CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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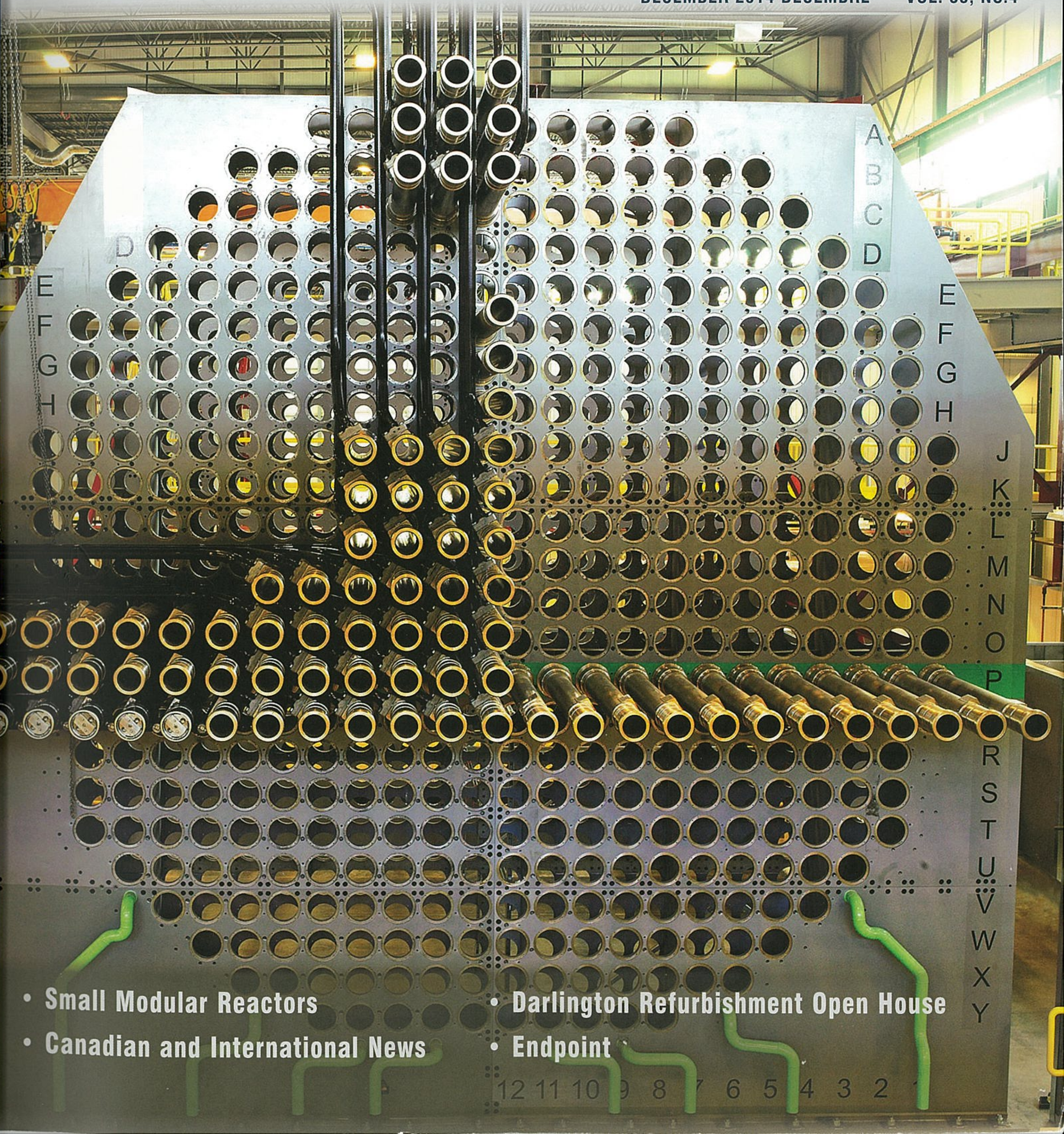
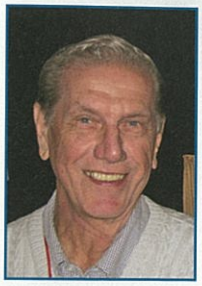


- Small Modular Reactors
- Canadian and International News
- Darlington Refurbishment Open House
- Endpoint

From The Publisher



CNS

After struggling with the financial deficits of the past two years, the CNS Council now predicts that the 2015 program will result in a balanced account.

That program includes two new conferences:

- 1st Technical Meeting on fire Safety and Emergency Preparedness for the Nuclear industry
- International Degradation of Materials in Nuclear Power Systems – Water Reactors

And a modified one:

- International Nuclear Components Conference

See the full page announcements following the CNS News section.

Canadian Program

There have been so many developments in the Canadian nuclear program that we chose to change the usual collection of "General News" to "Canadian News" with all the items dealing with activities or actions here at home.

The development of most interest is undoubtedly the formal announcement of the creation of Canadian Nuclear Laboratories, a further step in the Canadian government's plan to change the management of the Chalk River Laboratories. It will be interesting to see if the proposed GoCo model being pursued by the Canadian government does lead to significant changes to the program at CRL.

Despite the vocal outcries from anti-nuclear groups it appears that the Darlington Refurbishment will definitely proceed, especially when the Ontario Energy Minister praises the extensive mock-up facility Ontario Power Generation has built.

The announcements by Bruce Power related to their long-time refurbishment plan provide further optimism for the many organizations supplying products and services to the utilities.

Agreements between Candu Energy with China indicate that the unique features of the CANDU concept will lead to international projects.

However, there remains strong opposition to things "nuclear". The long set of hearings in Quebec about (primarily against) uranium mining, following the shutdown of the Gentilly station, is one evidence of that opposition. The nuclear community still has a long way to go to convince the general public that radiation is part of nature and that nuclear power is "environmentally friendly".

Random thoughts on retirement

It is a strange feeling to realize that after 24 year this is my final comment as publisher or editor or bot of this publication.

Although it was mentioned in an item in CNS News o the last issue about the future of the Bulletin, there ha been little said that this will be my last issue. I formall submitted to CNS Council last January my intentio to end my involvement with the Bulletin at the end o this year. No action or discussion took place until th September meeting of Council and no action until the las Council meeting at the end of October. More on that later

This has been the longest "job" I have had, and fascinating one as well. It has given me the opportu nity to stay connected with the many aspects of th Canadian nuclear program. It has also allowed me t blend my two major interests – technology and com munication, especially in the written form...

I had, over the years partially fulfilled those some what conflicting interests by serving as voluntee editor of publications such as the Varsity at U of T North Renfrew Times at Deep River and the Kanat Standard in the original part of that suburb of Ottawa

So, when I retired, slightly early, from the Atomi Energy Control Board, I looked for something similar and the fledgling Bulletin needed an editor.

My only stipulation was that I would run it my way or the (Council) could "fire" me. That arrangement has worke well over the years with the evolution of the Bulletin.

There was one contentious decision. At the time of m appointment the Bulletin was almost exclusively reprints o technical papers. I suggested accepting advertising to offse some of the costs and, in my view, enhance the publication A major argument ensued in Council with some members expressing fear that this would taint the scientific impartiality of the CNS. Fortunately, the more pragmatic members won out. AECL quickly filled the back cover with interesting ads and other major organizations followed.

Ric Fluke joined me in the early 1990s but then withdrew for a number of years because of pressure of his "real" work. It was great to have him return a number of years ago. Our combined exercises in assembling the material for each issue and then, with our marvellous "partner", Liz Kubica at our printers Vincent Press, producing an attractive publication, are always interesting, while sometimes stressful.

It was decided at the last CNS Council meeting that Colin Hunt will assume the role of "publisher". Although it has been agreed that the Bulletin would continue in its present form, Colin is also faced with the challenge of exploring a digital publication. You will hear more of that soon.

So, farewell readers. I will now join you.

Fred Boyd

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~ Cover Photo ~

The full scale made-in-Ontario mock-up of a Darlington Reactor will be used for training and tool development and testing before work begins inside the actual reactors during refurbishment.

Photo courtesy of Ontario Power Generation

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La SNC procure aux Canadiens intéressés à l'énergie nucléaire un forum où ils peuvent participer à des discussions de nature technique. Pour tous renseignements concernant les inscriptions, veuillez bien entrer en contact avec le bureau de la SNC, les membres du Conseil ou les responsables locaux. Les frais d'adhésion par année de calendrier pour nouveaux membres sont 82.40$, et 48.41$ pour retraités.

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Third Meeting on Small Reactors

by FRED BOYD

The *3rd International Technical Meeting on Small Reactors* was held in the Ottawa Marriott Hotel, 5-7 November 2014.

Originally sponsored and organized jointly by Atomic Energy of Canada Limited and the Canadian Nuclear Society it became a joint effort of the CNS and the newly created company Canadian Nuclear Laboratories (CNL).

Although CNL began officially just two days prior to the Meeting all of the presenters from Chalk River Laboratories had modified their slides to show the CNL name and logo.

The actual meeting was two days, November 5 and 6, with an optional visit to the Chalk River Laboratories on the Friday, November 7.

A plenary session was held the first morning with the balance of the two days devoted to technical papers in parallel sessions on *Research Reactors and Small Reactors.* Unlike the first two meetings on this topic the number of papers in the Research Reactor category exceeded those on Small Reactors.

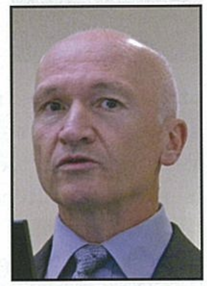
Metin Yetisir, from CNL and Chair of the organizing committee, opened the meeting with greetings and a brief outline of the program.

He then introduced **Dr. Robert Walker,** president of AECL, who announced that he is now also president of CNL.

"What's next ?" he asked, referring to the organizational changes at AECL. "The laboratories will be around for a long time", he assured the audience. The Canadian government, he said, is pursuing a two-step procedure in converting the laboratories to a GO-CO (government owned – contractor operated) structure. Several consortia have expressed an interest in being the operating contractor. The new company, CNL, will be the interim operator, with AECL as the owner, until the government chooses one of the bidding organizations.

Then, for those in the audience not familiar with the Chalk River Laboratories, he showed a video depicting many of the different activities at the site.

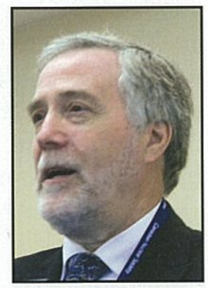
He referred to the Nuclear Leadership Forum of senior representatives of the major companies and organizations involved in the Canadian nuclear program. Over the past two years the Forum developed a "25 year Vision" for the Canadian nuclear program. He then mentioned the planned refurbishments of Darlington and Bruce nuclear power plants, commenting they must be done well.



Metin Yetisir

Noting the period 1954 to 1974, when AECL, Ontario Hydro, the Canadian and Ontario governments all agreed to proceed with a nuclear power program, he asked, could SMRs (small, modular reactors) be the next big idea? We have the people and the infrastructure, he noted. However, he added, missing are: customers; political support; financing; demonstration project; and public acceptance.

He closed by commenting that the (federal) government wants to proceed with the restructuring of the laboratories and would be receptive to credible proposals for small reactors.



Dr. Robert Walker

Unfortunately, Dr. Walker had to excuse himself immediately after his presentation.

The first scheduled plenary presentation was by **Dr. Robert Robinson,** head of the Australian Nuclear Science and Technology Organization (ANSTO). He titled is presentation *The Australian Experience with a New Multi-Purpose Research Reactor for Scientific Research, Isotope Production and Silicon Irradiation.*

Dr. Robert Robinson

He began by showing slides of OPAL, their relatively new research reactor, and of some of the experiments underway.

Noting that Australia does not have a nuclear power program, he said the reasons for ANSTO and the OPAL reactor in particular is to: support neutron beam research; provide the ability to produce radioisotopes such as Molybdenum 99; and, generally for broad national interest.

He spoke of a particular program using "cold" neutrons which, he said, form "blobs" with extremely small inter-atom spacing. These "cold" neutrons have been applied in biological and nano-technology research. The cold source, he noted, involves 20 litres of liquid deuterium.

In closing he noted that there is considerable commercial interest in the use of neutron beams.

The next speaker, **Dr. Kathryn Higley**, Head of Nuclear Engineering and Radiation Health Physics, Oregon State University, titled her presentation: *Why Academic and Industry Research Partnerships in Small Modular and Research Reactors are Essential.*

Primarily referring to the situation of the USA she noted that the nuclear program has an ageing workforce. We are losing experience, she asserted, and the supply of qualified students in nuclear studies is not guaranteed. Then she turned to the question of research versus teaching universities. Tuition fees are increasing and government grants are decreasing, she noted, and added that faculty must generate 25 to 50 percent of their income from grants. The future of nuclear programs in state universities is uncertain, she added.

On a more positive note she mentioned that their 40-year old TRIGA reactor, which has been converted to low-enriched fuel, is widely used and is now producing some medical isotopes. They also won a $225 million grant from the Department of Energy to support their program on small and modular reactors.

The first speaker after the break was **Dr. Neil Alexander**, recently appointed Executive Director of the new Sylvia Fedoruk Centre for Nuclear Innovation, which is based on the grounds of the University of Saskatchewan, in Saskatoon.

Creation of a "centre of excellence" for nuclear research and training is the basic goal of the Centre, he said. Based on the campus of U of S the centre will be in proximity of the Canadian Light Source synchrotron and a Slowpoke reactor and have connections with the Saskatchewan Cancer Centre and related faculties of the university.

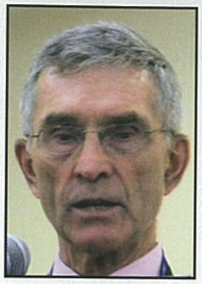
An early project will be to study the application of small, modular reactors for remote mining operations in the north of the province.

He closed with some personal comments, asking how did we lose "social licence" (public support). Then he offered some reasons, such as: over-promising but under-delivering; not emphasizing the environmental attributes of nuclear power; and dreadful use of language when dealing with the public and media.

An international view was offered by the next speaker, **Frances Marshall** from the International Atomic Energy Agency.

The IAEA lists 773 research reactors worldwide, she said, but 481 have been shut down and half of those still operating are under-utilized.

She commented that the staff at the operating reactors are ageing along with the unit Further, there is a widespread absence of purpose ar strategy, at least partly because of inadequate budget However, she added, the IAEA receives a number requests each year from countries interested in havi a small reactor for teaching and research.



Completing the list of plena speakers was **Dr. Ron Obert** President of the Organization Canadian Nuclear Industries.

SMRs (Small Modular Reactor must show they are competitive, stated. All industries are seekin lower costs. That, he suggeste requires a standardized design.

Proponents of SMRs should meet with potenti suppliers early in their planning phase, he stresse and noted that OCI had held a suppliers worksho in March of 2014. OCI member companies have th ability to make or build precision equipment and sy tems, he said, noting the complexity of the CAND pressure tube design.

He then turned to the opportunity provided by th need of Canada's remote communities for reliabl economic energy, electricity or otherwise. A majo challenge is the "up front" cost. Unlike some othe countries, such as China and Russia, there is no go ernment funding in Canada. He mentioned an effo in 2009 by the Canadian Remote Energy Corporatio but no investors could be found.

In closing he commented that Canadian supplie (OCI member companies) could be good partners wit SMR proponents.

Following lunch two parallel sessions bega one titled "Research Reactors", the other "Sma Reactors". That pattern continued into the ne day. There were 32 papers presented in the Researc Reactor sessions and 21 in the Small Reactor session

Buffet lunches were offered each day and on the eve ning of the first day a dinner was held in the rotatin restaurant at the top of the hotel.

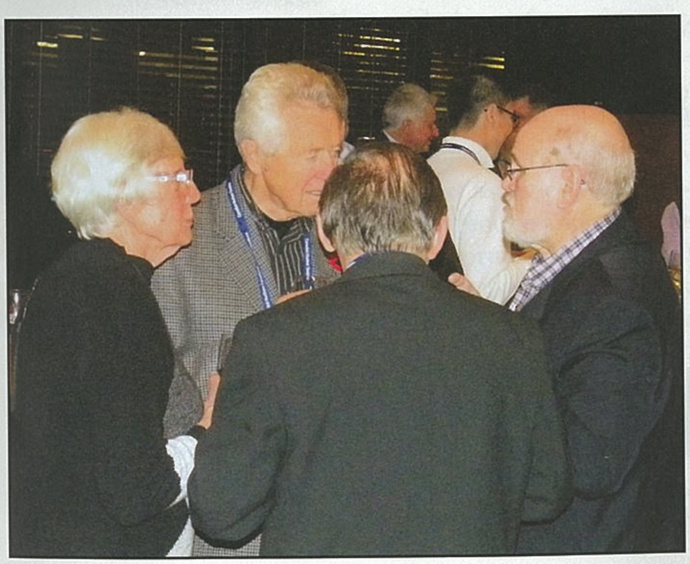
After the meeting dinner on th first evening, **Dr. John Hilborn**, long-term senior at the Chalk Rive Laboratories and renowned as th inventor of the super-safe Slowpok research reactor, gave a short talk His primary focus was the work of **Dr George Laurence** in the early 1940 who built, essentially alone, a sub-crit ical assembly of graphite and UO_2.

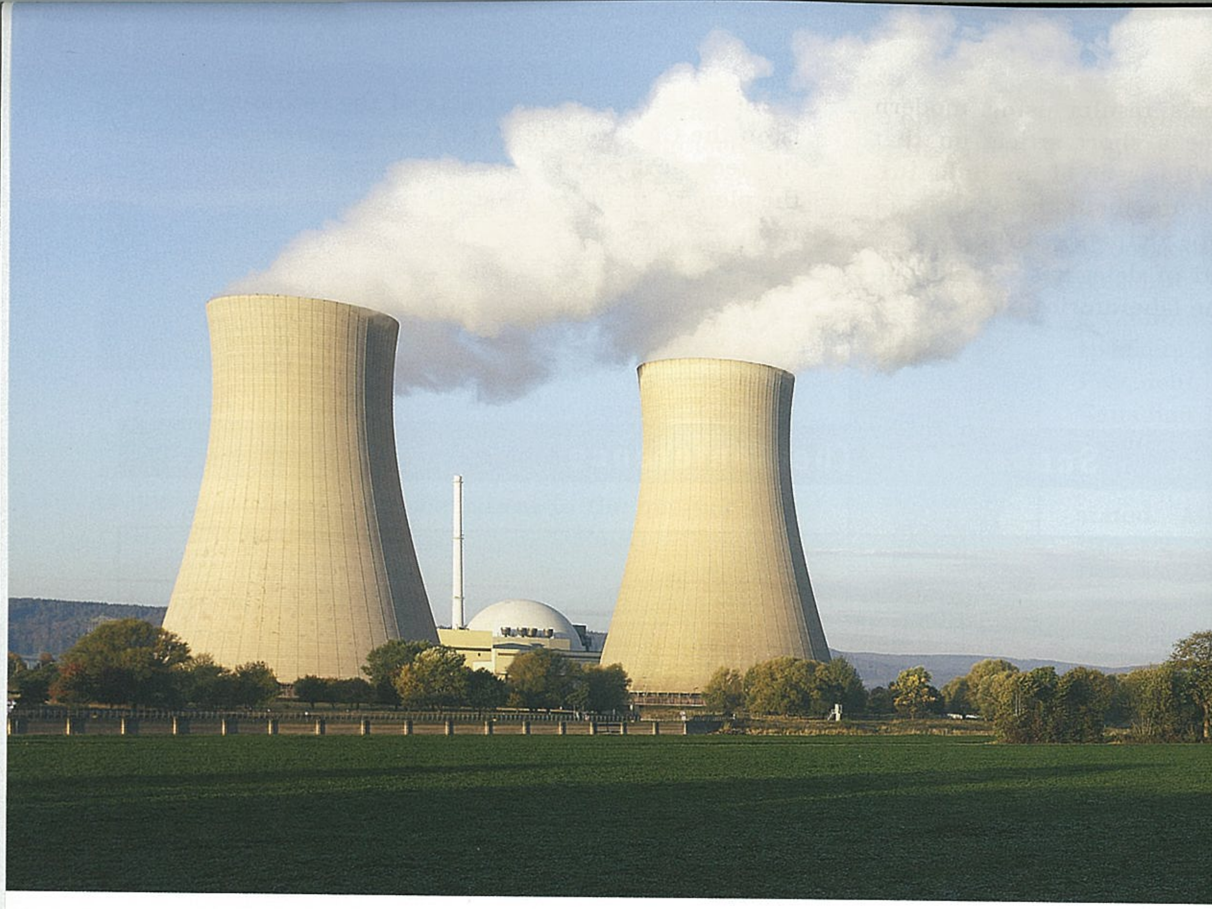
He referred to the work of two young participant of the 2014 Deep River Science Academy. Throug some prodding by CNS members who had studie Laurence's experiment, the organizers of the Dee River Science Academy included in their 2014 progran a recalculation of Laurence's results using modern core physics programs. (See a short article on that exercise in the September 2014 issue of the Bulletin). Hilborn had prepared handouts about the analysis of his assembly by two young participants of the.

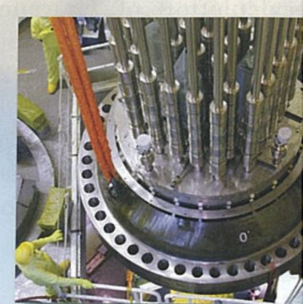
On the Friday, a bus-load of delegates travelled to Chalk River for a tour of the laboratories.

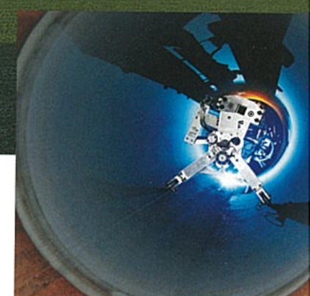
The program with abstracts of the technical papers is on the CNS website A CD was prepared containing the technical papers and the abstracts from most of the plenary speakers. That CD is available for purchase from the CNS office.

Scenes from The Conference









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Exercise Unified Response

A test of the ability of the utility and public organizations to respond to a simulated extreme event at the Darlington NPP

by FRED BOYD - based on documents presented at a meeting of the Canadian Nuclear Safety Commission,5 November 2014

Over the three days of May 26 – 28, 2014, Ontario Power Generation joined with more than 50 municipal, provincial and federal agencies in an exercise simulating a serious event at a unit of the Darlington station which was titled *Exercise Unified Response*

This was one more action in response to the Fukushima event of 2011.

The basic objectives were to:

(1) demonstrate that the emergency response of the various organizations can ensure the safety of the public and the environment

(2) test the integration of the emergency response and the ability of the participating organizations to operate together

(3) prepare a joint evaluation of the integration of the participating organizations.

Scenario

Day 1: The scenario chosen began with a simulated Loss of Coolant in Unit 4 of the Darlington station on the morning of the first day. This was initially categorized as an Abnormal Incident but subsequently changed to an On-site Emergency when radiation dose rates suggested fuel damage. Later in the morning the station received a Severe Thunderstorm Warning.

At noon an isolated tornado was assumed to hit the Darlington site knocking out the Bowmanville Switchyard, Standby Generators and Emergency Power Generators creating a station-wide loss of power.

Emergency Mitigation Equipment was used to maintain a heat-sink and safety monitoring. By the end of day 1 a heat sink was re-established. Regional, Provincial and Federal departments and agencies were notified.

Overnight the situation at Unit 4 was assumed to deteriorate with moderator level falling. Emergency equipment was successfully implemented. A further problem introduced was failure of an air-lock seal on the Vacuum Building, By the late evening the situation at Unit 4 deteriorated to the point that a release of radioactive material was anticipated.

Day 2: Based on the deteriorating situation the Provincial Emergency Operations Centre and the Federal Nuclear Emergency Plan were fully activated. The Regional Municipality of Durham activated its full public alerting system and its Regional Emergency Operations Centre. Subsequently the Province ordered Durham, to evacuate those in the zone immediately surrounding the station.

Ontario Ministry of Health and Long-Term Care ordered KI pill distribution.

By mid-day, several actors pretending to be persons worried about being contaminated showed up at the Lakeridge Health Bowmanville Hospital.

In the evening a two-hour unfiltered release was assumed causing low levels of contamination to the east of the station.

Day 3: During the third day the focus was on determining the extent and magnitude of the contamination The Regional Municipality of Durham set up an Emergency Workers Centre to process emergency workers entering and exiting the controlled zones.

The Provincial and Federal governments coordinated their survey teams. They conducted airborne as well as ground sampling.

Throughout the exercise the CNSC communicated with the USNRC and the IAEA.

Planning

The event was planned over an 18 month period by a Joint Exercise Planning Team with representatives of most of the organizations involved. The team was assisted by an Ottawa based consulting company, International Safety Research Inc.

Results

Overall, the Exercise was successful in demonstrating the basic plans of the many organizations. In particular the following plans were tested and validated:

- the Ontario Nuclear Emergency Response Plan
- the Ontario Implementing Plan for the Darlington NGS
- the Durham Region Nuclear Emergency Response Plan
- the Durham Region Evacuation and Sheltering Plan
- OPG's Consolidated Nuclear Emergency Plan
- The Federal Nuclear Emergency Plan

The CNSC staff will continue assessing the results and will be presenting suggestions and recommendations to the Commission in April 2015.

Figure 1: Exercise Locations in the Region of Durham

Table 1: Participating Organizations

Federal	
Agriculture and Agri-food Canada	Health Canada
Atomic Energy of Canada Ltd.	Natural Resources Canada
Canada Border Services Agency	Industry Canada
Canadian Food Inspection Agency	Government Operations Centre
Canadian Nuclear Safety Commission	Public Health Agency Canada
Department of Justice	Privy Council Office
Department of National Defence	Environment Canada
Department of Fisheries and Oceans	Public Safety Canada
Department of Foreign Affairs, Trade & Development	Employment and Social Development Canada
Transport Canada	
Provincial	
Ministry of Agriculture and Food / Ministry of Rural Affairs	Ministry of Government Services
Ministry Community Safety and Correctional Services	Ministry of Community and Social Services / Ministry of Children and Youth Services
Ministry of Labour	Ministry of Municipal Affairs and Housing
Ministry of Health and Long Term Care	Ministry of Natural Resources
Ministry of Energy	Ministry of Transportation
Ministry of the Environment	

Regional Municipality of Durham	
Durham Chief Administrative Officer	Durham Regional Police Service
Durham Emergency Management Office	Durham Transit
Durham Corporate Communications	Durham Health Department
Durham Emergency Medical Services	Durham Corporate Services
Durham Works Department	Durham Social Services
Durham Planning & Economic Development	Regional Fire Coordinator
Municipalities	**Local Partners**
Municipality of Clarington (includes Fire)	Lakeridge Health
City of Pickering (includes Fire)	Durham District School Board
City of Oshawa (includes Fire)	Durham District Separate School Board
City of Peterborough	Kawartha Pine Ridge District School Board
City of Toronto	Conseil Scolaire Viamonde
Utility	
Ontario Power Generation	

Nuclear Communications – A Second Opinion

As a friend and former colleague of Hans Tammemagi, I read his opinion piece "Decades of Delay in Nuclear Waste Disposal – a Failure to Communicate" and his rejoinder to the response by Shinya Nagasaki with more than a passing interest. Having worked in nuclear communications for many years, I feel that a more fundamental approach is necessary if we are to gain wide public support in the foreseeable future.

The Four Principles of Public Communication

While Tammemagi's article does contain a number of truisms about nuclear waste management, unfortunately his suggested solution adds little to advance the cause of either nuclear power or nuclear waste disposal with the general public.

None of the four principles suggested by Tammemagi for communicating with the public is new. All of them have been used for decades by senior AECL staff (including myself), who travelled the breadth of the country to talk about nuclear power in general and, later, nuclear fuel waste management. These four principles, therefore, come from the very box that the article suggests we avoid.

Certainly, communication with the public in a language that is clear and comprehensible is a vital component of the industry's drive for public acceptance, and the language should be tailored to the audience.

The remaining three principles, while useful, do not resonate strongly with the public. For example, many people understand that we live with natural radiation but they do not view that as a justification for producing more. Their argument is, rightly or wrongly, supported by the latest BEIR report. Comparisons with other industries and with common activities and practises do put things into context but do not change people's perspective on nuclear power. Finally nuclear medicine often elicits the comment that need outweighs the fear of radioactivity, and that is the only reason people accept it.

Thus, the four principles are useful, they do help broaden people's knowledge and do help maintain the status quo, but that is the extent of their effectiveness.

What to Do

I agree that nuclear fuel waste disposal will be a hard sell. The question is how to win over the public after years of rejection. Currently the focus is on a volunteer community for a waste disposal facility but, as Tammemagi points out, this has not worked in the past. What other strategies could we adopt? These strategies are not self-evident but perhaps the means of determining them are. We should dispose of all boxes and go back to first principles.

We should acknowledge that waste is inexorably linked to its source. If the source does not have popular support, then the waste will not be acceptable. So, selling nuclear waste management means first selling nuclear power. The nuclear industry has argued that waste already exists and must be disposed of. That is true, but it is no rationale for the continuation or growth of nuclear power.

We need to practise not only people-speak but also people-think. Instead of telling people what they should or should not be concerned with, as is suggested, we should listen to what they say and learn from it. We should ask ourselves "what makes something acceptable to the public?" We only need to look at the automobile to recognize the link between waste and its source. For decades, people were (and many still are) happy to ignore both the pollution that was spilling out of their exhausts on a daily basis and the thousands of deaths that occurred annually on the roads. Why? Because they were unwilling to give up the personal automobile, whatever the cost. Studying the fundamental reasons behind acceptability will give us a better understanding of the characteristics that are important for public acceptance of the nuclear industry.

We need to be honest. Denying that nuclear fuel waste is highly toxic can only damage our credibility, even if the nuclear industry is developing disposal technologies that are superior to other waste management technologies.

Selling the concept of safety for hundreds of thousands of years is a daunting task. While the benefits of nuclear technology should continue to be promoted, they will need major reinforcement to effect a change in public attitude. Studying the concept of acceptability from first principles could provide some of that reinforcement, by helping to determine the best strategy for enhancing public acceptance of the nuclear industry.

Robert Dixon

[Ed. Note: Robert spent 30 years at AECL as a research scientist and, later, Manager of Public and Government Affairs for AECL Research. He is also a former Chair of the CNS Ottawa Branch. His letter has been edited for length.]

Biophysics at the Intersection of Health Science and Nuclear Technology

by DREW MARQUARDT[1], RICHARD J. ALSOP[2], MAIKEL C. RHEINSTÄDTER[2] and THAD A. HARROUN[1]

[Ed. Note: The following paper was presented at the 3rd International Technical Meeting on Small Reactors, held at the Ottawa Marriott H November 5-7, 2014.]

Abstract

We're all on a quest for improved heart health, but what do we really know about it? A daily regimen of aspirin can help some people with heart disease. We need to lower our cholesterol, and increase our intake of omega fatty acids. There is simply no health benefit to taking extra vitamin E, and it's not known why. Apart from cardiac tests with radiopharmaceuticals, what role does nuclear technology play in this story? It turns out that cold and thermal neutrons are important tools for the biophysicists studying these topics. We will review some recently published studies that are advancing our understanding of how cholesterol, vitamin E, and aspirin all work at the molecular level, inside the membrane of our cells. These insights could not have been learned without access to research reactor neutron beams such as those at the Canadian Neutron Beam Centre, and how this new knowledge has really engaged the broader health science community into new ways of thinking about these molecules.

1. Introduction

The molecular mechanism by which drugs and nutrients interact with the membranes of our cells has become a central issue in pharmacological sciences. Cellular membranes are complex assemblies that are much more than simple permeable barriers or passive substrates for proteins. Rather, they play an active role in many cellular functions, and they have a rich metabolism of their own. Many of these functions rely on a diverse array of lipids, vitamins, sterols, proteins and carbohydrates.

One area of particular interest for the health of Canadians is cardiovascular diseases, which are the leading cause of death in adult Canadians. Of the six types of cardiovascular diseases highlighted by Health Canada, ischemic heart disease is the leading cause of death, account- ing for 54% of all cardiovascular deaths [1, 2]. Ischemic heart disease occurs when the blood supply to the heart muscle (myocardium) is cut off. Commonly, ischemia is a result from the accumulation of cholesterol-rich plaques in the coronary arteries (atherosclerosis).

The blockage of blood flow is not the only life threatening condition, which arises from ischemia. When treated, the restoration of the blood supply (reperfusion) can cause further damage to the myocardiu through oxidative stress, specifically free radi damage. The damage done during blood restoration known as ischemia-reperfusion injury and also occ during surgery when blood vessels are cross-clam [3]. Ischemia-reperfusion injury has been extensiv studied, but the underlying molecular mechanisms the pathology and treatments remain a mystery [4

Below we discuss the role neutrons have played in understanding of three small molecules with signific implications in the cause (cholesterol), preventat measure (aspirin) and recovery (vitamin E) of m cardium ischemia and reperfusion injury. Most in estingly, the availability of neutron beams is crucial obtain molecular level information in these systems

2. The Need for Neutrons

Compared to other biophysical techniques, neut scattering offers many advantages for the study of b logical systems at the atomic level. Firstly, it does rely on bulky fluorophore or spin label probes, wh can drastically alter the physical properties of mo membrane systems. Instead, neutrons scatter from e light elements (e.g., H, C, N, O, etc.) commonly fou in biological systems, and are able to distinguish betw isotopes of the same element, with the substitution hydrogen for deuterium being commonly used to s tematically manipulate contrast, as shown in Figure and 2 [5]. Scattering from individual components of system (i.e. lipid, solvent or protein) can be suppress through contrast matching, allowing for robust deter nation of bilayer organization, as shown in Figure 2.

3. Cholesterol

In mammalian cells, as much as 90% of all chol terol can be found in the plasma mem- brane [1 Cholesterol has been well established as a media of cell membrane fluidity. By interacting with lip tails, cholesterol causes the membrane tails to be co strained thereby reducing membrane fluidity.

1 Department of Physics, Brock University, St. Catharines, Onta Canada.

2 Department of Physics and Astronomy, McMaster Univers Hamilton, Ontario, Canada.

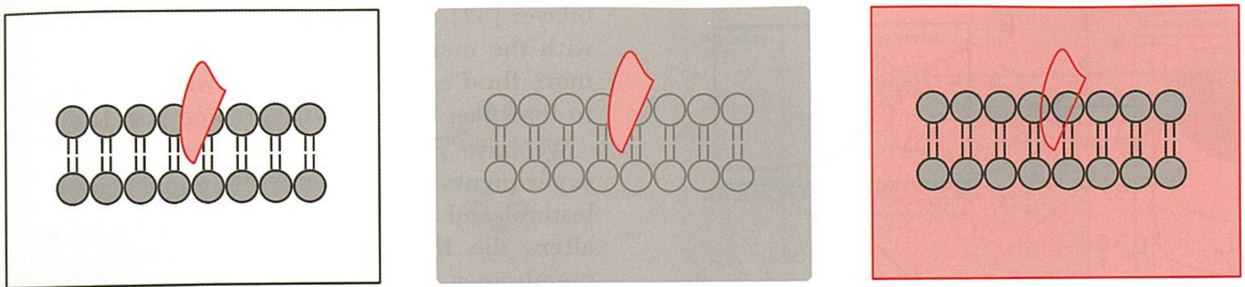

Figure 1: Schematic of possible neutron contrast variation experiments for a membrane (gray) with a protein inserted (pink). The left diagram represents the system with no contrast matching. The protein is highlighted in the centre diagram when the solvent (water) is contrast matched to the lipid bilayer. Membrane properties can be studied the diagram on the right when the solvent (ie. water) is contrast matched to the protein.

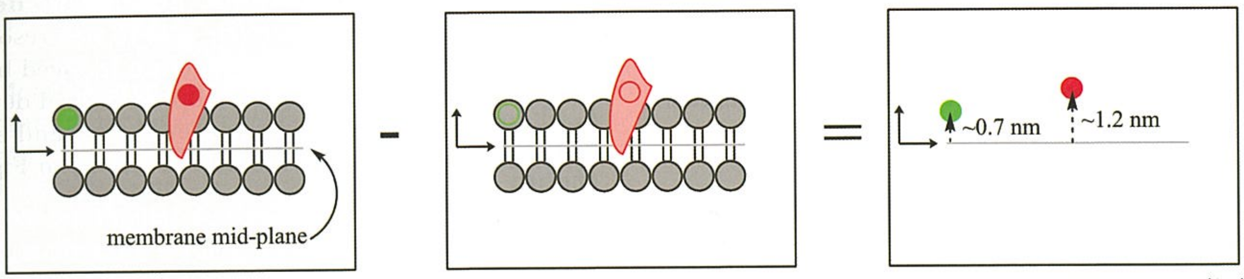

Figure 2: Biological systems have an intrinsic ability to be labeled due to the abundance of hydrogen (^{1}H) atoms that can be replaced (labeled) by deuterium (^{2}H). The substitution of deuterium atoms for hydrogen, at selective locations, provides contrast between the "labeled" sample (left) and the "unlabeled" sample (middle). The difference in scattering length density between the labeled and unlabeled sample yields the precise location and distribution of the ^{2}H label (red circle, right).

The action of cholesterol's membrane mediation is observed through the formation of highly ordered domains (patches) of membrane enriched with cholesterol, as depicted in Figure 3. Interestingly these patches are a unique lipid phase which requires the presence of cholesterol and is named the liquid ordered phase (L_o). The cholesterol poor counterpart to L_o is the thinner and more disordered liquid disorder (L_d) phase. At high concentrations of cholesterol, immiscible cholesterol bilayers may form [15, 16]. These cholesterol 'plaques' often occur in people with elevated cholesterol, and play a role in diseases such as atherosclerosis [17].

A study of nanosized domain formation in free-floating bilayers was conducted by Heberle *et al.* by **small angle neutron scattering.** In order to mimic a complex biological membrane, this pioneering study examined four-component model systems containing a saturated phos- pholipid, varying ratios of mono- and di-unsaturated phospholipid and a constant cholesterol concentration for the presence of domains [18]. Domain sizes were found to increase with unsaturation (di-unsaturation : mono-unsaturation ratio) but more interestingly there is a direct correlation between the domain size and the bilayer thickness mismatch of L_d and L_o. These results were one of the fi probe-free to observe these cholesterol rich nanodomains, as well as the fi to demonstrate how functional domains in cells may be regulated through changes in phospholipid composition.

Armstrong *et al.* has observed the existence of cholesterol induced highly ordered lipid domains within the L_o phase of a binary phospholipid:cholesterol system [19]. Using **coherence length dependent neutron diffraction,** the authors were able to, unambiguously and for the first time, resolve signals of L_o domains from L_d regions. In single phospholipid systems Lo was believed to be a homogeneous phase. In addition to the presence of these ordered domains existing Armstrong determined, for the fi time, dynamic properties cholesterol imposes on the L_o and did so before the formal observation of these domains [20, 21]. The nanoscale dynamics L_o were observed using an **in-elastic neutron scattering technique,** which does not rely on the use of bulky and perturbing probes. The domains in the cholesterol induced L_o phase appeared softer than the L_d phase, with a reduced membrane viscosity, but were more ordered than the gel phase. It is believed that cholesterol's "property amplifying" ability is one of the the driving forces for the formation of the hypothetical lipid rafts.

These studies, for the first time, give a detailed molecular picture of the fluid structure of lipid membranes. Cholesterol leads to the formation of ordered patches, which are enriched with cholesterol, and

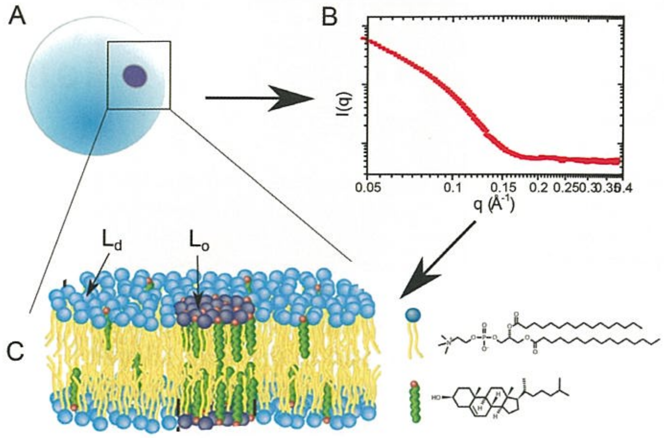

Figure 3: A) Lipid vesicle containing L_o domains. B) Small angle neutron scattering (SANS) curve which contains structural information about the bilayer as well as bilayer organization. C) Schematic of the membrane information contained within the SANS curve.

drastically different properties as compared to their surroundings. This change in membrane homeostasis has been shown to lead to reduced health in individuals with high cholesterol. Some of the reduced health effects include high blood pressure and hypertension, which increases the risk for ischemic heart disease.

4. Aspirin

A common treatment for the prevention of ischemia related events, in individuals with in- creased cholesterol levels, is a daily low-dose of acetylsalicylic acid (aspirin) [22, 23].

Unlike α-tocopherol, aspirin has long been associated with specific interactions when introduced into the body. Aspirin interacts with the cycloxygenase (COX) pathway, inhibiting platelet aggregation [24]. In patients with high cholesterol, a reduction in platelet aggre- gation can decrease the incidence of blocked arteries and reduce the chance of myocardial events [25]. This was long believed to explain the low-dose aspirin therapy. Recently, the role of the COX pathway in the low-dose aspirin therapy has been called into question, given the growing awareness of so-called "aspirin resistance" [26]. Platelets from aspirin resistant patients often appear unaffected by the drug, likely through COX independent mechanisms [27]. The confusion surrounding aspirin has been recently discussed in the media [28].

At the same time, there is an increasing evidence for a role of the lipid membrane structure and composition in platelet function [29]. Aspirin has recently been shown to strongly interact with membranes, both real and synthetic, residing in the lipid headgroup region [30, 31]. In particular, when introduced in model membranes, aspirin has been shown to dissolve harmful cholesterol plaques leading to a more fluid, healthy bilayer [32]. In addition, aspirin is believed to inte with the membranes of red blood cells, making t more fluid and compressible, which could allow t to flow past barriers with greater ease [33].

We have recently performed **neutron diffract** experiments on model membranes containing lesterol and aspirin. The data suggests aspirin loc alters the lipid environment when introduced membranes. By interacting with lipid headgro aspirin is able to increase lipid fluidity and compr ibility, opposing the effect of cholesterol. By work against the effects of cholesterol, aspirin is able to f trate the formation of lipid domains, fundament changing the membrane's structure and organizat Using the **coherence length dependent neut diffraction** technique, we were able to well resolve nano scale changes in lipid structure induced by a rin. Neutron diffraction gives unprecedented detail the molecular organization in membranes and ena us to develop molecular models, as shown in Figur

5. Vitamin E

There is simply no clear evidence for the he benefits of supplementing our diets with additio vitamin E (α-tocopherol), except of course, for spec deficiency syndromes [6]. This is true whether for g eral heart-health, or as part of conventional treatme of conditions such as ischemia-reperfusion injury. T despite in the case of myocardial ischemia reperfus injury, where maintaining redox homeostasis is piv in the survival of victims [7].

Tocopherol pretreatment is often used to prev myocardial ischemia reperfusion injury in the case bypass surgery patients [3]. However, diff t stu examining the benefits of tocopherol pretreatm yield contradictory results [3, 8]. What is missing clear molecu- lar mechanism of vitamin E antioxid action in a cellular membrane, or if such antioxid action exists *in vivo* at all. This is especially true w considering the conflicting data in the literature. example, some argue that it functions as an anti dant, while others argue from the same evidence t it has some other, not yet identified task. For examp Traber and Atkinson write: "...all of the observati concerning the in vivo mechanism of action of α copherol result from its role as a potent lipid-solu antioxidant" [9]. However in the same journal iss Azzi takes the counter argument that "... α-tocophe is not able, at physiological concentrations, to prot against oxidant-induced damage..." [10].

Recently we have shown evidence of an antioxid mechanism for α-tocopherol, which correlates stron with its physical location in a model lipid bilayer [11]. ' data addressed the overlooked problem of the physical tance between the vitamins reducing hydrogen and li

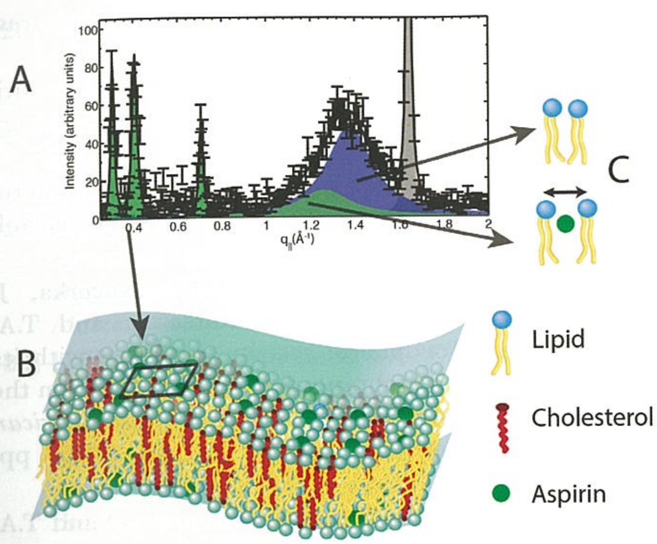

Figure 4: A) Neutron diffraction data obtained from model membranes containing cholesterol and aspirin. B) A 3D cartoon of a membrane containing cholesterol and aspirin, as determined by the neutron data. The cartoon highlights the regular distribution of aspirin(dark square on the membrane), leading to the frustration of lipid raft structures C) Cartoons highlighting the altered lipid environments introduced by aspirin. Aspirin interacts with the lipid headgroups leading to an increase in lipid tail separation, and an increase in lipid fluidity.

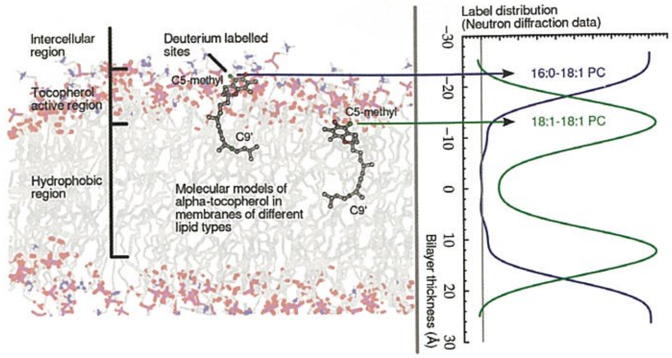

Figure 5: Schematic of α-tocopherol in a model lipid membrane as determined by neutron diffraction. The zone of α-tocopherol antioxidant action is confined to the region of the glycerol ester and above, extending practically to the aqueous phase. Although α-tocopherol can either terminate a lipid radical or intercept diff reactive oxygen species, its diff t locations within bilayers correlate well with its primary activity.

acyl chain radicals. Our combined data from **neutron diffraction,** nuclear magnetic resonance (NMR) spectroscopy, and ultraviolet (UV) spectroscopy studies all suggest that reduction of reactive oxygen species and lipid radicals occurs specifically at the membrane's hydrophobic-hydrophilic interface, as shown in Figure 5. Such a conclusion has eluded scientists for decades because no one had yet determined the location α-tocopherol with precision until we applied neutron diffraction with **deuterium labeling.**

A follow up study determined, by means of **small angle neutron diffraction,** that not only is α-tocophero's hydroxyl group located high in the membrane, but its tail also resides far from the center of bilayers of 1-palmitoyl-2-oleoyl-sn-glycero-3-phosphocholine (POPC) [12]. In addition, Marquardt *et al.* located the hydroxyl group of α-tocopherol above the lipid backbone in 1-palmitoyl-2-oleoyl-sn-glycero-3-phosphoethanolamine (POPE), 1-palmitoyl-2-oleoyl-sn-glycero-3-phospho-L-serine (POPS) and sphingomyelin, suggesting that α-tocopherol's location near the lipid-water interface may be a universal property of the vitamin [12].

Another important result which has originated from thermal neutron scattering was determining the location of vitamin E in the prototypical lipid dimyristoyl–phosphatidylcholine (DMPC). Without exception, the data point to α-tocopherol's active chromanol moiety residing deep in the hydrophobic core of DMPC bilayers, a location that is in stark contrast to α-tocopherol's location in other lipids. The discovery of α-tocopherol's residence in the centre of a DMPC bilayer explains some of the conflicting and inexplicable data found in the literature regarding α-tocopherols behaviour in DMPC bilayers versus other phospholipid bilayers [13].

6. Concluding Remarks

In this paper, we hope to have shown that neutron beams are an indispensable tool for cutting-edge research in molecular biology and pharmaceutical sciences.

Biological themed research remains a small and slowly growing component of the science conducted at neutron beam facilities. Annual report data from the Institut Laue-Langevin (Grenoble, France) tracks growth in experimental proposals classified as "biology" from 6% in 2002 to 10% in 2013. However, many experiments classified as "soft condensed matter" often have applications in biochemistry and molecular biology, and including these, as many as 1 in 8 instrument-days at the ILL is devoted to science involving some biologically related material.

One reason for the slow growth of using neutrons for biological research is the difficulty of new knowledge breaching the wall separating biology from neutron physics. Translating the results described above to clinical use is a daunting challenge, as these results are guided by methods and techniques drawn more from physics, and are far removed from petri dishes and cages of biochemical and animal research.

Most of these experiments are guided by physics-trained biophysicists, working in collaboration with colleagues from biochemistry and biology departments. Ultimately, it will be up to these biologists to flesh-out the theories necessary to reach clinical application.

However, we continue to recruit biochemists and biologists to consider conducting neutron beam experiments. Insights such as these shown above afford physiologists a molecular picture otherwise unattainable without the use of neutrons. One important way to make entry into this field easier for biologists lay outside the research reactor.

Deuterium plays an important role in neutron scattering for biology, and to that end many neutron beam laboratories have established their own ancillary laboratories dedicated to the incorporation of deuterium into biological molecules and systems.

For example, the Center for Structural Molecular Biology at the Oak Ridge National Laboratories (utilizing the High Flux Isotope Reactor) established the Bio-Deuteration Lab for this express purpose. The European Photon and Neutron Campus (EPN-campus), home of the Institut Laue-Langevin reactor, now shares its grounds with the Institut Biologie Struc- turale, and through the Partnership for Structural Biology, has established the Deuteration Laboratory platform (D-LAB).

It is thought that with a better knowledge foundation of how to incorporate deuterium into biological materials, more biologists will feel free to design more interesting neutron experiments. This also has the additional benefit that this knowledge will also help those researchers using nuclear magnetic resonance techniques.

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Publication

IAEA Publication

Small Angle Neutron Scattering – IAEA TECDOC 1486

Language: English

Small angle neutron scattering (SANS) is a powerful non-destructive technique to study the inhomogeneities formed during the synthesis of materials such as ceramics, cements and alloys. The method is useful for studying large molecules such as polymers, biomolecules or magnetic domains which have applications in materials development. This publication presents the work and results of an IAEA Coordinated Research Project focusing on the development of components like collimators, monochromators and position sensitive detectors, for improving the throughput of the instruments, fostering the effective utilization of research reactors and establishing links between developing and developed facilities. The publication will be of interest to the users and operators of research reactors wishing to develop an instrument and foster collaborations for capacity building.

The 25 MW Super Near Boiling Nuclear Reactor (SNB25) for Supplying Co-Generation Energy to an Arctic Canadian Forces Base

by H.W. BONIN, S. PAQUETTE and P.J. BOUCHER[1]

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Abstract

Nuclear energy represents a better alternative for the supply of heat and electricity to the Canadian Forces bases in the Arctic (CFS Alert and CFB Nanisivik). In this context, the Super Near-Boiling 25-MW_{th} reactor (SNB25) has been designed as a small unpressurized LWR that displays inherent safety and is intended to run in automatic mode.

The reactor employs TRISO fuel particles (20% enrichment) in zirconium-sheathed fuel rods, and is light water cooled and moderated with a normal output temperature is 95°C at atmospheric pressure. Control is via 133 control rods and six adjustable radial reflector plates. The design work used the probabilistic simulation code MCNP 5 and the deterministic code WIMS-AECL Version 3.1, permitting a code-to-code comparison of the results. Inherent safety was confirmed and is mostly due to the large negative void reactivity coefficient of -5.17 mk per % void. A kinetic model that includes thermal-hydraulics calculations was developed to determine the reactor's behaviour in transient states, and the results further confirm the inherent safety. Large power excursions temperatures that could compromise structural integrity cannot be produced. If the coolant/moderator temperature exceeds the saturation temperature of 100°C, the coolant begins to boil and the large negative void coefficient causes the reactor to become subcritical in 0.84 seconds.

The SNB25 reactor's core life exceeds 12 years between refuellings. A group of 4 SNB25 reactors meets both the heating and electricity requirements of a base like CFB Nanisivik via a hot water network and through an organic Rankine cycle conversion plant.

1. Introduction

The Canadian Forces are in the process of refurbishing the energy systems for their bases and stations. In addition, special attention is given to existing and projected bases in the Arctic (Alert and Nanisivik) in order to increase the Canadian presence in this remote part of this country and affirm the Canadian sovereignty in this rugged region. Because these military establishments are located too far from existing energy networks (electricity and natural gas), reliance on fossil fuels such as heating oil and diesel fuel for electricity generators must be minimized for costs and logistic reasons. In this context, nuclear ene provides an option that deserve consideration for supply of reliable heating and electrical energy.

The objective of the present research is to design a sn nuclear reactor able to provide 25 MW_{th} safely and relia The design is initiated on that of the NB (Near Boilin MW_{th} nuclear reactor designed to provide "hotel pow on-board of Victoria-class submarines of the Canad Navy [1]. The design of the SNB25 reactor is wa such as to maintain inherent safety. The reactor is ba on well known TRISO fuel particles [2] with a maxim 20% enrichment to respect the Non-Proliferation Tre The TRISO particle was developed in the early 1970s High Temperature Cooled Reactors and Pebble-Bed re tors, and consists in a few mm diameter fuel kernel m of UO_2 or UCO surrounded by four layers: porous carb buffer, inner Pyrolytic carbon, Silicon Carbide and ou Pyrolytic Carbon. In the SNB25 reactor, the TRISO pa cles are contained inside leak-tight Zircaloy sheathing w helium used as a filling gas.

2. Reactor Design and Simulati

The design of the SNB25 reactor was carried using two well-proven computer codes: the probabilis MCNP 5 simulation code and the deterministic WIM AECL Version 3.1 code. MCNP5 (Oak Ridge Natio Laboratory) [3] is a general-purpose 3-D coupled n tron/photon/electron transport code based on the Mo Carlo probabilistic method. WIMS- AECL 3.1 (Ato Energy of Canada Ltd) [4] is a deterministic 2-D mu group neutron transport code for multi-cell lattices w the possibility of performing fuel burnup calculatio and neutron leakage corrections. Since there are actual SBN25 reactors already built, validation of results of either codes with experimental measurem is not presently possible, but verification of the resu of one code against the other permits confidence in t accuracy of the simulations. Figures 1 and 2 and Tab 1 and 2 below present the main features of the SNB reactor with a comparison with the NB reactor.

Absorber and regulatory control rods provide long te burn-up and reactivity control respectively. A total of 1 hafnium control rods provide enough negative reactiv

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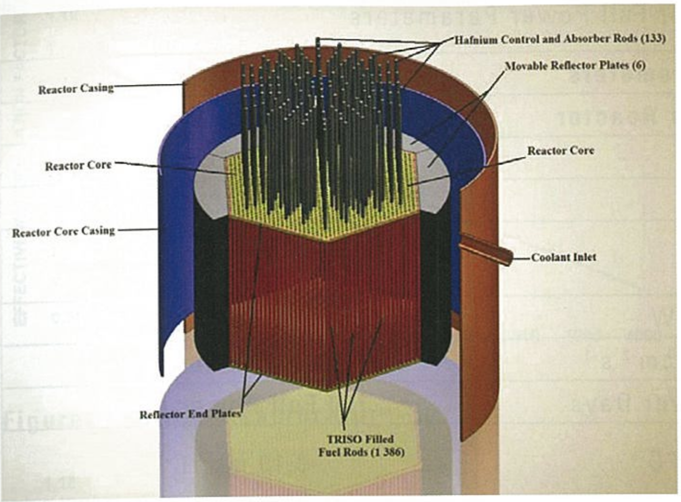

Figure 1: Configuration of the SNB25 nuclear reactor.

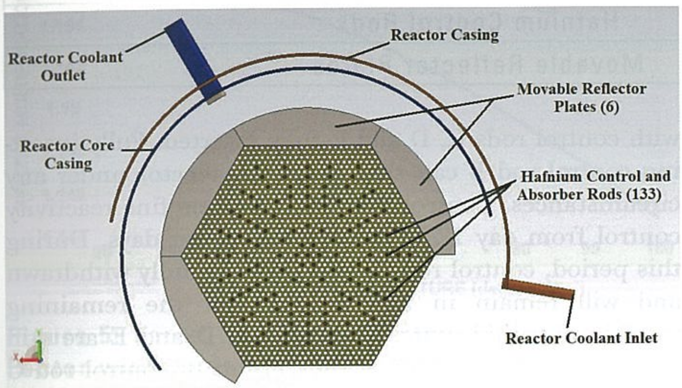

Figure 2: SNB25 Nuclear Reactor Top View.

to maintain the reactor subcritical in a "clean cold start scenario" with the reflector plates against the core. The control rods are divided into 5 distinctive banks, namely Control Rod A, B, C, D and E. A bank consists of a specific number of control rods connected to a common spider.

As far as the operator and control system computer are concerned, the SNB25 reactor is fitted with only 5 control rods. The 1,386 fuel rods are cooled by light water entering the space between the reactor casing and the reactor core casing and flowing down to reach the bottom of the reactor core. The water would then flow upward and be heated by the fuel rods to exit the core at its top and flow out via the reactor coolant outlet.

3. Burnup Control

An overall control strategy, projected over the expected life of the SNB25 reactor core, is based on the six adjustable beryllium plates that serve as the radial reactor reflector. At first reactor start-up, the core is freshly fuelled and the reactor operates under full power conditions, and the reflector plates are 5 cm away from the core; control rods B, C, D and E are fully inserted and act as absorber rods. The reactor's available excess reactivity is then 6.25 mk (below prompt critical). A reactivity of 1 mk is equal to 0.001 dk/k = 100 pcm = 15.4¢ for a U-fueled reactor. Control rod A provides regulatory control and is inserted 22% of its full length. The on-line reactivity is nil (k_{eff} is 1) and the SNB25 reactor outputs 25 MW_{th}. The gap between the reflector plate and the core, as well as the void created by the removal of control rod A, is filled with coolant (light water). As the fuel burns and fission products accumulate, the control system gradually removes control rod A from the reactor in order to maintain the system critical. Inserting control rod A by more than 22% would shut down the reactor at any time. The saturating fission products reaching steady state (saturation) in the fresh fuel cause a large drop of reactivity in the first few days of the reactor operation. After 18 hrs, the excess of reactivity is near 0. The reflector plates are then shifted inward by 2.25 cm (located at the 2.75 cm position) and the reactivity value

Table 1: SNB25 and NB Reactor Specifications

Physical Characteristics		
Description	**SNB25 Nuclear Reactor**	**NB Nuclear Reactor**
Core Arrangement	Hexagonal	
Core Outer Radius	93.9 cm	39 cm
Core (Fuel Rods) Height	150 cm	80 cm
Number of Fuel / Control Rods	1,386 / 133	318 / 13
Core Casing Material (Thickness)	AISI Plain Carbon Steel (2 cm)	
Coolant/Moderator	Light Water	
Fuel (Enrichment)	Uranium Oxide TRISO Fuel Particles (20 weight%)	
Fuel Mass ^{235}U	300 kg	16.43 kg
Fuel Rod Diameter (Pitch)	3 cm (4.2 cm)	2.5 cm (4 cm)
Control Rod Material	Hafnium	
Reflector (Thickness)	Beryllium (15 cm)	Beryllium (20 cm)

Table 2: SNB25 and NB Reactor Full Power Parameters

Operating Parameters		
Description	**SNB25 Nuclear Reactor**	**NB Nuclear Reactor**
Maximum Fuel Temperature	120°C	102°C
Reactor Inlet Coolant Temperature	30°C	52°C
Reactor Outlet Coolant Temperature	95 °C	
Thermal Power	25.03 MW	1.1 MW
Average Thermal Flux	3.75×10^{12} n cm^{-2} s^{-1}	2×10^{12} n cm^{-2} s^{-1}
Core Life	4,270 Full Power Days	750 Full Power Days
Moderator Temperature Coefficient	-0.11 mk °C^{-1}	-0.19 mk °C^{-1}
Void Fraction Coefficient	-5.17 mk per % of void	-3.9 mk per % of void
Fuel Temperature Coefficient	-9×10^{-4} mk °C^{-1}	-7×10^{-3} mk °C^{-1}
Regulatory and Shut Down Control	Hafnium Control Rods	
Burn-up Control	Movable Reflector Plates	

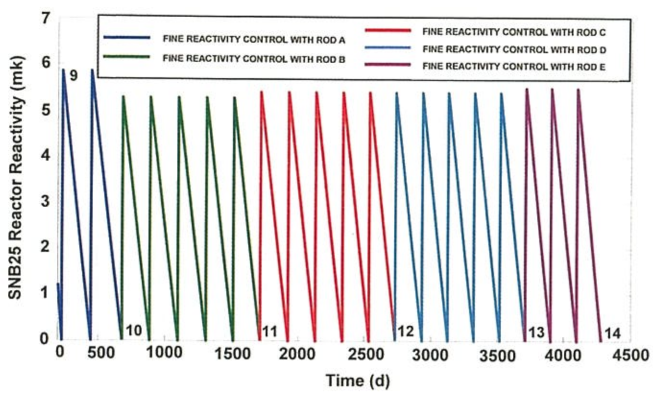

Figure 3: SNB25 Reactor Reactivity (From Day 200 to Day 4,283).

increases to 5.85 mk. This excess of reactivity drops near the critical value 10 days later and the reflector plates must be moved to the 1.65 cm position to bring it back to 5.85 mk. After 82 days of operation, the excess reactivity approaches zero and is increased to 5.85 mk by moving the reflector to the 1.1 cm position. It will take another 149 days for the reactor to become near critical and once again, the reflector is moved to the 0.55 cm position. This process continues for the entire life of the reactor core. Prompt critical state will never be reached with this control strategy. Following the saturation of the fission products, the reactor can operate up to 7 months with the reflector plates in a specific position.

After a total of 680 full power days of operation, the reflector plates are against the core, and the excess of reactivity is near 0. At this point, control rod A will be fully withdrawn and will remain in this position for the remaining life of the reactor core. Fine reactivity control will be assumed by control rod B for the next 1,036 days, with control rods C, D and E fully inserted. Fully in ing control rod B can shut down the reactor under circumstances. Control rod C will assume fine react control from day 1,716 for 820 full power days. Du this period, control rods A and B will be fully withdr and will remain in this position for the remai reactor operating years. Control rods D and E are fully inserted. Like control rods A and B, control ro is capable to bring the SNB25 reactor to a sub-cri state at any time. This process continues for the en life of the reactor. Therefore, control rod E will pro reactivity control from day 3,711 to day 4,283. Du this operating period, all remaining control rods wi withdrawn and maintained in this position unless t full insertion is needed in an emergency shut-down o reactor. The flexibility of the control system also al for positive reactivity to be inputted if required. In event that the SNB25 reactor needs to be restarted in hours following a normal shut down, shifting the re tor plates inward and/or removing one or more con rods from the core can provide a "boost of reactiv in order to overcome the saturating fission product soning effects. Figure 3 illustrates the variation of reactor's excess reactivity along this operating strate

The control rod configuration is safe, simple and vides an important amount of redundancy with little o ator intervention required. With the exception of Con Rod A, all control rods first act as absorber rods and th are used for fine reactivity control. Once a control has been used for fine reactivity control, it is comple removed from the reactor core and becomes in a stan mode. This control rod is not expected to be used ag during normal reactor operation, but remains availabl a reserve of negative reactivity. As an example, during sixth year of operation, Control Rod C will be used for

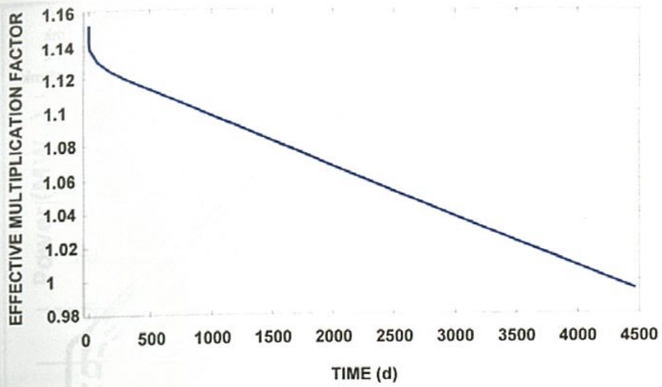

Figure 4: SNB25 Reactor Burn-up.

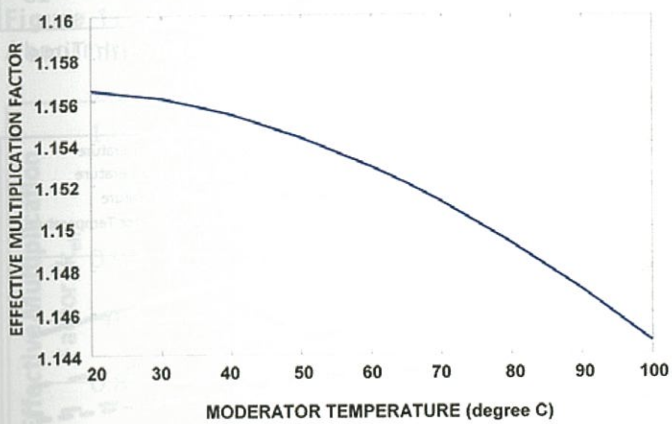

Figure 5: Variation of the Effective Multiplication Factor with Moderator Temperature.

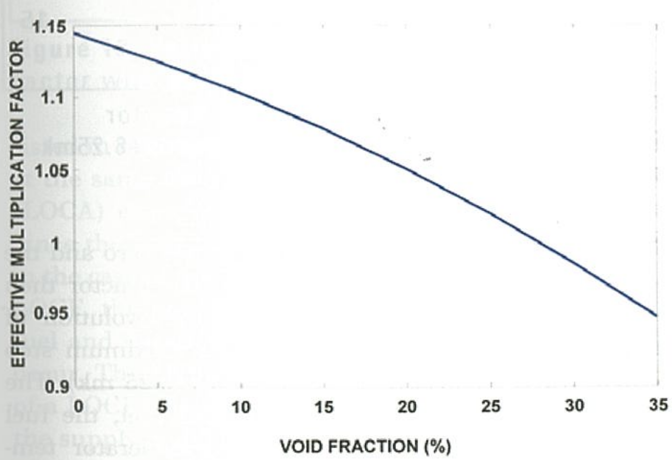

Figure 6: Variation of the Effective Multiplication Factor with Void Fraction.

reactivity control. Control Rods A and B will be completely removed from the core, in a stand-by mode. Control Rod C is capable to shut down the reactor by itself, however, inserting Control Rods A and B with C would provide more negative reactivity, resulting in a quicker drop of the neutron flux in the case of an emergency shutdown (SCRAM). According to the Canadian Nuclear Safety Commission (CNSC) requirements for reactors licensing, the SNB25 reactor must be fitted with two independent, fast acting, safety shutdown systems. The SNB25 reactor is currently fitted with 133 hafnium shutdown rods capable of shutting the reactor down under any circumstances. A secondary independent shutdown system, involving the injection of a high pressure poison such as gadolinium nitrate into the low pressure moderator could easily be fitted (CANDU reactors are provided with such an emergency shutdown system that injects rapidly gadolinium nitrate into the D_2O moderator).

4. Toward Inherent Safety

Figure 4 below shows how the effective multiplication factor evolves as the reactor accumulates fluence from initial start-up. The burn-up evaluation at Figure 4 shows that there is ample excess reactivity for the SNB25 reactor system to remain critical for over 4,270 full power days. Calculations for the moderator temperature and void fraction coefficients are based on Figures 5 and 6. These curves are generated from reactivity calculations carried with both WIMS-AECL and MCNP5 codes for several moderator temperature and void fraction values. The reactivity coefficients are determined from the gradients of these curves. The moderator temperature reactivity coefficient is -1.1 x 10^{-4} K^{-1} (-0.11 mk K^{-1}) over a range of moderator temperature from 20°C to 100°C. As seen in Figure 5, this coefficient becomes more negative as the moderator temperature increases: a very desirable feature toward inherent safety. The void fraction coefficient (Figure 6), which represents the change in reactivity per increase in void fraction, is -5.17 x 10^{-3} per % of void (-5.17 mk per % of void) over a range of void fractions from 0% to 35%. These strong negative coefficient values are essential, but not sufficient, conditions for inherent safety.

5. SNB25 Simulation in transient states

In order to determine whether the SNB25 is inherently safe, a point kinetic model has been developed to predict the time behavior of the reactor in transient states. A 6-delayed neutron group kinetic model was used, resulting in a set of 7 differential equations solved by MATLAB [5]. Step positive reactivity insertions from +1 mk to +6.25 mk were simulated. Thermalhydraulics equations as described in Glasstone & Sesonske, Chapter 6 [6], were used to determine the temperatures of the reactor components and the reactor power as time progresses following the step reactivity insertion using a quasi-static approach. The full power operating conditions for the SNB25 is a 25 MW_{th} thermal power output with the coolant outlet temperature at 95°C (368.15 K), the Zircaloy sheath temperature at 95.5°C (368.65 K) and the average fuel temperature at 120°C (393.15 K), all these temperatures well below the point where any structural damage can occur. Of course, the k_{eff} is equal to 1. Figures 7 to 10 show how several of the key parameters of the reactor evolve with time follow-

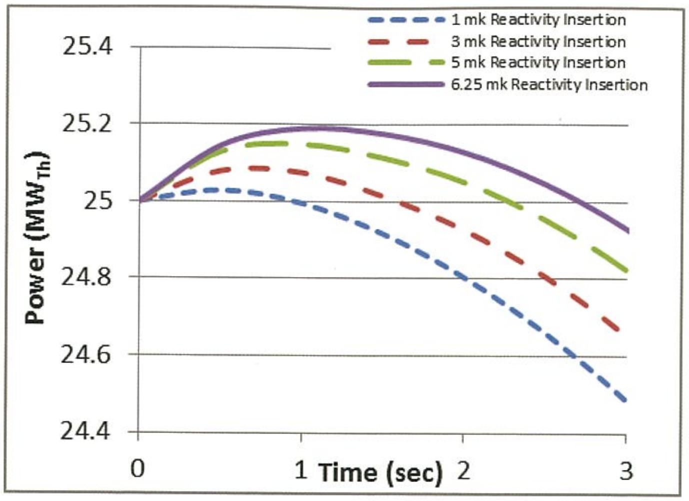

Figure 7: Variation of Reactor Power with Time for Positive Step Reactivity Insertions.

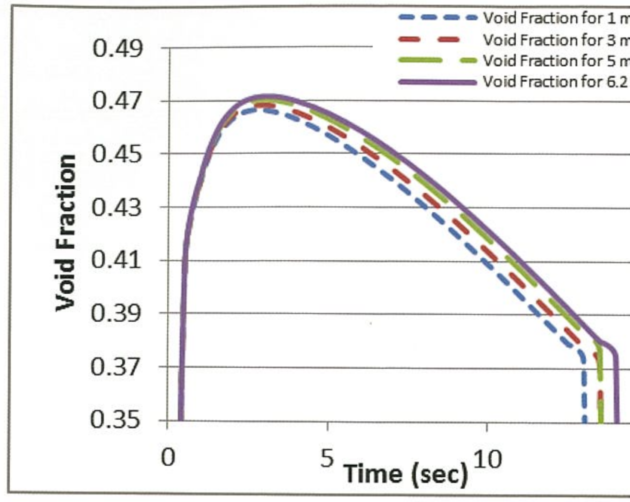

Figure 8: Variation of the Void Fraction with Tir for Positive Step Reactivity Insertions.

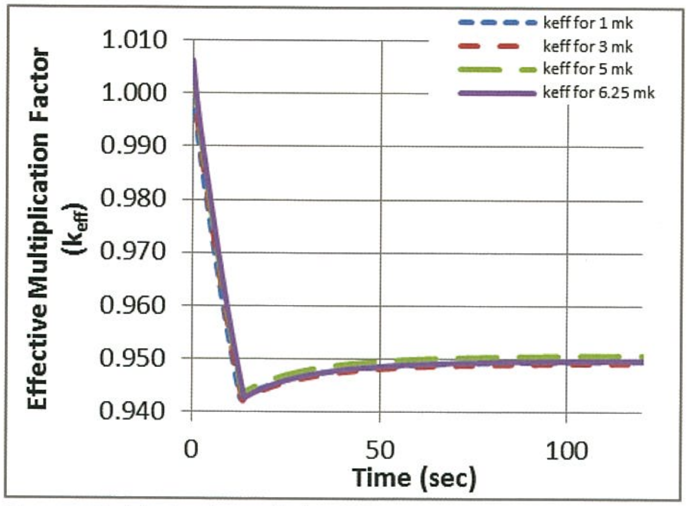

Figure 9: Variation of the Effective Multiplication Factor with Time for Positive Step Reactivity Insertions.

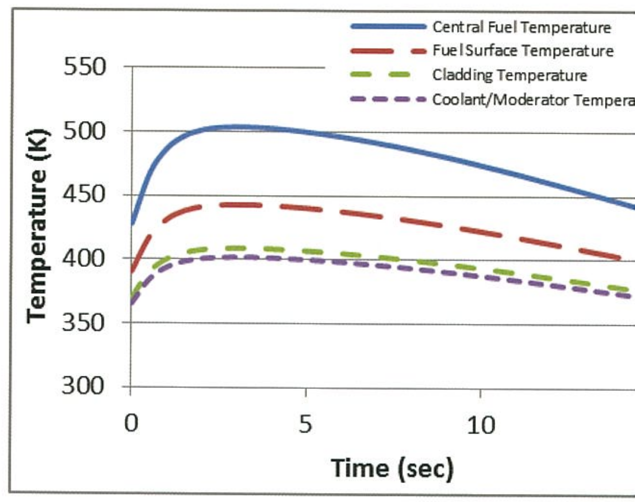

Figure 10: Variation of the Average Reactor Component Temperature with Time for a +6.25m Step Positive Reactivity Insertions.

ing a step insertion of reactivity when the reactor was in operation at full power and steady state before the perturbation. One may see in Figure 7 that the reactor power reaches higher values for larger values of the step reactivity insertion, and also the maximum power is reached later after the insertion. Past the maximum power, there is a steady decrease because of the void that is created when the coolant starts to boil, caused by the large negative reactivity coefficient due to the void fraction. Figure 8 shows how the void fraction evolves during the transients. In the case of the +6.25 mk insertion, the void reaches 47.25%, nearly half the coolant volume. However, this does not last long as the void fraction rapidly drops, permitting liquid water to cool the fuel rods more efficiently. The sudden drop between 13 and 15 s indicates that the temperature of the coolant is back to values below 100°C. In Figure 9, the effective multiplication factor decreases rapidly within 14 seconds of the perturbation from values as high as 1.00625 to about 0.943, then increases slightly

to 0.950 because the void fraction becomes zero and reactor temperature decreases slightly. The reactor remains subcritical. Figure 10 shows the evolutio the average reactor temperature for the maximum positive reactivity insertion investigated (+6.25 mk). curves present the values for the central fuel, the surface, the cladding and the coolant/moderator peratures. At a maximum value of 504 K, the central temperature never reaches the value of 1,600°C (187 at which the TRISO fuel particles have been tested proven to be able to withstand without damage. Simil the fuel surface and the sheath maximum temperat (443 K and 409 K, respectively) are way below the 2 K melting point of the Zircaloy 4 sheathing material for the moderator/coolant, the maximum tempera reached was 402 K, well below temperatures for w metal-water chemical reactions would produce hydro in significant amounts.

More abnormal conditions were investigated and

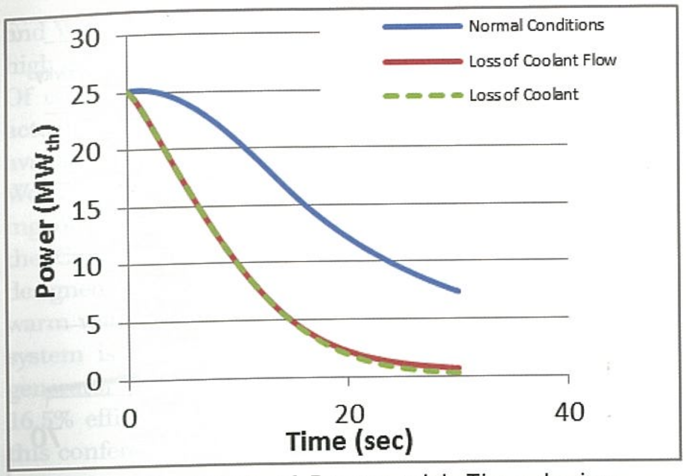

Figure 11: Variation of Power with Time during Abnormal Conditions.

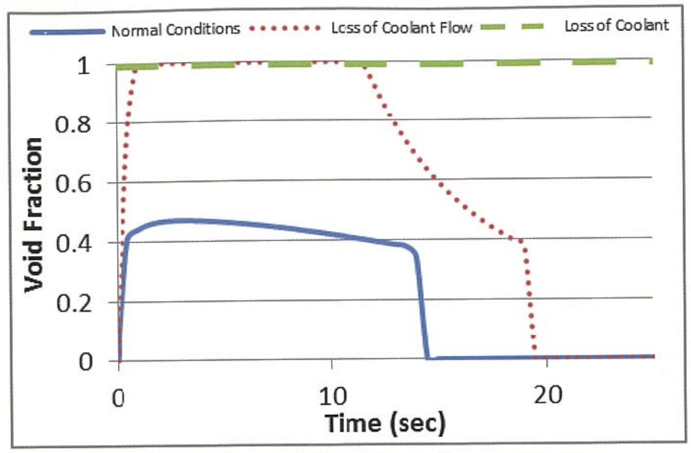

Figure 12: Variation of Void Fraction with Time during Abnormal Conditions.

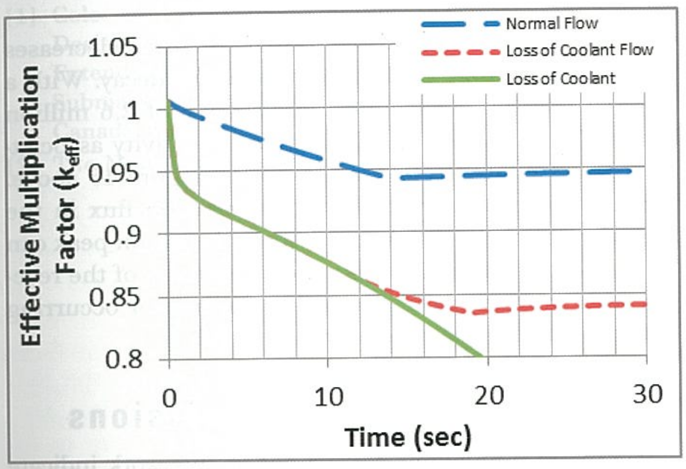

Figure 13: Variation of the Effective Multiplication Factor with Time during Abnormal Conditions.

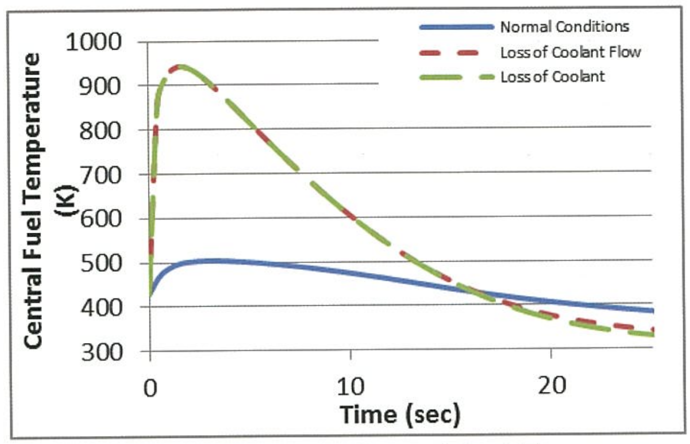

Figure 14: Variation of the Central Fuel Temperature with Time during Abnormal Conditions.

sisted in inserting large positive step reactivity increases at the same time the reactor incurred a loss or coolant (LOCA) event or a loss of coolant flow (LOCF) event. Since the heat produced by the fuel cannot be removed in the case of the LOCA or only partially removed for the LOCF, the potential exists for the temperatures of the fuel and sheath to reach values for which damage may occur. The SNB25 was designed such that in the event of a LOCF, the reactor core would remain flooded since the supply and discharge lines are located above the top of the core. The LOCF is simulated using the kinetic model with the mass flow rate of the coolant reduced from the 63.45 kg s^{-1} to a near- zero value, chosen as 0.05 kg $^{s-1}$. The simulation included a quick rise of the coolant inlet temperature from 35°C to 95°C, and also included the +6.25 mk reactivity step increase. To simulate the LOCA, the void fraction was set at 100% and the mass flow rate again reduced to 0.05 kg s^{-1} in the model. The scenario of assigning suddenly a 100% void fraction represents an extreme case far worse than in reality where the only very improbably way the coolant could be rapidly lost is via a large perforation near the bottom of the reactor vessel. Figures 11 to 14 present the results of these abnormal condition transients.

Because of the large negative reactivity coefficient due to the void fraction, both instances of LOCA and LOCF immediately result in a sudden drop of the keff, effectively shutting down the reactor. This is obvious in Figure 13 and Figure 11 shows that the reactor power drops immediately. The thermal-hydraulics parameters behave differently as a result of their "inertia". In the case of the LOCA, this situation is represented by a 100% void fraction, hence the horizontal dashed green line in Figure 12. As for the LOCF, the sudden lack of cooling efficiency represented by the red dotted line indicates that the liquid water present soon flashes to steam and remains as such until the temperatures decrease enough to enable condensation and eventual return to liquid form after some 20 seconds. Figure 14 is representative of the temperature variations in the reactor components, and similar graphs are obtained for the sheath and the coolant (in the case of the LOCF). For all these graphs, the maximum occurs at about 3 s after the initiation of the transient. The maximum fuel temperature is 942 K,

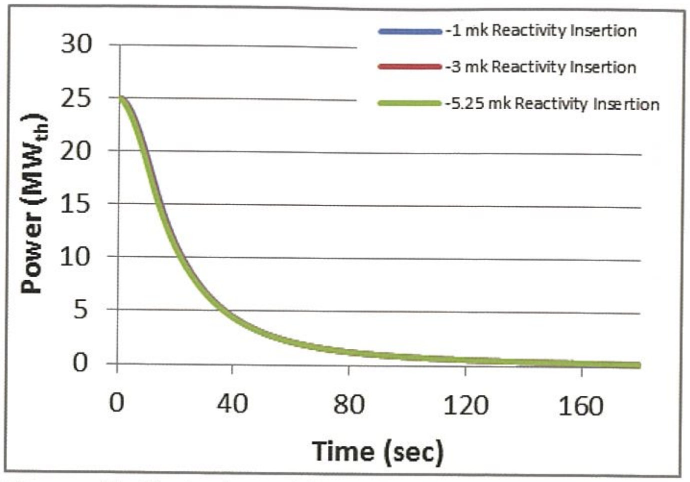

Figure 15: Variation of Reactor Power with Time during Shutdown.

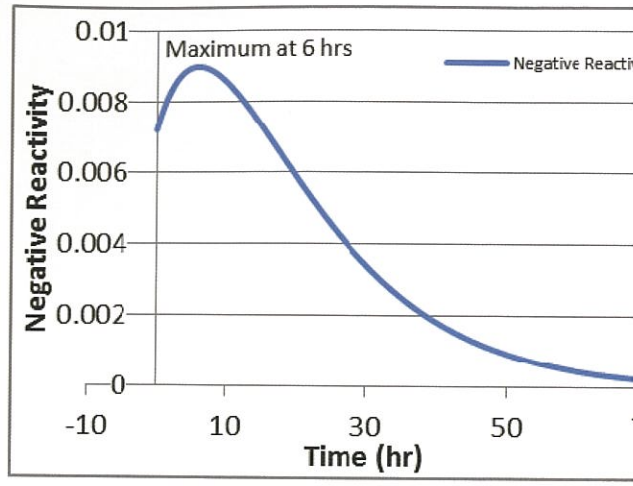

Figure 16: Variation of Negative Reactivity with Time due to Xenon Buildup.

the sheath temperature reaches a maximum value of 856 K and the steam has a maximum temperature of 849 K in the case of the LOCF. It is also worthy of noticing that the curves overlap for both the LOCA and the LOCF transients, indicating the very poor efficiency of steam as a coolant when compared with liquid water. Again, these maximum temperatures remain well below values for which damages would occur, and it can be concluded that the integrity of the SNB25 is not compromised.

6. Reactor Shut-down

The kinetic model can also simulate the reactor shut-down. It is a requirement of inherent safety that the reactor be provided with a reliable shut-down system that not only can bring the reactor to a shut-down status, but also maintain this status. In the case of the SNB25, the control rods system has been designed such that any one of the five banks can bring the reactor to a shut- down condition. In addition, chemical shims or poison may be injected in the moderator at all times. Except for the early part of the life of the reactor, the beryllium reflector plates can be moved away from the reactor core, thus providing yet additional negative reactivity. This part of the present study focusses on using the control rods to insert negative reactivity. Using the kinetic model, the scenario chosen here is with the reactor operating at steady state and critical at the time of the negative step reactivity insertion, when all the beryllium radial reflector are against the core (close to end-of-core life). The central control rod is then able to provide a -5.25 mk reactivity insertion, and the simulations covered other values of reactivity up to -5.25 mk.

Figure 15 is representative of the results obtained with the reactor power from 25 MW to a few MW within a minute. When the reactor is shut down, the accumulated ^{135}I at the time of the reactor shut-down decays into ^{135}Xe and the total cumulative ^{135}Xe concentration in the reactor then increases to a maximum some 6 hours following the shut-down. The ^{135}Xe concentration then decre as this radioisotope undergoes radioactive decay. Wi thermal neutron absorption cross section of 2.6 mi barns [7], 135Xe has a large negative reactivity asso ed with its concentration as shown in Figure 16 ab Due to the relatively small thermal neutron flux in SNB25 reactor, the -9 mk reactivity at the xenon peak be overcome by the +153 mk excess reactivity of the r tor, with concern about re-starting the reactor occur only close to the very end of the core life.

7. Discussion and conclusions

The many simulations carried out in this work indi that the SNB25 reactor has the characteristics of in ent safety. Inherent safety of a reactor is defined by International Atomic Energy Agency (IAEA) as: *"Inhe Safety refers to the achievement of safety through the el nation or exclusion of inherent hazards through the fu mental conceptual design choices made for the nuclear pl Potential inherent hazards in a nuclear power plant inc radioactive fission products and their associated decay h excess reactivity and its associated potential for po excursions, and energy releases due to high temperatu high pressures and energetic chemical reactions. Elimina of all these hazards is required to make a nuclear po plant inherently safe. For practical power reactor sizes appears to be impossible. Therefore the unqualified us "inherently safe" should be avoided for an entire nuc power plant or its reactor"* [8]. The transient simulati have shown that temperatures for which the reactor in rity would be compromised are never approached. B MCNP 5 and WIMS-AECL are widely used for the des of several types of nuclear reactors and about 6% uncert ty is given to both codes by the authors in a conserva fashion. As for the point kinetics and the thermalhydrau models, well proven equations have been used here an 15% uncertainty is given conservatively for this part of work. Comparisons of the results produced by MCN and WIMS-AECL yielded very good agreement resulting in high confidence in the validity of the results of this work. Of course, it is only when a prototype SNB25 reactor is actually built and operated that experimental data will be available for a thorough validation of these simulations. Work on the design of the reactor is continuing and focusing on the energy delivery systems to an Arctic base of the Canadian Forces. The district heating component is designed with a 4% loss target for the heat exchangers and warm water conduit system, and the electricity generating system is based on a Rankine cycle with a turbine and generator propelled by n- pentane fluid with an expected 16.5% efficiency. Details of this research are presented at this conference in a companion paper [9].

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The Integral Molten Salt Reactor (IMSR)

by DAVID LEBLANC[1]

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Abstract

The Integral Molten Salt Reactor is a simple burner or converter design that seeks to maximize passive and inherent safety features in order to minimize development time and achieve true cost innovation. Its integration of all primary systems into a unit sealed for the design life of the reactor will be reviewed with focus on the unique design aspects that make this a pragmatic approach. The IMSR is being developed by Terrestrial Energy in a range of power outputs with initial focus on an 80 MWth (32.5 MWe) unit primarily for remote energy needs. Similar units of modestly larger dimension and up to 600 MWth (291 MWe) are planned that remain truck transportable and able to compete in base load electricity markets worldwide.

1. Introduction

Molten Salt Reactors (MSRs) were originally developed as potential aircraft reactors with a successful test reactor built in 1954 which ran at up to 860°C. This work led to a major breeder power reactor program from the late 1950s to mid 1970s at Oak Ridge National Laboratories, highlighted by the 8 MWth Molten Salt Reactor Experiment (MSRE) that ran from 1965 to 1969. Design work evolved to a Single Fluid, graphite moderated Molten Salt Breeder Reactor (MSBR) in competition with the sodium cooled, fast breeder reactor. Given the belief at the time of very limited uranium resources, a breeder design with as short a doubling time as possible was the ultimate goal - doubling time being that needed to breed the startup fissile of the next breeder reactor. This led to an aggressive proposed salt processing procedure, removing most fission products from the MSBR salt on a 10 day cycle giving an impressive 20 year doubling time. Ultimately though, in the mid 1970s the U.S. decided, for reasons beyond the scientific case for the MSR, to focus solely on the fast breeder option and the ORNL program was canceled.

The MSR's fundamental advantage lays in its most novel feature, that of being a liquid fueled reactor. To the uninitiated, the utilizion of a fluid fuel may appear to be a daunting task. However, molten salt provides the foundation for an enhanced safety profile for the MSR based on its low pressure operation, devoid of any chemical or mechanical driving forces and having many layers of very secure containment. As a fluid, the fuel's mobility can be used to transport decay heat either using a traditi fuse plug and drain tank, or in fact by in situ met that rely on the liquid fuel's ability to establish na circulation. Being able to rely upon truly passive s features is also key to cost innovation which must b place for any advanced nuclear system to reach com cialization. Fluid fuel also adds numerous advant including unlimited burn-up potential, no fuel fab tion, no structural material needed within the core no concern for local hot spots.

The re-emergence of interest in Molten Salt Reac was affirmed when the MSR was chosen as one o GEN IV reactor types in 2002. An objective review sh MSR's many unique attributes, leading to clear po tial advantages ranging through overall costs, sa resource sustainability and long lived waste reduct [1]. Much of this revival of interest has continue focus on breeder options or MSR-Breeders, inclu revived interest in the fast spectrum approach suc the Molten Salt Fast Reactor program in Europe A fast spectrum does offer some advantages but many unique and significant challenges leading t expected lengthy development period. In general MSR-Breeders, while liquid fuel does simplify proc ing technology, the degree of difficulty and costs often underestimated, especially in terms of nee R&D before commercialization. Furthermore, M Breeders require the use of highly enriched uran which would call for treaty revisions worldwide. Fin to attain breeder status, even break-even level, requ numerous sacrifices to conserve neutron losses.

2. MSR-Burner Approach

A potentially superior approach involves simpli convertor designs or MSR-Burners that forego c plex on-site salt processing at the modest expens needing a small annual makeup of low enriched nium (LEU). This work is based on the final fun efforts of ORNL in the late 1970s on a design term Denatured Molten Salt Reactor (DMSR) [3] propo to run a 30 year lifetime on a single batch of started on LEU and thorium but supplemented by annual makeup of LEU. This greatly simplified pl design and also increased proliferation resistance

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1 Terrestrial Energy, Mississauga Canada

denaturing any ^{233}U with ^{238}U. In fact this approach has been singled out as having maximum proliferation resistance [4]. Even without salt processing, uranium utilization was determined to be excellent, roughly 1/6th that of LWR. Moreover, a single batch process after many years of use to recycle transuranic elements, in particular Pu, would give a waste profile virtually free of troublesome transuranic wastes.

Another major factor that favors the MSR-Burner approach is flexibility in carrier salt choice. MSR-Breeders are forced to utilize expensive and currently unavailable 99.995% Li-7 and/or beryllium, as a mixture often termed FLiBe. Beyond high cost, both of these produce copious amounts of tritium (roughly equal to CANDU rates). Tritium is of great concern, at least from a regulatory standpoint, as it can pass directly through the hot metallic walls of heat exchangers. Binding tritium before it could potentially reach building containment or the final working fluid such as steam is a challenging and important duty. Tritium capture techniques have been at the foundation of all MSR-Breeder work since the concept's inception. With MSR-Burners however, alternate salts that avoid tritium production are possible at the minor penalty of a fractionally larger annual uranium consumption [5]. As example, 46%NaF-33%RbF-21%UF4 with a melting point of 470°C, which is an even lower melting point than traditional FLiBe fuel salt but with somewhat inferior heat transfer properties.

Many of the advantages of MSRs come from the superior nature of the fluoride salts as coolants, operating at ambient pressure with very high boiling points and high volumetric heat capacity. This has led to a recent concept to use fluoride salts as coolants of TRISO solid fuels in the form of pebble beds or solid fuel blocks [6,7]. While these "salt cooled" cousins of "salt fueled" MSR-Burners do not have as strong a case on resource sustainability and long lived waste profile, many view these new options, termed FHRs (Fluoride salt cooled High temperature Reactors) as potentially a less encumbered step, in particular due to the U.S. NRC's prescriptive focus on solid fuels. Many innovations have been made in the FHR field that may see use for liquid fuel MSRs as well.

3. Remaining Challenges of the MSR-Burner Approach

The fundamental challenge of even a simplified MSR-Burner approach is that of materials lifetime. Any proposed facility needs, at minimum, a 30 year design life and assuring this full lifetime out of primary reactor components and/or the ability to service or replace is a daunting task. While a fluid fuel can be drained to storage tanks during maintenance outages, there will inevitably remain residual fission products associated with any component in contact with the fuel salt. The three main areas of concern are the reactor vessel itself, the primary heat exchangers and graphite moderator if employed.

Reactor vessel walls are subject to potential neutron induced helium embrittlement by both thermal and fast neutron flux as well as potential corrosion mechanisms particularly due to fission products such as tellurium. Extensive salt loop and the in-service experience of the MSRE gained in the 1960 and 1970s, clarified corrosion issues and mechanisms. Modified Hastelloy N, the commonly proposed wall material, would be expected to perform very well in terms of corrosion and there are numerous, somewhat less well substantiated alternatives including some common stainless steels. The issue of potential neutron damage is greatly aided by a graphite moderated approach as this allows for methods to substantialy reduce neutron flux reaching the outer vessel. This is achieved through a method termed an under-moderated outer zone where a higher salt to graphite ratio gives a localized harder spectrum and encourages fertile absorptions over fissile. This effectively curtails neutron leakage out of the core and limits flux at the vessel wall. In general, it can be said that assuring multiple decades of use is likely an achievable goal but one that would require far more experimental verification and would add to the regulatory challenge.

Heat exchangers (HX) could employ a similar material as the reactor vessel, but in this case a 30+ year lifetime without service or replacement is unlikely. In traditional ORNL MSR development, the concept has been to put the utmost care into HX tube in shell fabrication as it was deemed impractical to undertake repair operations. This is due to the inevitable build up of noble metal fission products on metal surfaces. ORNL design thus called for multiple (typically 4) independent external primary heat exchangers. If any fault was discovered during operation, salts could be drained from the HX, the shell opened and the entire tube bundle removed and replaced with a new one. Only after many years would the bundle possibly be repaired for reuse. This replacement operation would be very challenging from a regulatory perspective due to the possibility of a release of fission products upon opening the HX shell and tube bundle transport. Furthermore, it had been a concern of ORNL that if the HX was drained shortly after shutdown for whatever reason, noble metal fission product heat generation in the now dry HX could be damaging.

Of greatest importance in regard to reactor material lifetime is the graphite moderator. The use of graphite imparts many advantages in MSR design but its usable lifetime is directly related to the power density employed. This is due to fast neutrons causing vacancies and interstitials that cause graphite to at first shrink modestly but then to expand, eventually beyond its original dimension, leading to physical cracking. In most non-MSR graphite reactor use, for example Magnox or AGR, power density is limited by the thermal hydraulic limitations of removing heat from the solid fuels, so as a consequence, very large dimension cores are common. While this lower power density (and low fast flux) is detrimental in an economic sense, it does allow many decades of use of the graphite. In the MSR case, there are no such thermal hydraulic limitations and it is very advantageous to attain higher power densities. Thus a simple choice has long faced developers. That choice is to to design with low power density to achieve a full plant lifetime out of graphite (the "Sealed" approach) or, alternatively, to employ a far more compact, high power density core but to provide provisions for graphite replacement (the "Swap" approach).

All ORNL work on MSBR designs in the 1960s and early 1970s assumed the swap-out route with a power density, giving a typical graphite lifetime of 4 years.. The proposed replacement operations were, however, a massive undertaking and would be considered perhaps even more daunting today. Any opening of the reactor vessel risks some level of volatile fission product release even though fuel salts would of course be drained well in advance. The bigger challenge is that the graphite to be moved would be substantially radioactive (both by activation and some fission product deposition primarily from Xenon and Krypton precursors). In the traditional MSBR Single Fluid 1970s design, it was planned that the core would be moved as a unit, employing a 250 tonne hoist and a two inch thick steel shielding cask to encase the core and upper vessel head during transit to a nearby storage cell. As the reactor could not be out of service for a long duration, these operations would be only 10 days after shutdown and would require the building to have a 90 cm thick domed concrete shell simply as shielding to assure radiation exposure outside the building did not exceed regulations during the brief transit.

The great challenges of graphite replacement or swap-out led many later MSR proposals to choose the sealed approach and employ a low power density. Examples of these include the 1978-1980 DMSR designs of ORNL and later FUJI [8] work from Japan on a similar but non- denatured Th-^{233}U burner. In the DMSR design, the 1000 MWe unit would have required a graphite core of 8.6 m by 8.6 m within a roughly 10 m by 10 m reactor vessel. As well, capacity factors of the period were expected to be lower (75%) and as such the DMSR's 30 year lifetime was only 22.5 full power years. A modern version would likely need to raise this lifetime by going to even lower power density. Although this sealed approach solves the enormous challenges of graphite replacement while keeping the great advantages of graphite, it does sacrifice significantly in terms of potential cost innovation.

4. The IMSR: A New Design Philosophy

The concerns listed above for a practical gra
MSR burner have been addressed through a s
but major change in basic reactor design. The
design philosophy of the Integral Molten Salt Re
(IMSR) is to maximize the simplicity and advan
of the graphite- moderated MSR-Burner appr
while also offering a novel solution to the m
al lifetime challenges of graphite, vessel and
exchangers. This patent pending solution [9], i
integration of all components with lifetime chall
into a permanently sealed core-unit and, centr
the concept, to design for periodic replacement
core-unit itself in order to allow far higher and
economically viable power densities. With replac
core-units and the ability to refurbish other co
nents such as steam generators or turbines, a
decades long plant lifetime is possible. The o
advantages including the easing of regulatory co
ance, minimizing of R&D and providing operat
lifetime confidence are most significant in this 'S
and Swapped' approach.

The IMSR, while taking much from the D
also owes much of its design philosophy to the
recent work on fluoride-salt cooled, high temper
reactors (FHR), specifically the SmAHTR. In the
SmAHTR 125 MWth ORNL design [7], heat exch
ers, both primary and those for passive decay
removal, are integrated into a modestly sized re
vessel. This salt cooled design is limited on p
density related to thermal hydraulic and solid
burn issues to allow a 4.2 year core life betwee
fuel core replacements. Heat exchangers emplo

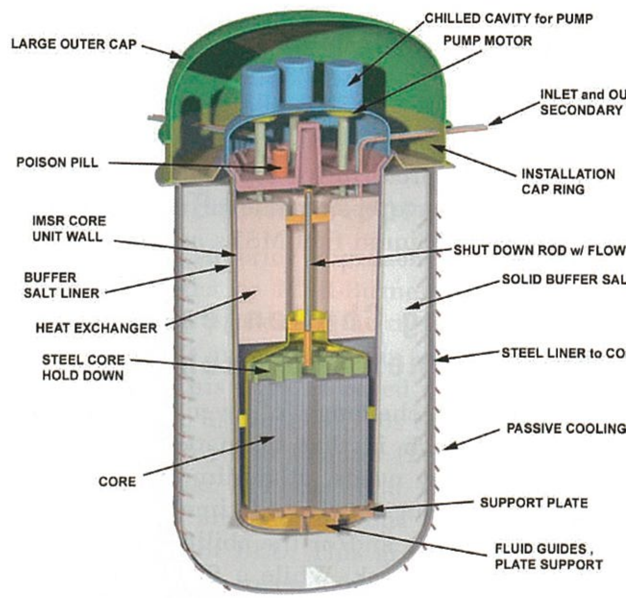

Figure 1: The IMSR Core-unit nested within a buffer salt liner.

Table 1. General Features and Parameters of the IMSR

Integral Molten Salt Reactor	
Thermal Capacity	Three sizes: • IMSR80: 80 MWth • IMSR300: 300 MWth • IMSR600: 600 MWth
Electrical Capacity	Three sizes: • IMSR80: 32.5 MWe • IMSR300: 141 MWe • IMSR600: 291 MWe
Primary Fuel/Coolant Salt	Liquid Fluoride Fuel Salt such as $LiF-BeF_2$ $-UF_4$ or $NaF-RbF-UF_4$
Secondary Coolant	Liquid Fluoride salt such as; $NaF-BeF_2$ or $KF-ZrF_4$
Moderator	Hexagonal Graphite Elements
Primary Circulation	Low pressure pumped
System Pressure	Near Atmospheric
Core Outlet Temperature	700 °C
Thermodynamic cycle	Superheat Rankine
Cycle Efficiency	48.5% for IMSR600
Fuel Material	LEU as UF_4 Within Liquid Carrier Salt. Thorium use optional
Fuel Enrichment – Initial Loading	< 5%
Fuel Enrichment – Makeup Fuel	5% to 19.9%
Fuel Cycle	>84 months
Reactivity Control	Long Term Reactivity Changes by Periodic Liquid Makeup Fuel Additions
Shutdown Mechanism	Primary: Passive Buoyancy Driven Rod Insertion Secondary: Passive, Temperature Induced Poison Injection
Emergency Safety Systems	Passive
Residual Heat Removal Systems	Passive
Design life	Plant >50 years Sealed primary unit >7 years
Design Status	Pre-Conceptual Design Completed
Planned development	Early 2020s
Distinguishing Features	MSR-Burner system with integrated primary heat exchangers. High power density core and 7 year operating life from a sealed and replaceable low maintenance core-unit.

of 3 philosophy such that if a fault develops, the unit can continue its 4.2 year fuel cycle while running on the remaining two heat exchangers, which can later be swapped out during fuel core swap out.

The IMSR, like the SmAHTR, will have multiple, independent heat exchangers that can be isolated and taken out of service if a fault occurs within the operational lifetime of the core-unit, with power production continued in its absence with the remaining heat exchangers. As a default, the IMSR plan calls for six independent primary heat exchangers, each with its own dedicated pump and inlet and outlet secondary coolant lines. The IMSR is designed with a high power density - chosen to give an upper limit approaching 10 years of graphite lifetime, which however, for planning purposes will be assumed to be a more conservative 7 year unit lifetime. Optimization at the conceptual design level will determine the most pragmatic core-unit lifetime. Various aspects are shown in the basic figures below, such as the use of in-situ decay heat removal through the vessel wall aided by a surrounding buffer salt.

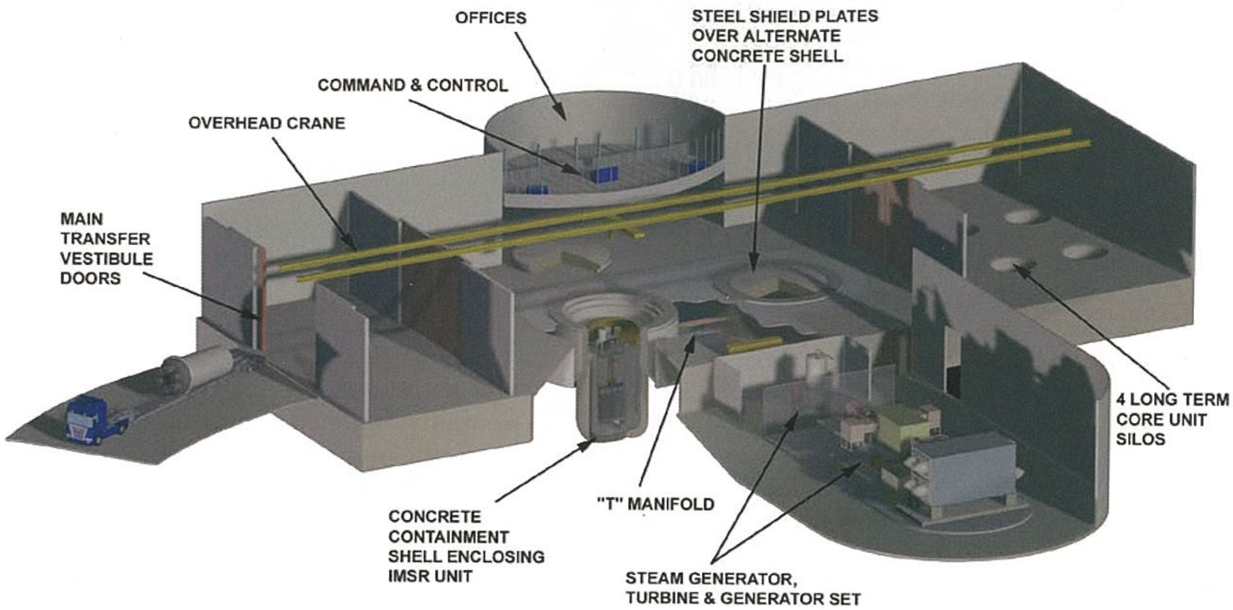

Figure 2: Generalized facility layout showing the IMSR Core-unit within its containment cavity.

Following in the footsteps of the 125 MWth SmAHTR FHR design of ORNL, the IMSR is planned with a limit on its outer diameter of 3.6 meters to allow flat-bed truck transport. Separate shipping of core graphite and/or heat exchanger sections may prove warranted. The first goal of Terrestrial Energy's development of the IMSR is a small IMSR80 unit of 80 MWth and 32.5 MWe, with first instalment meant as a commercial demonstration for rapid further deployment.

As the IMSR in many aspects is very similar to the proven 8 MWth MSRE design run by ORNL in the 1960s, a smaller pilot stage is not deemed warranted. The IMSR80, while significantly larger than the MSRE, will be substantially reduced in dimension from SmAHTR's 3.6 wide by 9 m high unit. Two subsequently larger versions, but still flatbed deliverable, are planned at the 300 MWth and 600 MWth size to supply larger industrial users and baseload electrical production.

In summary, the design philosophy of the IMSR is that the primary reactor vessel is sealed for its design life, currently planned for 7 years. Any heat exchanger failure is dealt with by isolating the affected HX and operation continues with the remaining heat exchangers somewhat uprated to maintain power levels. Pump failure may be handled in a similar fashion but it remains to be determined what level of pump motor and/or bearing/shaft maintenance will be planned for (pump failure is considered of higher frequency than HX failure). Once the design life of the unit is complete, it is shutdown and an identical core-unit takes over operation in an adjacent containment silo by connecting coolant lines to the new unit. The spent core-unit can remain in place for the next 7 years and at any later point, fuel salt can be removed for re-use, recycle or conversion to waste form. The drained unit will be devoid of any actinides, however both graphite heat exchangers represent a low to intermediate waste due to neutron activation, noble metal plat and noble gas daughter products within a surface of the graphite. After this 7 year cool down perio first spent core-unit is then lifted out and transf to long term storage, making way for the third unit, and the cycle continues. The IMSR core-unit also serves a secondary duty as a medium to long waste sequestration vessel, without the need to u the core-unit for decades - if ever.

5. Safety Case Basics: Decay Heat, Shut Down Systems ar Reactivity Coefficients

The IMSR approach also differs significantly other major MSR efforts in terms of decay heat agement, passive shutdown systems and all impo temperature reactivity coefficients.

Removal of decay heat by passive means has been an advantage of MSR design. Traditionally has been in the form of a fuse plug and emerg dump tank in which a frozen plug of salt mel electrically powered cooling of the plug ceases. salt then passively drains by gravity to tanks specifically for decay heat removal. While this op remains for the IMSR, there do exist potential fa modes (drain blockage) and as such in-situ decay removal would be advantageous and would ad system simplification. The new innovation devel is to rely again on the fluid nature of the fuel bu this case for it to naturally circulate within the unit and have heat removed from the vessel walls removing heat through the metallic vessel wall, cooler and denser fuel salt in the outer annulus will drive natural circulation. Only very slow flow rates are needed as the fuel salt has a very large thermal inertia. For example the IMSR80, is currently planned with 3.5 m3 of fuel salt giving a total heat capacity of 16 MJ/°C. At the instant of shutdown, with a decay heat of at most 7% of 80 MWth, the salt temperature would only be rising at 21°C per minute. Decay heat drops to 3% within a few minutes and to 1% within two hours, and by this time it would only be 3°C per minute. This ignores any other heat removal pathways and the very large heat capacity of graphite, along with the fact that some short lived fission products leave as off gas. Adding in roughly 15 tonnes of graphite in core and its heat capacity of 27 MJ/°K drops the temperature rate change to about two thirds. Thus even natural circulation with a cycle time of an hour or more within the core-unit is adequate to avoid excessively high temperatures of the salt in any location.

The large thermal inertia of graphite moderated designs with substantial salt volumes was recognized early on to be a desirable trait. By comparison the graphite-free 3000 MWth MSFR [2] must minimize salt volume for economic reasons as the fast spectrum calls for a fissile loading per unit volume approximately 10 times that of thermal spectrum MSRs. The MSFR projects just 18 m3 of fuel salt and thus has 37.5 times the power but only about 2.4 times the heat capacity of an IMSR80

As seen in Figure 1, the IMSR vessel wall is surrounded by a liner that contains a solid buffer salt, chosen to have a melting point just slightly above the normal vessel wall temperature. During normal operation this thick layer is both a thermal insulator and neutron and gamma shield. During a failure of all secondary cooling however, this buffer salt begins to melt and pull away decay heat. As it melts, the liquid form will move heat to the remaining frozen buffer salt through highly effective convective heat transfer. Even a modest thickness can absorb many hours or even days of decay heat. When the buffer salt is nearly completely melted, a surrounding water jacket embedded in the outer concrete silo transitions to be the main heat sink while keeping the concrete at modest temperatures. A surface tank supplies several weeks of coolant water by which point normal radiative losses assure the overall system remains secure if for any reason power or makeup water has not returned.

A full description of reactor control, operation and fuel utilization is beyond the scope of this introduction to basic IMSR principles but it should be mentioned that two independent and passive shutdown systems are currently planned. Both systems originate from salt cooled or FHR work. The primary shutdown mechanism consists of a buoyancy-driven control rod [10], of slightly higher density than the fuel salt at normal temperature. Pump induced flow keeps the rod out of the core until a pump failure or a salt density decrease due to a rise in temperature passively initiates rod drop. As independent backup, a thermally activated neutron poison injection [11] is planned, wherein a eutectic salt mix of GdF or EuF will melt and mix into the fuel salt if a threshold core temperature is exceeded.

Basic supporting reactor physics modeling to date has been through sponsored efforts at the University of Tennessee (UTK) under direction of Dr. Ondrej Chvala [5]. This work has studied the previously largely unexplored set of alternate carrier salts that avoid enriched lithium and beryllium to avoid their cost and tritium production. An obvious drop in conversion ratio was found as expected, typically between 0.1 and 0.2 compared to a FLiBe carrier salt. The resulting increase in annual uranium usage is very modest however, especially in terms of cost per kwh. For example, an MSR-Burner dropping from conversion ratio of 0.8 down to as low as 0.6, only means makeup fuel costs increasing from about 0.1 cents/kwh to 0.2 cents/kwh.

More importantly, recent modelling work at UTK has been confirming the expectation of superior temperature reactivity coefficients. It is vital to attain an overall negative temperature coefficient and some previous MSR-Breeder efforts only predicted a very weakly negative term, for example -2 pcm/K for the early 1970s MSBR. There are three contributing factors in the overall temperature reactivity coefficient;

Fuel-salt density. A decrease in density removes fuel salt from the core, changing the fuel-to-moderator ratio and increasing neutron leakage. Fast acting.

Doppler broadening of resonance-absorption peaks. Higher temperature produce broader peaks increasing neutron absorption in 238U or 232Th. Prompt response.

Graphite temperature. Higher temperature shifts the Maxwellian thermal neutron peak to higher energy, and into (or out of) fission-resonance peaks. Slow acting.

While the Doppler term is consistently strongly negative, in graphite moderated MSR-Breeders, the density term can sometimes be positive and the graphite term is consistently positive. In fact there is debate whether the global reactivity term for the 1970s MSBR design might actually be slightly positive.

The IMSR already benefits from having a smaller dimensioned core as this typically leads to a negative density factor (increased neutron leakage with lowered fuel density). The major difference however is that, as an MSR-Burner, the IMSR will have either reduced or non existent levels of ^{233}U (depending if LEU is used on its own or with thorium). The positive graphite term results from the shift of the Maxwellian peak of thermalized neutrons moving to higher energy as graphite heats up. In this region of interest, the drop in absorption cross section of thorium is much steeper than the drop in fission cross section for ^{233}U. As well, the leading edge of the Maxwell peak begins to enter a strong ^{233}U fission peak. As the ratio of fissile to fertile absorption rises, this drives up reactivity. For other fissile isotopes, especially 235U, this is not the case, and in fact a negative graphite term typically dominates.

While modeling efforts are ongoing, results to date are showing all three terms to be separately negative, with a strongly negative total. Many core size and fuel salt combinations have been investigated at beginning of cycle conditions. For these scoping exercises a global total reactivity coefficient ranging from -5 to -11 pcm/°K has been observed. This strong term greatly aids in transient response as even hard to imagine reactivity insertions are merely countered with a modest shift upwards in fuel temperature.

6. Conclusions

While Molten Salt Reactors have long held great promise, there appears no reason to complicate initial commercial development by attempting a breeder approach. The MSR- Burner approach is the pragmatic approach and one that is able to lead to more rapid and widespread commercialization. The IMSR concept is predicated on further reducing all of the developmental challenges of bringing these much needed systems to market. Development is a major undertaking that will call upon many international partners, but Terrestrial Energy plans to continue to focus development within Canada with the objective of demonstrating its IMSR80 early in the next decade. A growing interest from industry and academia and the more performance-based regulatory body in the CNSC bodes well for the future. The Canadian market also holds great promise, ranging from remote communities to mining interest [12], as well as the western oil sands where the high temperature output (700°C) and scalability of the IMSR appears ideal for replacement of natural gas use in Steam Assisted Gravity Drainage (SAGD) [13,14] bitumen production.

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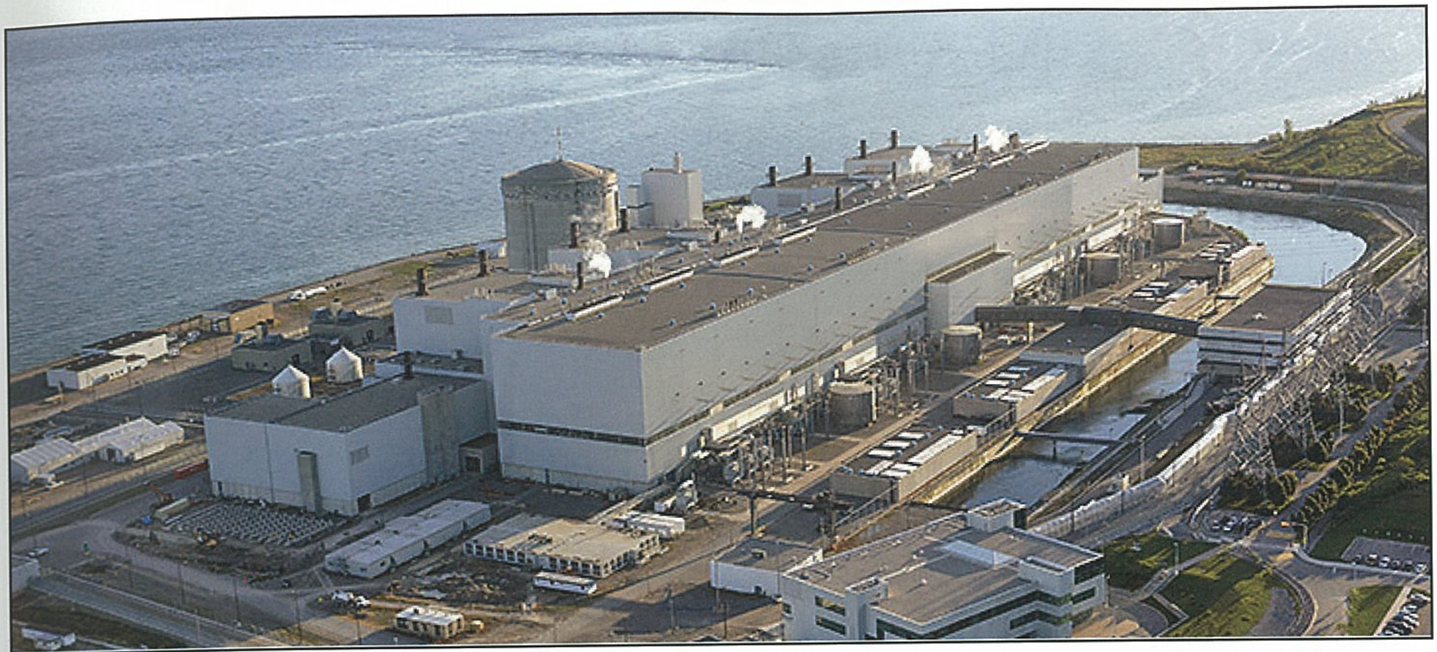


Aerial view of Darlington Nuclear Power Station, the setting for the Exercise Unified Response *(see page 10)**.*

CANADIAN news

(Compiled by Fred Boyd from open sources)

Canadian Nuclear Laboratories Officially Launched

Following is a slightly edited version of the official announcement from Atomic Energy of Canada Limited of the creation of Canadian Nuclear Laboratories.

On November 3, 2014, Atomic Energy of Canada Limited (AECL) launched a wholly-owned subsidiary named Canadian Nuclear Laboratories (CNL). This is a major milestone in the restructuring of AECL.

The organization employs approximately 3,400 people at 12 locations across Canada. The corporate headquarters and core research and development operations will remain situated at Chalk River Laboratories in the upper Ottawa Valley. CNL will continue to develop highly qualified people, and will be a source of highly skilled jobs and a key driver of local economic benefit in the communities where it operates.

Canada helped build the global nuclear industry and created a unique platform for power generation known as CANDU.

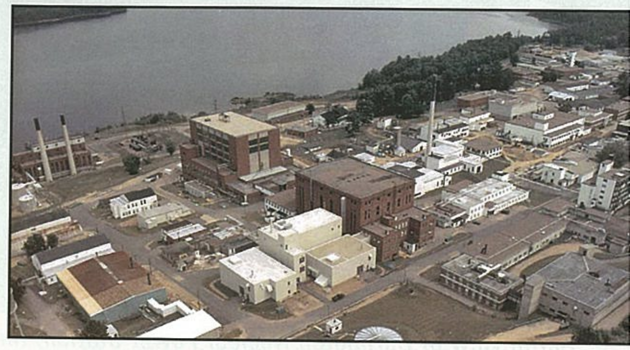
"CNL may be a new organization, but it stands on the shoulders of a Crown corporation with a proud history that spans over six decades of cutting-edge nuclear science and technology," said Dr. Walker, President of AECL. "This new model of operation will capitalize on burgeoning market opportunities and private sector management, opening up a promising new era before us," he added.

CNL will focus on three key mandates going forward:

- Managing Canada's radioactive waste and decommissioning responsibilities accumulated during the more than 60 years of nuclear research and development at the Chalk River and Whiteshell Laboratories.
- Ensuring that Canada's world-class nuclear science and technology capabilities and knowledge continue to support the federal government in its nuclear roles and responsibilities – from health protection and public safety to security and environmental protection.
- Providing access to industry, on a commercial basis, to address its need for in- depth nuclear science and technology expertise.

Restructuring Background

In 2013, the Government of Canada announced its intention to implement a Government-owned, Contractor-operated (GoCo) model for the management of AECL's Nuclear Laboratories. The goals are to create value and reduce risks and costs for taxpayers



Aerial view of Chalk River Laboratories.

while continuing to fulfill AECL's core mandate.

The implementation of the GoCo model entails steps. The first step is the creation of CNL as a sidiary of AECL, to be operated largely with the g nance, management systems and workforce that been in place under AECL. On November 3, 2 CNL will assume full responsibility for all day-t operations of AECL sites.

The second step occurs at the conclusion of Government's procurement process: to select GoCo contractor, the GoCo contract is awarded; ownership of CNL is transferred from AECL to contractor. Transfer to the new GoCo contract anticipated in autumn of 2015. At that time, CNL become a private-sector entity, and AECL will small Crown corporation focused on the managen and oversight of this contract.

AECL will oversee the performance of the contra al obligations of the contractor. AECL will also re ownership of the Nuclear Laboratories' physical intellectual property assets and its liabilities.

About AECL

Atomic Energy of Canada Limited (AECL) Canada's premier nuclear science and technology o nization. For 60 years, AECL has been a world lea in developing peaceful and innovative applicati from nuclear technology through its expertise in p ics, metallurgy, chemistry, biology and engineer Approximately 3,400 highly skilled employees deliv range of nuclear services – ranging from research development, design and engineering to speciali technology, waste management and decommissioni

Open House at Darlington Refurbishment Facility

Ontario Power Generation's (OPG) Darlington Energy Complex welcomed about 3,500 awestruck and appreciative visitors on Nov. 4, 5 and 8, 2014. The public were invited in to see the full scale mock-up of a replica nuclear reactor built for training and tooling development.

"We're thrilled to have hosted so many people this past week", said Dietmar Reiner, OPG's Senior Vice President, Nuclear Projects. "The Darlington Energy Complex is an innovative training facility that features a made-in-Ontario mock-up reactor. All workers will be fully trained and tools will be fully tested before anyone works inside a Darlington reactor. This will ensure that refurbishment of Darlington is a success."

Al Pearce and Lisa Carnwith photograph themsleves in front of the mock-up Calandria at the Darlington Refurbishment Open House, November 8, 2014.

Photograph courtesy of Ontario Power Generation

L-3 MAPPS Upgraded Heysham 1 Simulator

L-3 MAPPS of Montreal announced November 18, 2014 that it participated in the official opening of the upgraded Heysham 1 plant training simulator on October 22, 2014 in Lancashire, United Kingdom (U.K.). The ceremony was attended by numerous EDF Energy representatives. L-3 MAPPS was represented by Michael Chatlani, vice president of marketing & sales.

L-3 MAPPS had previously ported the legacy simulator to a Windows platform and replaced the thermal-hydraulic and core neutronics models with L-3's ANTHEM™ and Comet Plus™. In the first phase of this latest upgrade, L-3's previous generation of simulation software development and maintenance tools was replaced with a subset of L-3's newer Orchid® products That phase was declared "Ready For Training" (RFT) in January 2013.

In the second phase, the simulator's legacy balance of plant and electrical system models were replaced with higher-fidelity models developed with Orchid Modeling Environment. Phase 2 was completed in February 2014.

The third phase involved expanding the legacy simulator to incorporate both Reactor 1 and Reactor 2 control desks, resulting in a fully integrated dual-unit control room simulation environment. The plant models were modified to support both operator desks and related common services. Phase 3 was RFT in October 2014.

EDF Energy generates approximately one-fifth of the U.K.'s electricity and employs around 15,000 people. The Heysham 1 Power Station started generation in July 1983 and is made up of two Advanced Gas-cooled Reactors (AGRs) with electrical output of 1,160 megawatts. The Heysham 1 plant and simulator are located on the northwest coast of England.

L-3 MAPPS has more than four decades of expertise in supplying plant computer systems for Canadian heavy water reactors.

Bruce Power Signs Major Contract with B & W Canada

On November 27, 2014, Bruce Power forged a $300 million agreement with B&W Canada, which will see the Cambridge company supply important services for all Bruce Power units, to meet the company's ongoing operational needs.

The agreement was signed by at a ceremony at the B & W Canada plant in Cambridge, Ontario by Duncan Hawthorne, Bruce Power's President and Chief Executive Officer, and John MacQuarrie, President, B&W Canada.

Ontario's Minister of Energy, Bob Chiarelli, and Cambridge MPP Kathryn McGarry attended the ceremony along with community leaders and B&W Canada staff.

The agreement will allow B&W Canada to continue to be a major employer, providing highly skilled jobs within the Kitchener-Waterloo-Cambridge Region, while also supporting the affordable production of electricity from Bruce Power.

The contract includes engineering, tooling development, skilled trades training and site work execution.

Work associated with the award of this contract will commence in January 2015 and is expected to carry on

Duncan Hawthorne, CEO of Bruce Power signs agreement with B&W Canada, November 27, 2014, at Cambridge, Ontario. Looking on are: L to R, Cambridge MPP Kathryn McGarry; John MacQuarrie, President, B&W Canada; and Ontario Minister of Energy, Bob Chiarelli.

to 2020. It also provides a foundation to be expanded as Bruce Power proceeds with extending the lives of its units as outlined in Ontario's Long-Term Energy Plan.

About Bruce Power

Bruce Power operates the world's largest operating nuclear generating facility and is the source of roughly 30 per cent of Ontario's electricity. The company's site in Tiverton, Ontario is home to eight CANDU reactors. Formed in 2001, Bruce Power is an all-Canadian partnership among Borealis Infrastructure Management (a division of the Ontario Municipal Employees Retirement System), TransCanada, the Power Workers' Union and the Society of Energy Professionals. A majority of Bruce Power's employees are also owners in the business.

About B&W Canada

B & W Canada is a subsidiary of Babcock & Wilcox Company which is headquartered in Charlotte, N.C., USA. The Babcock & Wilcox Company is a leader in clean energy technology and services, primarily for the nuclear, fossil and renewable power markets, as well as a premier advanced technology and mission critical defense contractor. B&W has locations worldwide and employs approximately 11,600 people, in addition to joint venture employees throughout the world.

House of Commons Passes Energy Safety and Security A

On November 7, 2014, the House of Com passed the Energy Safety and Security Act (Bill in the House of Commons.

The legislation increases the absolute liability for offshore and nuclear companies to $1 billion

The Act, when approved by the Senate, will r the 1976 Nuclear Liability Act which limited t bility of nuclear power plant operators to $75 m

The new Act will also amend the Canada-Nova Offshore Petroleum Resources Accord Implemen Act, the Canada-Newfoundland Atlantic A Implementation Act, the Canada Oil and Operations Act (COGOA) and the Canada Petr Resources Act (CPRA).

The Government of Canada worked collabora with the Provinces of Nova Scotia and Newfoun and Labrador to develop the offshore portion C-22, and mirror legislation is being develope considered by those provinces' legislatures.

The Energy Safety and Security Act has now referred to the Senate for consideration.

Positive Review of AFCR Technology in China

On November 06, 2014 Candu Enery Inc issue following statement.

Candu Energy Inc., a member of the SNC-L Group (TSX: SNC), welcomes the positive revi the Advanced Fuel CANDU Reactor (AFCR) Expert Panel of Chinese nuclear experts. AFCR nology uses both recycled uranium and thorium fuels to deliver high-performing reactors with s environmental benefits.

The China Nuclear Energy Association (C hosted the Expert Panel review of Candu En AFCR technology, which has been developed in nership with China National Nuclear Corpo (CNNC). The panel, composed of 22 Chinese nu experts from both industry and academia, iss statement saying that AFCR technology forms ergy with China's existing pressurized water rea (PWRs) and that it is positioned to "promot development of closed fuel cycle technologies industrial development" which is consistent the overall strategy of nuclear power developme China.

The panel went on to say that the AFCR "mee latest nuclear safety requirements and the re ments for a Generation III nuclear power techn and has achieved a good balance of advancemen maturity." It concluded by recommending tha

AFCR be further developed and that the proper time should be chosen to "initiate the construction of AFCR to unlock and utilize its various advantages."

Candu Energy and CNNC presented the technical and strategic case to build AFCRs in China. The AFCR complements China's light water reactor (LWR) technology. One AFCR can be fully fuelled by reusing the spent fuel from four LWRs as recycled uranium. The AFCR also allows China to reduce spent fuel volume, reduce reliance on imported uranium and generate a greater portion of its electricity from carbon-free sources. China currently operates two CANDUreactors at the Qinshan site, and both are expected to be modified to use recycled uranium fuel in 2015.

In July, SNC-Lavalin signed a memorandum of understanding with CNNC in Vancouver, BC, to collaborate on nuclear energy projects in China and internationally.

About the AFCR

Candu Energy's Advanced Fuel CANDU Reactor (AFCR™) is a 700 MW Class Generation III reactor based on the highly successful CANDU 6® and Enhanced CANDU 6® (EC6®) reactors with a number of adaptations to meet the latest Canadian and international standards. Its fuel flexibility allows it to use recycled uranium or thorium as fuel.

Darlington Refurbishment Approval Upheld

On November 22, 2014, the Federal Court announced that it had dismissed a lawsuit challenging regulatory decisions on the environmental assessment of the planned refurbishment and continued operation of the four-unit Darlington nuclear power plant.

A group of four environmental organisations - Greenpeace Canada, the Canadian Environmental Law Association, Lake Ontario Waterkeeper and Northwatch – had sought a judicial review of the Canadian Nuclear Safety Commission (CNSC) and the Department of Fisheries and Oceans (DFO) assessment of the environmental implications of the work. They alleged that the regulators had not carried out their assessment in accordance with federal regulations, and had failed to consider aspects including potential effects on Lake Ontario's fisheries and the impact of unpredictable major accidents.

The Court found that the two regulators had made no errors in the methods they had used in deciding that the project, with its associated mitigation steps, was not likely to cause significant adverse environmental effects. The ruling also noted that the regulators had behaved in a reasonable manner in making their assessments. "The assertion that a regulatory authority must consider any accident which may possibly occur is unsustainable in reality and law," the ruling notes.

The groups are reviewing the judgment, and have not yet decided whether to appeal.

Bruce DGR Review Panel Closes Record

On November 18, 2014 the Joint Review Panel for the Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste (DGR) proposed for the Bruce nuclear site gave notice that it had closed the record for the environmental assessment.

The Joint Review Panel is proceeding with the preparation of its Environmental Assessment Report which will set out the rationale, conclusions and recommendations of the Panel, and a summary of comments received from the public during the course of the review.

The Joint Review Panel has written to the Minister of the Environment and the President of the Canadian Nuclear Safety Commission to indicate that, due to the volume and complexity of the information received, it is not feasible for the Panel to complete its report within 90 days of the close of the record as stipulated in the original Joint Review Panel Agreement Terms of Reference.

The Panel has, however, stated that it will complete its report within the timeline set out in the amended Joint Review Panel Agreement of August 2012 on or before May 6, 2015, which is 515 days following the coming into force of the Canadian Environmental Assessment Act, 2012 (July 6, 2012). The 515 days does not include the time that was taken by the proponent to provide additional information as required by the Panel.

Following the submission of the Panel Report, and subject to the Government of Canada's decision on whether the project may proceed, the Panel may then make a decision on the proponent's application for a Licence to Prepare a Site and Construct the DGR.

Documents related to the review are available on the online public registry at ceaa.gc.ca , reference number 17520. The letter from the Joint Review Panel to the Minister of the Environment and the President of the Canadian Nuclear Safety Commission can be accessed directly at http://www.ceaa-acee.gc.ca/050/documents/p17520/100520E.pdf.

About the Project

The DGR is a proposal by Ontario Power Generation to prepare a site, and construct and operate a facility for the long-term management of low and intermediate level radioactive waste at the Bruce Nuclear site, within the Municipality of Kincardine, Ontario. Low level radioactive waste consists of industrial items that have become contaminated during routine clean up and maintenance activities at nuclear generating stations.

Intermediate level radioactive waste consists pr ly of used nuclear reactor components, ion-excl resins, and filters used to purify reactor systems. nuclear fuel will not be stored or managed in the

Obituaries

James Terence (Terry) Rogers

Terry Rogers, a leading analyst, professor and advisor, died in Ottawa on November 25, 2014 at the age of 88.

Terry was born and raised in Montreal and attended McGill University where he was the first recipient of a PhD in mechanical engineering. After brief periods in Montreal, Chalk River and San Diego he joined the Civilian Atomic Power Department of Canadian General Electric working on the designs of NPD, Whiteshell research reactor and the first Pakistan nuclear plant.

In 1970 he joined the Faculty of Engineering at Carleton University and quickly became an advisor and consultant to the Atomic Energy Control Board (predecessor of the Canadian Nuclear Safety Commission. In that context he conducted a number of seminal analyses of the safety of early CANDU designs. Among his analyses was one that refuted claims of other nuclear plant designers b showing that a CANDU unit would survive a tota failure of the main cooling pipes.

His work was recognized in 1993 when he wa awarded the W. B. Lewis Medal for outstandin scientific or engineering contributions.

That same year he retired from Carleton but con tinued to consult and served on the Research an Development Advisory Panel of Atomic Energy o Canada Limited until three years ago.

Terry was also an avid sportsman. He playe on the McGill Redmen football team despite hi modest build. Over the years he was an active skier At home he was a prodigious reader of history politics, science and technology.

Terry leaves his wife Sharon, four children an nine grandchildren. He was buried in the family plo in Montreal on November 28. A celebration of hi life was held in Ottawa the afternoon of December 1 with a large gathering of friend and colleagues.

Stanley Ronald (Stan) Hatcher

Stan Hatcher, a former president of Atomic Energy of Canada Limited, died November 30, 2014.

Hatcher was born in England in 1932. He obtained a B.Sc. and M.Sc. in Chemical Engineering from Birmingham University then emigrated to Canada in 1954 where he earned his Ph.D. from the University of Toronto in1958.

He then joined AECL as a research engineer at the Chalk River Nuclear Laboratories.

He spent the next 34 years with AECL, 19 of which were at the Whiteshell Nuclear Research Establishment (WNRE) in Manitoba.

In 1986 he was appointed President of AECL Research which had been spun off as a separate entity. Three years later, in1989 he was named President and CEO of AECL. Three years later, in 1992, he left AECL and co-founded a consulting company, Energy Strategists Consultancy Limited, in Washington, D.C. and became very active in the US nuclear program.

Shortly thereafter he was elected President of the Pacific Nuclear Council (originators of the series of Pacific Basin Nuclear Conferences such as PBNC 16 which the CNS organized in Vancouver in August 2014). He also became very active in the American Nuclear Society and became the second non-American to hold that position. (The first was W.B. Lewis.)

Over the years he was honoured many times for his contributions to nuclear science and engineering. This included the Ian McRae Award from the Canadian Nuclear Association. He was named a Fellow of many engineering and nuclear organizations, including the Canadian Nuclear Society.

A funeral service was held at St. Alban's Anglican Church in Georgetown, Ontario, on December 8, 2014.

CNS news

From the President

As I near the middle of my term as your President (yes, time flies!), and with 2015 fast approaching, I would like to leave you with two important messages.

OUR EVENTS – conferences, technical meetings, workshops and courses – are the life blood of our Society, helping it fulfill its goals and keeping it financially sound. These events do not happen on their own; they need countless volunteer hours, strong support from our industry partners and involvement from you, our Society members.

Take a look at what the CNS is offering in 2015:

March	CANDU Reactor Technology & Safety Course
May	CNS Annual Conference + CNS/CNA Student Conference + OCI Supplier Event
June	**First** International Technical Meeting on Fire Safety and Emergency Preparedness for the Nuclear Industry
August	International Conference on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors
October	International Conference on Simulation Methods in Nuclear Engineering
November	International Nuclear Components Conference

These are challenging times for the nuclear industry, and for the CNS. I am asking each and every one of you who has not done so already to get engaged in our activities. Please roll up your sleeves and help us succeed:

- Convince your employer to give a bit of your time to the CNS, to sponsor an event, to put up an exhibit.
- Advertise CNS events at your workplace
- Join the team and help organize/run an event.
- Be a presenter.
- Simply attend.

The CNS has over 1100 members. Think of what we can achieve as a team!

TAKE THE TIME to enjoy the Holiday Season with your family and friends. There is no better time to stop and focus on what is most important in our lives. If this seems to be in conflict with my first message, it is! Take a REAL break! Come back refreshed in the new year! And take a New Year's resolution to do at least one thing for the CNS. Merry Christmas and Happy 2015!

CNS Membership Note

It is time to renew your CNS membership for 2015. Please log in to your personal CNS profile: You can access your account at any time by logging in to https://cns-snc.ca/accounts/cns_member_renew (or via the Membership page of the CNS website, www.cns-snc.ca). You can then very easily and quickly renew your membership.

Earlybird renewal fees are available right now, until December 31, so I strongly encourage you to take advantage of the discount!

And please remember to keep your CNS profile current when there are changes in your information.

Best regards,

Ben Rouben
Chair, Membership Committee

Note d'adhésion à la SNC

Il est temps de renouveler votre adhésion à la SNC pour 2015. Accédez à votre compte personnel en visitant https://cns-snc.ca/accounts/cns_member_renew ou bien à partir de la page des adhésions au site de la SNC (www.cns-snc.ca). De là vous pourrez renouveler votre adhésion très facilement et rapidement.

Il y a un escompte sur les renouvellements jusqu'au 31 décembre. Je vous encourage donc d'en profiter !

Et veuillez bien vous rappeler de mettre vos données à jour chaque fois qu'il y a un changement.

Bien cordialement,

Ben Rouben
président du comité d'adhésion

News from Branches

Ed. Note: Most of this report is based on submissions to Council for its meeting October 31, with some later material included.

BRUCE – John Krane

The Bruce Branch is planning a presentation later on this Fall.

CHALK RIVER – Scott Read

Speakers

- The CNS and Women in Nuclear (WiN) hosted a joint talk on the evening of **October 23rd.** The speaker was Larkin Mosscrop who gave a talk titled *"Environmental Remediation of Contaminated Nuclear Sites"*. The talk was well attended and the audience engaged in an active Q&A session afterwards.

Our Branch AGM is the next thing scheduled for us.

DARLINGTON

Merger of Darlington/Pickering Branch to form Durham Branch is progressing.

NEW BRUNSWICK –

Search of new Branch Chair is progressing well.

On the evening of Wednesday, **October 1, 2014** members and guests of the CNS-NB branch gathered in the Mary Oland Theatre at the New Brunswick Museum in Saint John for **Norm Sawyer's** presentation on "Managing Difficult Challenges" in the nuclear industry.

Well known to many in the audience from his early years in the commissioning and start-up of Point Lepreau, Norm has also worked in leadership roles with the CNSC, as Station Manager of Gentilly-2, as a Senior Executive with Bruce Power, and in an Executive advisory role to WANO and INPO. Norm recently founded ION Nuclear Consulting Ltd. to assist clients with sustainable strategies and approaches to enhance performance based on his extensive and exclusive experiences from the Canadian and international nuclear industry.

Norm led the audience through various topic areas of interest including; risk management and the critical importance of understanding the acceptable risk an organization can absorb, the effect of natural gas pricing on the economics of nuclear power in North America. Norm also addressed his thoughts on managing difficult challenges given the constraints of corporate culture, governance and management. Drawing from his years of leadership experience, Norm provided the group with significant examples of industry experience in managing enterprise risk in a complex industry.

Norm concluded his presentation with some personal observations about the importance of effective management oversight, understanding enterprise contracting strategy limitations and the impor of controlling the scope of work to match the re ments of financing and timing.

OTTAWA Branch – Ken Kirkhope

Current Branch Executive

The current executive is as follows:

Ken Kirkhope -	**Chair**
Mike Taylor -	**Past Chair**
Fred Boyd -	**Treasurer**
Jeet Khosla -	**Secretary**
Ron Thomas -	**Program Coordinator**

Two past branch executive members, Satyen Ba and Ruth Brinston, stepped down recently an present executive would like to gratefully acknow their contributions over the past few years. The b executive also acknowledges the assistance provid Wei Shen and Jovica Riznic.

Meetings

On Thursday, **25th September 2014,** the O Branch hosted a presentation by **Mr. Garry Schv** of the Canadian Nuclear Safety Commission (C entitled *"Cernavoda NPP - The EU Stress* The presentation began with a brief history o Cernavoda CANDU® Nuclear Power Plant (NPP) ect in Romania. This included a description of u features of the site and the major phases of the pr from construction until the present time. The pres tion then described the European Union (EU) stres process that took place in Europe following the acc at Fukushima, with particular emphasis on Cern NPP. Examples of actions taken by European in response to Fukushima were discussed, and a comparison made with the Canadian nuclear ind

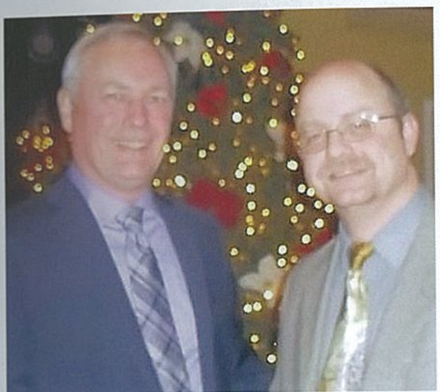
Ken Kirkho and Garry Schwarz at CNS Ottaw Branch Me on 25th Se 2014.

response to Fukushima. A very lively question & answer session followed, and at the conclusion of the session, Branch Chair Ken Kirkhope thanked Garry for a most interesting presentation.

Two events were held late in the fall.

On November 6, Dr. Neil Alexander, Executive Director of the Sylvia Fedoruk Canadian Centre for Nuclear Innovation presented an overview of the new Centre located om the campus of the University of Saskatchewan.

On December 4, a pre-holiday dinner was held with special speaker, Dr. Jeremy Whitlock, well known in CNS circles. He entertained and educated the more than 40 attendees with his comprehensive and well-illustrated story of "75 Years of Fission".



Ottawa Branch chair, Ken Kirkhope (L) and special guest speaker Jeremy Whitlock pose for the camera following Jermy's interesting presntion at the Ottawa Branch special dinner meeting, December 4, 2014.

SHERIDAN PARK – Raj Jain

The executive of the CNS Sheridan Park Branch met on November 12 to discuss and plan the Branch activities for the next few months.

TORONTO Branch – Andrew Ali

The Canadian Nuclear Society's Toronto branch in conjunction with the University of Toronto's Astronomy and Space Exploration Society hosted a presentation by Nicholas Sion entitled *"Are Humans Ready to Land On Mars?"* on Friday, November 21. The presentation covered a wide range of topics associated with human space travel to Mars and amongst them were radiological and nuclear considerations associated with deep space exploration. The pertinent radiological issues included background radiation dose levels on Mars and how they compare to those on Earth and on the International Space Station. In addition, the radiation dose received by crew members during this deep space mission and the effectiveness of various types of radiation shielding materials in dose reduction were discussed. The relevant nuclear issues included a thorough discussion on the use of Plutonium-based radioisotope sources as a power source. However, the use of radiological/nuclear materials for propulsion must be further researched. The presentation was well attended and concluded with a question and answer session.

UOIT Branch – Terry Price

The UOIT Branch continues with its operations. Highlights of recent activities include:

- Participation in UOIT Home-Coming
- Hosting **Fred Boyd** who gave his presentation on Peaceful Nuclear Explosive on **September 11th.**
- Hosting **Sergey Khulapko,** a visiting researcher from the Russian space corporation Energia who gave a presentation on **October 8th** about radiation protection problems aboard the International Space Station
- Hosting our monthly Energy Issues and Nuclear Science Discussion Group.

The UOIT Branch is currently looking for speakers to fill its 2015 line-up.

WESTERN – Jason Donev

Duane Bratt gave a presentation to the International Energy Agency on the state of nuclear power in Canada.

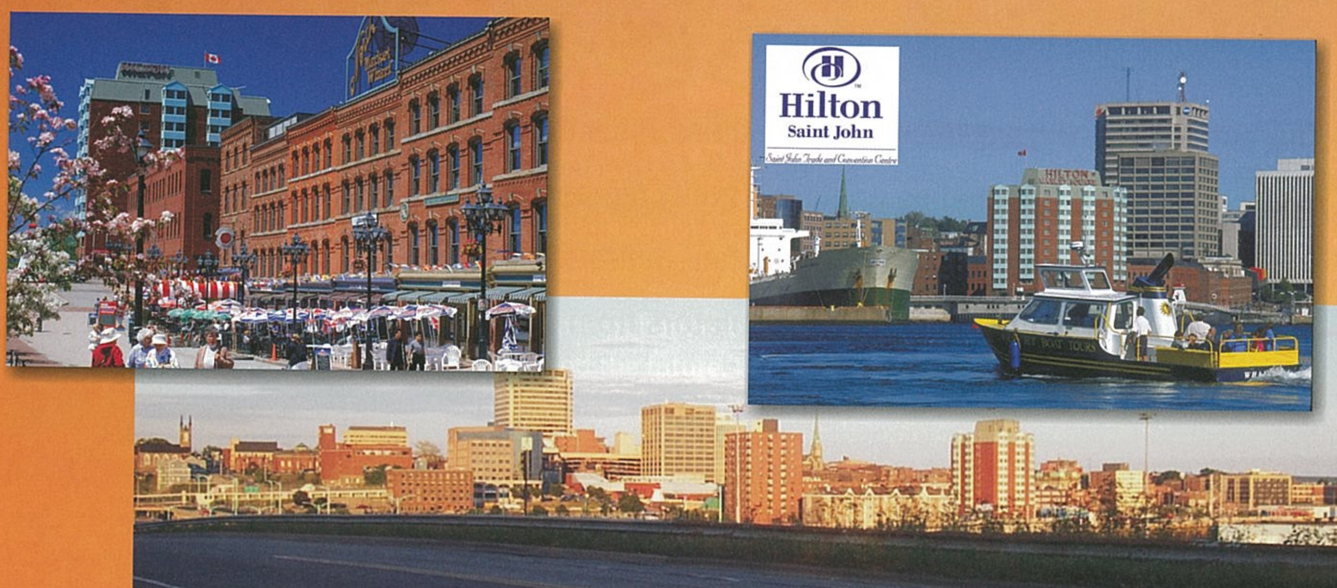
Jeremy Whitlock presented a colloquium at the University of Calgary. He spoke on the history of fission (75th anniversary talk). He spoke with several CNS student members, **Caleb Tymo, Jacqueline Williams, Shining Chen, James Jenden, Ellen Lloyd** and **Braden Heffernan.** While here he and **Jason Donev** discussed with CNS member **Michael Taylor** how we may be able to get a Geiger Counter program into the Telus Science Centre here in Calgary. It was pointed out that this would have a greater impact even than high school science teachers as it would be used far more regularly.

Neil Alexander and **Matthew Dalzell** did a great job putting together the Fedoruk Centre's annual NuclearFACTS. **Duane Bratt** and **Jason Donev** went to Saskatoon to moderate and participate in discussions along with meeting up with **Cody Crewson** and **John Hayes.** Roughly 100 people attended the public gathering in the evening and the daytime peer-to-peer discussions were lively conversations among Saskatchewan researchers who work in fields related to the nuclear industry. The following day many attendees participated in a workshop jointly held with the CNA. **Jason Donev** also had extensive conversations with U of Saskatchewan's nuclear attitudes social science group.

Michael Taylor presented the NORM workshop for Calgary's Telus Spark Science Centre to much enthusiasm and interest. Many misconceptions about radiation were addressed.

Jason Donev presented to a group of high school students who are specializing in energy related issues in a local high school tech program. The students had an in-depth discussion about energy poverty, climate change and the essential need for nuclear power to combat these problems.

Jason Donev convinced the University of Calgary to purchase a copy of the Rickover documentary for institutional use.



Hilton
Saint John

35th Annual Conference of the Canadian Nuclear Society
and 39th Annual CNS/CNA Student Conference

Nuclear Innovation through Collaboration
La collaboration facilitant l'innovation nucléaire

2015 May 31-June 3

Hilton Saint John / Saint John Trade & Convention Centre, Saint John, NB, Canada

Call for Technical Papers

The Canadian Nuclear Society's 35th Annual Conference will be held in Saint John, New Brunswick, Canada, 2015 May 31-June 3, in conjunction with the 39th Annual CNS/CNA Student Conference, at the Hilton Saint John / Saint John Trade & Convention Centre.

The central objective of this conference is to provide a forum for exchanging views, ideas and information relating to the application and advancement of nuclear science and technology, and for discussing energy-related issues in general.

- Invited speakers in Plenary sessions will address broad industrial and commercial developments in the nuclear field.
- Speakers in ***technical sessions*** will present papers on industrial, research and other work in support of nuclear science and technology.
- Plenary, technical and student sessions will highlight future developments in the field and discuss the challenges faced by the nuclear community.
- University students in Student sessions will talk about their research and academic work (a separate Call for Students' Extended Abstracts will be issued for the Student Conference).

Conference Website:
www.cnsconference2015.org

Deadlines

- **Receipt of Abstracts: 2014 November 1.**
- **Receipt of full papers: 2015 February 1.**
- **Notification of accepted paper: 2015 March 1.**

Paper abstracts (<100 words) should be submitted to the Conference Website. Please note that the abstract submission represents the author's commitment to submit a full paper on or before 2015 February 1 and, if the paper is accepted by the Conference Paper Review Committee, to present it at the Conference.

General Guidelines for Full Papers

Papers should present facts that are new and significant, or represent a state-of-the-art review. They should include enough information for a clear presentation of the topic. Usually this can be achieved in 8-12 pages, including figures and tables. The use of 12-point Times New Roman font is preferred. Proper reference should be made to all closely related published information. The name(s), affiliation(s), and contact information of the author(s) should appear below the title of the paper.

NOTE

For a paper to appear in the Conference Proceedings, at least one of the authors must register for the Conference by the "early" registration date (2015 April 15).

Paper Submission Procedure

The required format of submission is electronic (Word or pdf). Submissions should be made via: www.softconf.com/d/CNS2015Technical

Questions regarding papers and the technical program should be sent to:

Ruxandra Dranga
CNS-2015 Technical Committee Chair
e-mail: cns2015@cns-snc.ca
Tel: 613-584-3311, Ext. 46856

General questions regarding the Conference may be addressed to:

Ben Rouben
e-mail: cns2015org@cns-snc.ca
Tel: 416-977-7620

7th International Conference on Modelling and Simulation in Nuclear Science and Engineering

October 18-21, 2015, Ottawa, Canada

Call for Papers

The Canadian Nuclear Society is announcing its 7th International Conference on Modelling and Simulation in Nuclear Science and Engineering at the Ottawa Marriott Hotel, Ottawa, Ontario, Canada, from October 18 to 21, 2015.

Objective

The objective of the Conference is to provide an international forum for discussion and exchange of information, results and views amongst scientists and engineers working in various fields of nuclear engineering in industry and academia.

Topics of Interest

The scope of the Conference covers all aspects of modelling and simulation in nuclear engineering, including, but not limited to:

- Reactor and Radiation Physics
- Thermalhydraulics
- Probabilistic and Deterministic Safety Analysis
- Fuel and Fuel Channels
- Material Science and Chemistry
- Computer Codes and Modelling
- Verification, Validation, and Uncertainty Qualification
- Best Estimate and Uncertainty Analysis
- Monte Carlo Methods and Applications
- Operations Support
- Modelling and Simulation in Fusion Engineering
- Advanced Reactors & Advanced Fuel Cycles
- Real-Time Simulator, Instrument and Control
- Used-Fuel Management, Proliferation Resistance

Important Deadlines

Submission of abstract (<100 words):	2015 Jan. 31
Submission of full paper:	2015 Apr. 30
Notification of acceptance of paper:	2015 Jun. 30
Submission of final paper:	2015 Aug. 15

Embedded Events

- Tour of Canadian Nuclear Laboratories (CN formerly AECL Chalk River Laboratories)
- Workshops on DRAGON and SERPENT

Conference Registration Fees (Canadian Dollars

	By / After 2015 August 3
CNS Member:	$630 / $71
Non CNS Member:	$780 / $86
CNS Retiree Member:	$250 / $30
Full-Time Student:	$400 / $450
Workshop fees with Conference registration:	$ 7
Workshop fees without Conference registration:	$14
CNL Chalk River Tour transportation fee:	$ 3

Honorary Chair

Fred Dermarkar (President, CANDU Owners Group)

Executive Chair

Dr. Elisabeth Varin (Montreal Nuclear Services Inc.)

Technical Program Chair

Dr. Wei Shen (Canadian Nuclear Safety Commission)

Plenary Chair

Dr. Laurence Leung (Canadian Nuclear Laboratories)

Conference Organization Committee Members

Fred Adams (CNL), Constantin Banica (OPG), Adriaan Buijs (McMaster), Ruxandra Dranga (CNL), Pascal Hernu (MNS), Guy Marleau (EPM), Ovidiu Nainer (BP), Dorin Nichita (UOIT), Ben Rouben (12&1 Consulting), Alex Trottier (CNL), Mohamed Younis (AMEC NSS)

Guidelines for Abstracts and Full Papers

- Abstracts should be less than 100 words in length.
- Full papers should present facts that are new a significant or represent a state-of-the-art review. Th should include enough information for a cle presentation of the topic.
- Abstract and full-paper templates available on t Conference Website.

Submission Procedure

Submissions of full papers, preferably in MS Word format, must be made electronically via the link on: https://www.softconf.com/f/7icmsnse/

Questions?

Technical program: wei.shen@cnsc-ccsn.gc.ca
General questions: CNS Office: cns-snc@on.aibn.com
Conference Website: http://cns2015simulation.org/

Canadian Nuclear Society
Société Nucléaire Canadienne

1st Technical Meeting on Fire Safety and Emergency Preparedness for the Nuclear Industry

Delta Meadowvale Hotel & Conference Centre
Mississauga, ON, June 17 – 19, 2015

The 1st International Meeting on Fire Safety and Emergency Preparedness will provide a forum for nuclear professionals to network and communicate changes presently impacting the industry. It is an opportune time as the new standard, CSA N393 Fire Protection for Facilities that Process, Handle or Store Nuclear Material is approved for use. This standard may affect facility licenses as early as 2014. It is expected that CSA N393 will be included in a broader range of facility licences and will replace NFPA 801 Standard for Fire Protection for Facilities Handling Radioactive Materials in existing licences.

Emergency Preparedness is at the forefront of the nuclear industry since the 9.0 magnitude earthquake and tsunami 2011 that resulted in the Fukushima nuclear incident. The CNSC has introduced REGDOC 2.10.1 Nuclear Preparedness and Response to clarify emergency preparedness requirements. This document is now in draft form and has been issued for comments.

The conference is intended to attract participants from various sectors of the nuclear industry relating to power reactors, research reactors, nuclear laboratories, mines, processing, storage and handling facilities, decommissioned nuclear facilities, nuclear medicine and transportation of nuclear materials.

FSEP 2015 – Call for Abstracts

The Technical Program Committee invites the submission of abstracts for proposed presentations pertaining to the topic areas within each of the four conference themes. Abstracts are to be no more than 300 words in length and the deadline for submission of abstracts is **December 15, 2014**. Details will be on the conference website soon, www.cns-snc.ca.

Get engaged: plan to participate as a Speaker, Session Chair or member of the Organizing Team.

Technical Focus

Business Performance and Governance	Human Performance	Technology	Processes and Programs
Regulatory Affairs	Succession Planning	Communication	Nuclear Safety
Codes & Standards	Instructional Systems Development/Training	Event Simulation	Integrating Services
License and Laws	Personnel Safety	EME	Fire Prevention
Organizational Design/Alignment	Human Resources	Fukushima	Engineering Change Control
Management Oversight	Leadership	Emerging Technologies	Business Continuity
Visions of the Future	Ethics	Analytical Tools	Risk Management
Strategies	Human Factors	Fire Protection Systems	OPEX
Business Metrics	Management of Performance Systems	Emergency Response Equipment	Analysis, Evaluation and Measurement

Conference Chair:
Tracy L. Pearce
Atomic Energy of Canada Ltd
Chalk River Laboratories
1-800-377-5995 x 44084 pearcetl@aecl.ca

Technical Chair:
Rudy Cronk
Professional Loss Control
3413 Wolfedale Road, Suite 6, Mississauga, ON
1-800-675-2755 rcronk@plcfire.com

Calendar

2015

Feb. 21-Feb. 26 — **9th International Conference on Nuclear Plant Instrumentation, Control & Human-Machine Interface Technologies (NPIC & HMIT 2015)**
Charlotte, NC
website: www.cns-snc.ca

Mar. 9-Mar. 11 — **CNS CANDU Reactor Technology and Safety Course**
Courtyard by Marriott Hotel, Toronto
website: www.cns-snc.ca

Mar. 15-Mar. 18 — **7th International Symposium on Supercritical Water-Cooled Reactors (ISSCWR-7)**
Helsinki, Finland
website: www.cns-snc.ca

May 25-May 27 — **4th Climate Change Technology Conference (CCTC-2015)**
Hotel Omni, Mont-Royal
website: www.cns-snc.ca

May 31-June 3 — **CNS 2015 Annual Conference**
Saint John Hilton and Conference Centre
website: www.cns-snc.ca

June 7-June 11 — **ANS Annual Meeting**
San Antonio, Texas
website: www.ans.org/meetings

June 17-June 19 — **1st International Technical Meeting o Fire Safety and Emergency Preparedn for the Nuclear Industry**
Delta Meadowvale Hotel and Conference Centre, Mississauga, ON
website: www.cns-snc.ca

Aug. 9-13 — **17th International Conference on Environmental Degradation of Materia in Nuclear Power Systems – Water Reactors**
Fairmont Chateau Laurier Hotel, Ottawa
website: www.cns-snc.ca

Aug. 30-Sept. 5 — **Nuclear Reactor Thermal Hydraulics (NURETH-16)**
Chicago, USA
website: www.cns-snc.ca

Oct. 18-Oct. 20 — **7th International Conference on Simula Methods in Nuclear Engineering**
Ottawa, ON
website: www.cns-snc.ca

Nov. 1-Nov. 4 — **International Nuclear Components Conference**
Mississauga, ON
website: www.cns-snc.ca

A Shot in The Dark

by JEREMY WHITLOCK

Dear European Space Agency,

Congratulations on landing a spacecraft on a comet. Well done. You deserve all the accolades for successfully flying a machine 6.4 billion kilometres to the depths of our solar system, and landing on a four-km wide piece of ice hurtling at 135,000 km/h.

The opportunity for knowledge that you have given the human race is as monumental as it is rare: a once-in-a-lifetime chance, when you consider not just the vagaries of the mission itself, but the fickle winds of policy and bureaucracy that converged on a successful launching of Rosetta over a decade ago.

What, in the name of Arthur C. Clarke, were you thinking when you powered Rosetta and its lander, Philae, with solar cells?

It's not so much the sheer distance from earth, where the sun's energy is four per cent what it is at home – but the almost complete randomness of the landing. What you did was like investing your life's savings in a bank of solar panels to power your retirement home, and then giving the panels one big spin and locking them down in whatever orientation they came to rest.

Are you surprised that poor Philae settled in the shadow of a cliff, and had two glorious days of data acquisition before its batteries died out?

"Yeah but... hey, we still landed on a comet!" – the desperation in this cup of lemonade squeezed from a truckload of lemons was palpable.

Half a century ago we invented something called a Radioisotope Thermoelectric Generator (RTG) – a way to generate power independently of the sun.

It's what powers (and warms) the Cassini probe, orbiting Saturn since 2004 – where sunlight is as rare as common sense in a German energy plan.

It's what keeps the Curiosity rover ploughing over the surface of Mars, even as its solar-powered cousins, Spirit and Opportunity, sputter and stall with each passing dust storm.

A few kilograms of plutonium-238 would have lessened your anxiety over the final orientation of your Philae lander – think of the extra nights' sleep you all would have had without that added uncertainty. With its batteries on continuous charge Philae would have ridden 67P/Churyumov-Gerasimenko all the way to the sun, like a nuclear-powered Slim Pickens from Dr. Strangelove, hooting and hollering its game-changing data all the way.

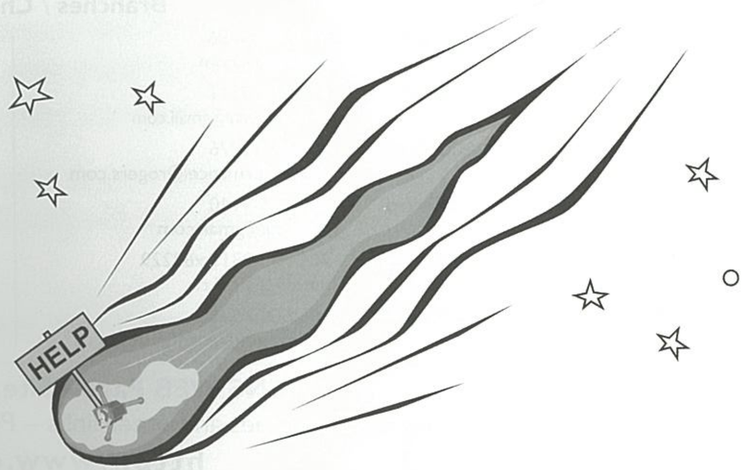
Instead, you find yourselves gambling on one last-minute nudge before the batteries died, a hope that Philae can be awoken in a year's time, and a prayer that its PV cells won't be damaged by dust and gas of the type that ... well ... spews copiously from a comet as it nears the sun.

Now I know that the EU is not enamoured with nuclear power, but we're not talking about a nuclear fission reactor here – surely the brilliant minds that planned and executed the Rosetta/Philae mission could put politics aside for one moment of unquestionable relevance to the success of a 1.4 billion Euro shot in the dark.

In a way, this outcome is not too surprising – perhaps a cautionary tale about letting idealism and fear guide technical decisions. Especially technical decisions with potentially show-stopping repercussions.

But I can't help imagining poor Philae, all alone in the dark on that dust-covered ice ball, so far from the Euro hand-wringing over nuclear politics – its last thought as it slips into deep sleep (perhaps forever): a wish that the sun-worshippers back home who built its useless power source could see just how small the sun appears in the black, cold distance...

Best of luck with the mission.



2014-2015 CNS Council • *Conseil de la SNC*

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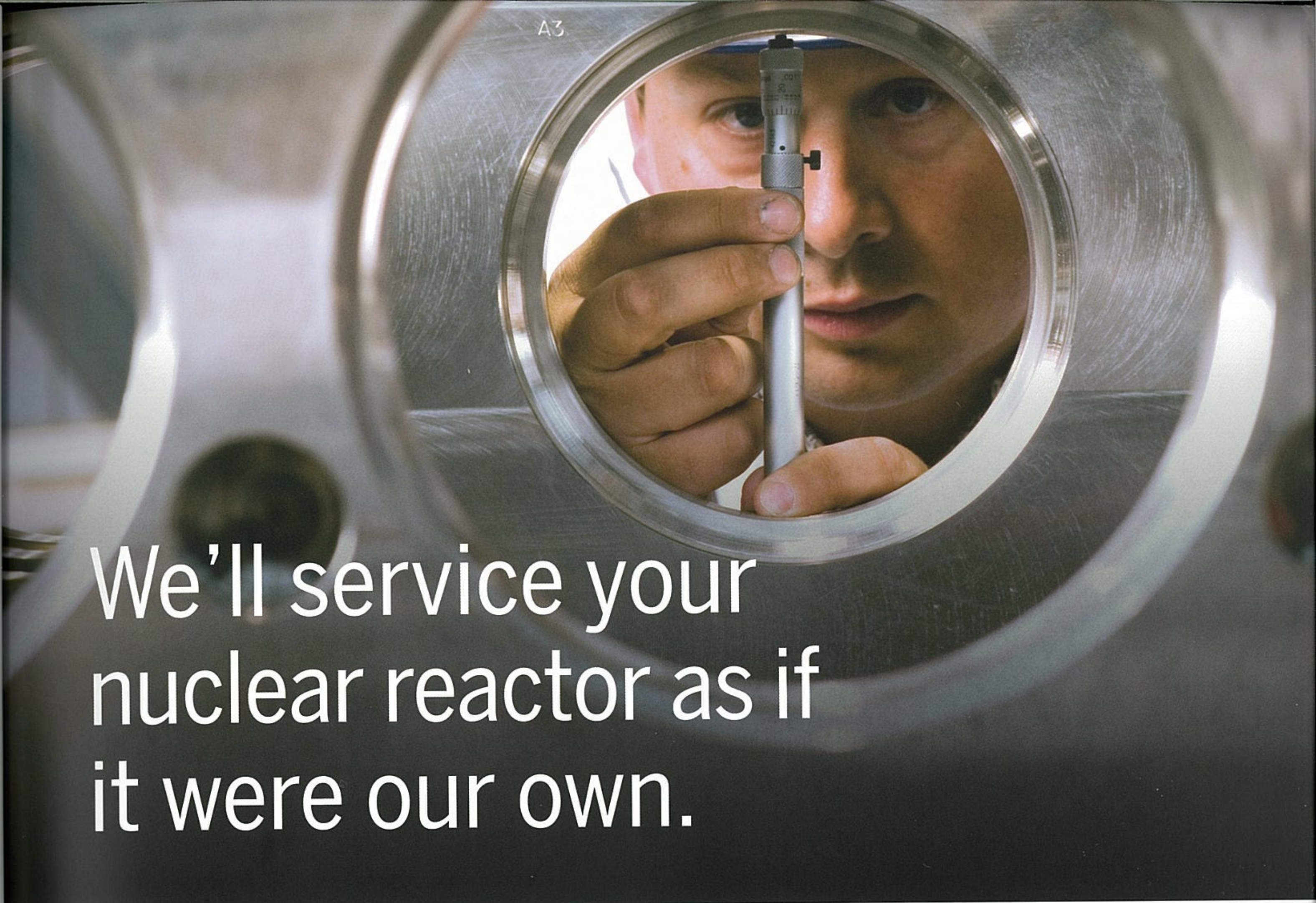
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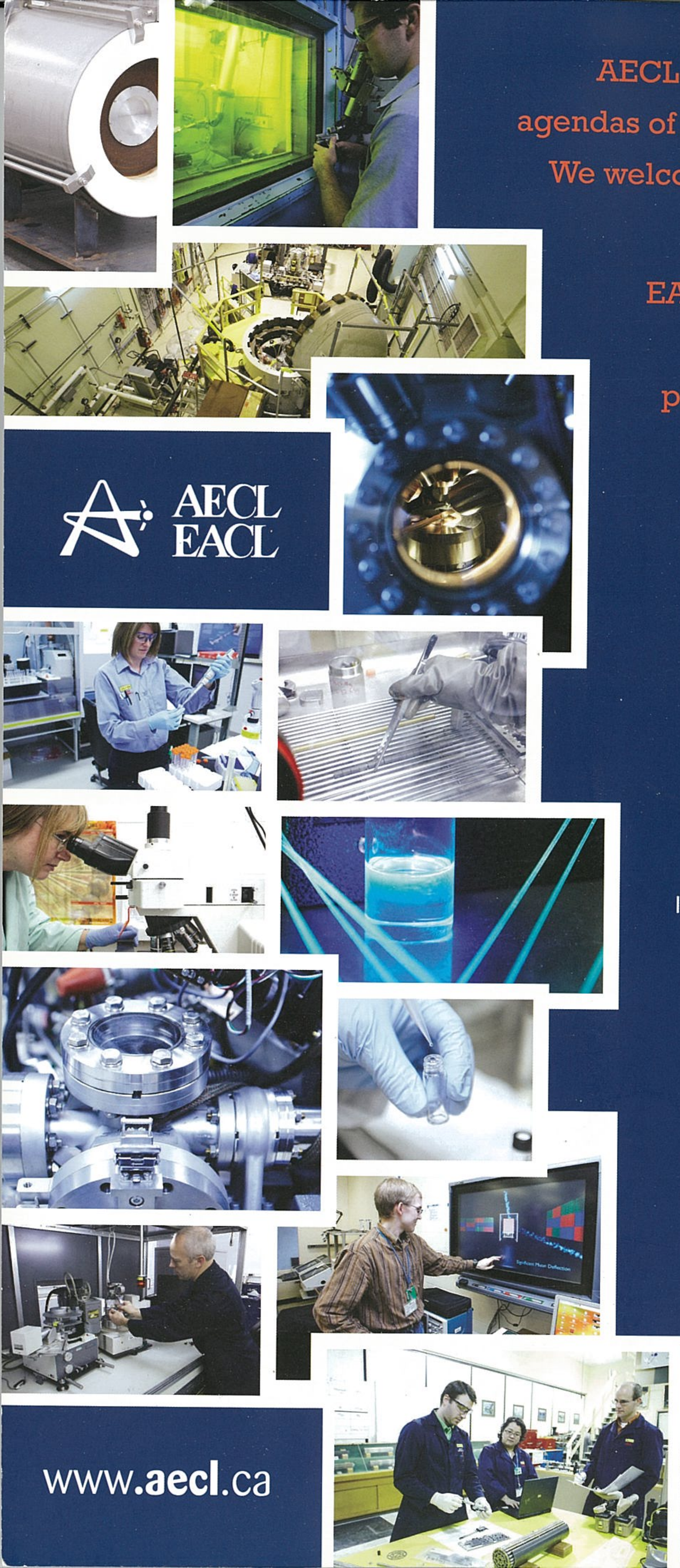

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