science exists to stimulate change within the community so that Black, African Canadian and Caribbean students and adults are ready to face some of the challenges of the century.

CNS Council recently supported an ECC proposal to sponsor a "town hall" meeting in Toronto to be organized by Women in Nuclear Canada. At the CNS Annual Conference, Susan Brissette of WiN Canada described a series of unconventional encounter sessions that were sponsored by Bruce Power to provide an information and education opportunity to women of influence in selected communities. This new initiative is planned for 2006.

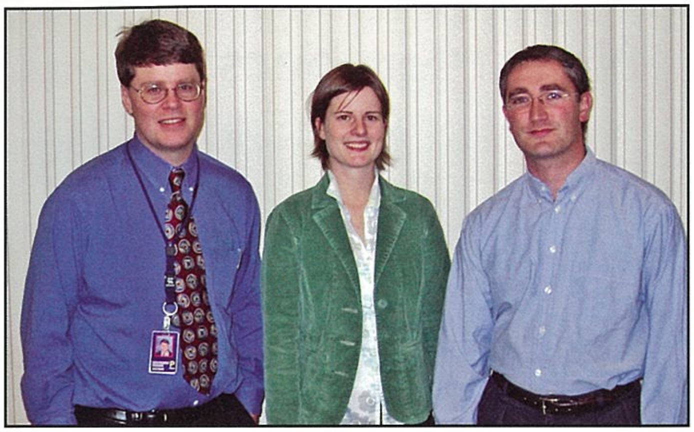
Branch News

Chalk River Branch - Morgan Brown

The Chalk River Branch cosponsored the first seminar of the fall season with the Algonquin Chapter of the Professional Engineers of Ontario. Deny See Hoye of AECL presented "In Praise of an Older Lady - Keeping NRU Young and Alive". He described the measures taken to improve the safety of Canada's largest and oldest operating research reactor at Chalk River as well as the plan to assure the CNSC that continued operation of NRU in 2006 and beyond is responsible.

The second seminar and Branch Annual General Meeting were held on November 24th. Branch Chair Morgan Brown was succeeded by Blair Bromley. The balance of the Branch executive continued in their positions with the exception of Michael Stephens who is now free of the onerous responsibilities of past-chair to which Morgan has gleefully acceded.

Following the AGM, Thierry Joulin and Penny Neal of AECL Chalk River Laboratories presented "The World Nuclear University Summer Institute - Sharing Experience". They provided an overview of their experiences attending the 2005 WNU.



Blair Bromley, Penny Neal, Thierry Joulin

New Brunswick - Mark McIntyre

The New Brunswick Branch held a meeting on Friday November 18, 2005 at the Point Lepreau Generating Station STOIC Building Theatre. The presenter was Mark McIntyre of Atlantic Nuclear Services. His topic was "The 2005 World Nuclear University (WNU) Summer Institute". The lecture focused on the ideas presented to the WNU Fellows while attending the inaugural 6 week program in Idaho Falls, Idaho.

The WNU brought together 77 Fellows who benefited form over 30 presenters on subjects ranging from uranium mining to excellence in nuclear operations to advanced decommissioning techniques. Some of the highlights were presentations by Hans Blix (former IAEA Director General), Geoffrey Ballard (General Hydrogen), Zack Pate (Former INPO President), Susan Eisenhower (Eisenhower Institute) and US Senator Larry Craig. Idaho Falls was selected as the location for the institute because of the long history of nuclear research at the Idaho National Lab. Mark showed many photos from the technical tours and the social & cultural activities. Mark concluded by informing the audience that the organizers are currently accepting applications for the 2006 Summer Institute in Stockholm Sweden.

Ottawa - Jim Harvie

The Ottawa Branch held its first meeting of the season on November 30 with a talk by Don Amundrud who spoke on his experience as an inspector for the International Atomic Energy Agency in Iraq.

Mike Taylor, retired head of regulatory policy at the Canadian Nuclear Safety Commission, has joined the executive of the Branch.

Sheridan Park - Adriaan Buijs

David Scott, AECL, presented a seminar titled: "Retubing a CANDU 6", on November 9. The topic was the scheduled retubing of the Point Lepreau Station. It was a standing-room-only event where David showed the state-of-the art engineering techniques to be used for completing this task.

New Members

We would like to welcome the following new members, who have joined the CNS in the last few months.

Nous aimerions accueillir chaudement les nouveaux membres suivants, qui ont fait adhÈsion ‡ la SNC ces derniers mois.

Andrea Badcock, Bruce Power
Michael Campbell, Black and McDonald Limited
Christopher Canniff, AECL
Teresa Cheuk-Ying Chee, University of Toronto
Bill Degnan, Black and McDonald Limited
Brian Fehrenbach, AECL
Steve Greenwell, Nova Machine Products
Raheel Hameed, Zircatec Precision Industries Inc.
Hélène Hébert, AECL
Abdullah Kadri, University of Western Ontario
Sofiya Kaznadiy, Ontario Power Generation
Nick Lalli, Bruce Power
Ru Quan Liang, University of Toronto
Cho Su Lim, AECL
Jianping Ma, University of Western Ontario
Frank MacDougall, Black and McDonald Limited
James (Jim) McCulloch, Bruce Power
William Milburn, University of British Columbia
Carmen Neferu, Bruce Power
Bruce J. Ottenbrite, Ontario Power Generation
Vladimir Ponomarev, Bruce Power
Sumit Sikder, University of Toronto
Michael L. Trudeau, Ontario Power Generation
Varaprasad Babu Tummalapalli, University of Manitoba
Richard J. Van Lochem, Stern Laboratories Inc.
Dave White, Black and McDonald Limited
Polad Zahedi, University of Western Ontario
Laszlo Zsidai, AECL

A first! Pictured are Eric Williams (left) and Brent Williams, the first father / son team on the CNS Council. Eric is 2nd Vice President and Brent is chair of the NA-YGN committee.

Call for Papers

CWESI-2

Canadian Workshop on Engineering Structural Integrity-2

April 3rd - 4th, 2006
Toronto, Ontario, Canada

THEME

Organized by the Canadian Nuclear Society and co-sponsored by the Canadian Society for Mechanical Engineering, the Second Canadian Workshop on Engineering Structural Integrity (CWESI-2) will be held on April 3rd and 4th, 2006 in Toronto. This workshop is aimed at providing a forum for discussion of various issues associated with assurance of structural integrity in Canadian industries with the objective of sharing the information and technology transfer between industries. The workshop is a great place to present your ideas and to meet colleagues from Canadian industry sectors. Workshop topics include: Manufacturing, fabrication and residual stresses; Design and analysis; Corrosion and material degradation; Pipeline and offshore systems; Codes, standards and regulatory issues; Service experience and inservice evaluation; Inspection; Risk assessment.

Interested authors should submit a 200-word abstract to the workshop website www.softconf.com/start/CWESI2 by Jan. 31, 2006. A final paper, extended abstract or final presentation should be submitted no later than Feb. 28, 2006.

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Why This Is "CANDU Country"

by Jeremy Whitlock

There is something comfortably self-evident about the recent declaration that "Canada is CANDU Country". With billions invested over fifty years to advance a technology as unique as poutine and beavertails, what other kind of country could we be?

It's our mouse that roared on the global stage, the David that took market share from Goliath. It is hundreds of private manufacturers tooled up, tens of thousands gainfully employed, and a lineage to the discovery of fission itself.

It's the definition of our regulatory regime and a straight jacket for all other designs, from 10 MW research reactors to 1600 MW PWRs: CANDU is part of our cultural fabric.

We even starved out the competition for CANDU itself within these borders: the Civilian Atomic Power Division (CAPD) of GE Canada, celebrating its 50th anniversary in 2005, built the first CANDU at Rolphton and pioneered the CANDU export market in Pakistan, before bowing out of the reactor supply business. In the 1960s this land wasn't big enough for two reactor suppliers, particularly one tied to an American parent company. (GE Canada continues as a fuel supplier in the CANDU industry).

So "CANDU Country" it is, although one suspects that most Canadians would not be so quick to paint their country in that hue. In fact, it is likely that most Canadians would have barely heard of CANDU, and a good fraction of those that did would probably consider it an artifact of the 50s and 60s. They'd be correct, of course, but that's not the point.

Fewer still would know that the Canadian engineering community, on the occasion of its 1987 centenary, identified the CANDU reactor as one the nation's top ten engineering achievements of the preceding century. The lack of mainstream fame is no slight, since Canadians are equally likely to be unaware of the other nine laureates.

True, if asked, they'd probably guess two of them: the CPR railway and the Bombardier snowmobile. The remaining seven are all appropriately deserving: the St. Lawrence seaway, Polymer Corporation's synthetic rubber, the Athabascan oil sands development, Hydro Quebec's high-voltage transmission system, the De Havilland Beaver aircraft, the Alouette satellite, and the trans-Canada telephone network.

Interestingly, a poll of average Canadians would probably find near-unanimous support for nine of the ten being on the list, while CANDU's presence would no doubt stir controversy.

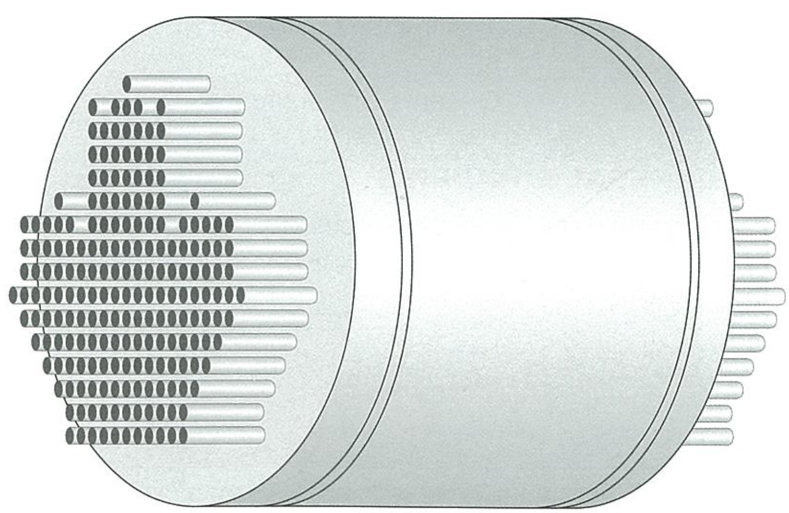
Also interestingly, in 1999 the same engineering community compiled another list of the five "most significant Canadian engineering achievements" of the 20th century, and none of 1987's top ten made the cut. In fact, four of the five winners were relatively new to the scene (the PEI Confederation Bridge, the Canadarm, IMAX, and CPR's new Rogers Pass project). The fifth honouree was the Hopps pacemaker, subsequently chosen through an Angus Reid poll as the one of the top five that made people "most proud to be Canadian".

When CANDU reactors make Angus Reid respondents "proud to be Canadian", then this will truly be "CANDU Country".

In fact, the more people get to know CANDU technology, the more they might find it a metaphor for Canada itself and all that we hold dear. Consider: Although one of the largest power reactor designs, it is mostly empty space dotted with pockets of isolated activity. A federation of pressure tubes, if you will, composed of diverse participants working side by side (thanks to bi-directional fuelling) for the greater harmony.

At the same time there is a challenge of controlling spatial sub-modes, and an ongoing need for regional over-power protection. In the end, however, it is a concept evolved from peaceful rather than military fundamentals, and a concept that continues to effect global change through subtle, long-term interaction (on-line refuelling) rather than brute force.

Come on people, how can you not love this technology?



CALENDAR

2006

Feb. 12 - 15
ANS Topical Meetings - 9th Emergency Preparedness & Response - 11th Robotics & Remote Systems
Salt Lake City, Utah
website: www.sharingsolutions.com

Feb. 22, 23
CNA Nuclear Industry Seminar 2006
Ottawa, Ontario
website: www.cna.ca

Apr. 3, 4
CWESI-2
2nd Canadian Workshop on Engineering Structural Integrity
Toronto, Ontario
contact: CNS office

Apr. 27, 28
PLIM + PLEX 2006
Paris, France
website: www.neimagazine.com/plex

May 9 - 12
EIC Climate Change Conference 2006
Ottawa, Ontario
website: www.ccc2006.ca

May 31 - June 2
WIN Global
Cambridge, Ontario
Contact: Susan Brissette, Bruce Power
email: susan.brissette@brucepower.com

June 4 - 8
ANS Annual Meeting & ICAPP 2006
Reno, Nevada
website: www.ans.org

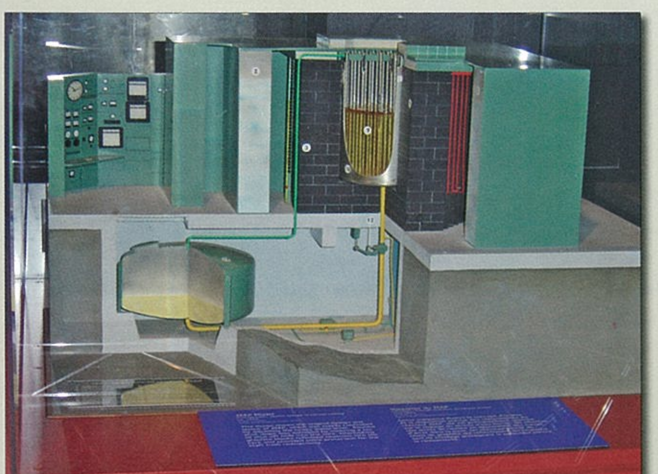
June 11 - 14
27th CNS Annual Conference & 30th CNS/CNA Student Conference
Toronto, Ontario
website: www.cns-snc.ca

Sept. 10 - 14
Physor - 2006 Physics of Reactors 2006 Advances in Nuclear Analysis and Simulation
Vancouver, British Columbia
website: www.cns-snc.ca/physor2006
email: physor2006@aecl.ca

Oct. 15 - 20
15th Pacific Basin Nuclear Conference
Sydney, Australia
website: www.pbnc2006.com
email: pbnc2006@tourhosts.com.au

Nov. 12 - 16
ANS Winter Meeting
Albuquerque, New Mexico
website: www.ans.org

On October 21, 2005 a special exhibit was opened at the Museum of Science and Technology in Ottawa, with a reconstruction of ZEEP, the first reactor in Canada and the first outside the USA. Pictured is the original tank that held the heavy water and uranium rods used to confirm calculations for the NRX reactor and subsequent designs, now installed at the museum.



A model of the complete ZEEP reactor and control area that accompanies the ZEEP display at the Museum of Science and Technology.

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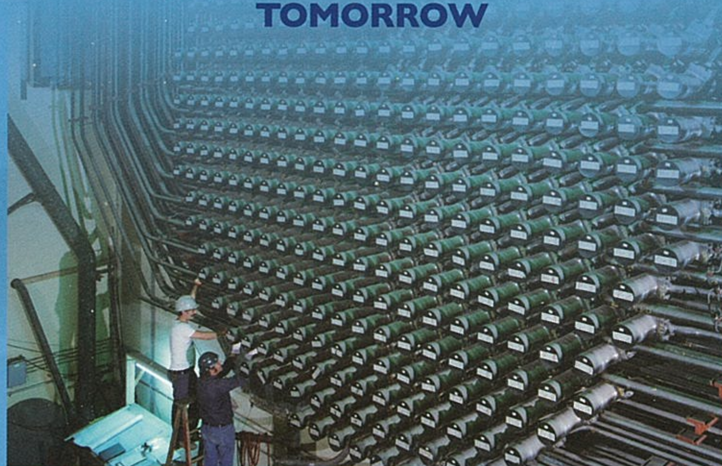

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