What's up with Global Warming?

If you guessed temperature, you would be wrong. There has been no measureable global warming in the last 18 years despite increases in atmospheric CO_2. Although lately the arctic has seen warmer temperatures and melting ice, the Antarctic has seen the opposite. These are the facts based on science, where scientific method is observation and measurement, not policy or politics.

Politically, however, the issue of global warming is indeed heating up. The Encyclical of Pope Francis, *Laudato Si'*, contains a concept called "Integral Ecology", that is, creatures exist in their environment, and human activities should not cause environmental deterioration. The Encyclical states that there is a scientific consensus that anthropogenic greenhouse gas emissions are causing global warming, but politicians are taking sides with that issue.

The Encyclical states "*With regard to climate change, the advances have been regrettably few. Reducing greenhouse gases requires honesty, courage and responsibility, above all on the part of those countries which are more powerful and pollute the most*." With the recent visit of Pope Francis to the US Congress, democrats gave him a standing ovation for his climate change remarks whereas most republicans refused to stand or applaud his remarks.

The large corporations that have a vested interest in fossil fuel are making huge tax-deductible financial contributions to politicians who support the "deniers" of global warming, mostly republicans. Other politicians, mostly democrats including US President Obama are expressing grave concern about global warming and are pushing a new Clean Energy Act. Environmental groups are also sounding the alarm on global warming although they tend to be more alarmist than scientific.

Is science predicting global warming? No. Science is based on observation and measurement and global temperatures are a matter of records and databases. Predictions of global warming are coming not from science, but from "studies" using large computer models, such as General Circulation Models (GCM). These models are based on mechanisms assumed to be important, but like all mechanistic models the output is wrong if mechanisms are missing. For example, most GCMs do not account for the effects of solar cycles, changes in the earth's orbital tilt, or even lunar effects known to drive the ocean's tides (which, among other things, affect the CO_2 exchange between the oceans and atmosphere).

To include more mechanisms requires more powerful computers. On the other hand, empirical models are based less on mechanistic and theoretical approaches but rather on observation and measurement, the basis of scientific method. The problems, however, are (a) insufficient scientific observation and experiment and, (b) insufficient precision of temperature measurements to obtain a global average. There are very few temperature measurements over the oceans, yet oceans cover most of the planet. Furthermore, due to limitations in computer modelling the GCMs discretizes the globe into such a course grid that it exceeds the span of clouds, so cloud influence is not captured.

Scientific observation and experiment comes from research, but research requires funding. Traditionally sources of funding have been governments, universities and some corporations and foundations. In Canada, research funding has been systematically reduced, and government scientists are "muzzled", that is, their research papers are censored or heavily edited. University research scientists are not censored, but being reliant on ever-reducing government funding, less research can be conducted. Environmental groups such as Greenpeace do not have sufficient funding for proper research, and resort to high profile media coverage of alarmist tactics to raise funds. Who gets the limited funds for research? The unbiased scientists who adhere to scientific principles, or those who already believe that anthropogenic emissions are causing global warming? The latter. So it is then that the science of climate change has become politicized.

The Intergovernmental Panel on Climate Change (IPCC) is commonly believed to be a consensus of scientific knowledge; in fact, as a panel of the United Nations, its members are nominated by governments (politicians).

All of the above is not to suggest that global warming is not occurring - it is, about 0.7°C over the last 100 years according to NASA measurements. But the extent to which anthropogenic CO_2 can accelerate future warming needs to be determined by science, not politics.

In This Issue

Our lead item is the report on the very successful International Conference on Environmental Degradation of Nuclear Materials. The topic is timely given many utilities are planning refurbishments and life extensions. Also important and cause for celebration is our 70 years in the Canadian nuclear business. The History section describes how we got to where we are, as well as a paper describing the building and operation of the ZEEP reactor at Chalk River (shown on the cover page). This paper was first presented at the 2005 CNS annual conference.

Our new President is Paul Thompson. Fred Boyd (former Bulletin Publisher and Editor) has prepared a "Meet the President" article. And last but never least, Jeremy Whitlock commiserates the obligatory yet dreaded "Class Reunion" in Endpoint.

Comments and letters are always welcome!

From The Publisher

It's the fall of 2015, and with the falling of leaves has come the dropping of writs. Our country is now engaged in its 42nd general election. Let's pause there just for a moment. This is the 42nd time that Canadians have gone to the polls in 148 years since Confederation. That means that we do this almost precisely every three and a half years on average.

This one must be important. Since the dissolution of Parliament on August 2, it will be an election campaign of no less than 78 days before voting day on October 19, making this the longest national election in Canada's history. One would think that 78 days would allow plenty of time for exploring thoroughly all of the issues confronting the future prospects of our nation. It is then reasonable to ask whether or not nuclear science and technology will emerge as a possible area of interest to either voters or the assorted candidates seeking their support.

Elections are supposed to be about great events or crises confronting the nation. From all of the overheated rhetoric over the past months and years, the average observer might presume that climate change (or Anthropogenic Global Warming to use its proper and honest technical name) would be a matter of some concern. After all, if restricting or eliminating emissions of carbon dioxide is of such great national importance, how do the various parties propose to achieve this?

What we have seen thus far is a veritable smorgasbord of policy choices on offer. They range from various forms of alternative generation of electricity to assorted measures to tinker with the cost of energy. The latter comes in two basic varieties: a tax on the emission of carbon dioxide or some form of cap and trade scheme. The former comes in the form of advocating for various types of so-called renewable generation.

There's a problem in all this, as the constitutional division of powers in Canada means that decisions on the generation of electricity lie with the provinces, not the federal government. Hence, for any federal government, supporting various technologies can only come indirectly through things like supporting research and development, not through direct implementation.

Let's deal with the tinkering with the cost of energy first. Regardless of which device is chosen, cap and trade or carbon tax only achieve the end of a flat tax. Flat taxes by their very nature are the most unfair of all forms of extracting wealth from citizens, particularly where it is levied on a commodity, electricity, which everyone needs. Let us also at the same time dispose of the myth of a "revenue-neutral" tax. There's no such thing. At the very least, there's the cost of administration of the tax. What politicians, activists or advocates mean by "revenue-neutral" is a redistribution of collected wealth into the hands of their favoured beneficiaries or causes.

Being a community of scientists, engineers and technical people, we in the nuclear industry prefer to deal with empirical data rather than airy speculations. So here are the hard facts. Since 1980 there have been five periods in Ontario's economic history when emissions of carbon dioxide have declined on a year over year basis. Three of those periods, 1982-3, 1992-3 and 2007-8, had reductions caused by economic recessions. Only two of the five periods, 1984-7 and 2008-2014, have been accompanied by any economic growth. In both cases, Ontario's reductions were achieved by the direct substitution of nuclear generated electricity for fossil fuels. In the 1980s, the reductions were achieved by the completion of the B plants, and since 2008 the reductions have been achieved by the return to service of six nuclear reactors. Only that return to service permitted the closure of Ontario's last coal fired stations: Lakeview, Nanticoke, Lambton and Atikokan.

In short, only nuclear energy has actually demonstrated in Canada the ability to displace fossil fuel and reduce emissions on any significant scale. But is there any discussion of nuclear as a means of achieving such a seemingly important goal?

Not a whisper.

The conclusion is evident. Until Canadians and their policy makers openly discuss the importance of nuclear energy in what is claimed to be the global crisis of all time, all of the rhetoric about global warming can be dismissed as meaningless blather.

So whatever this 78-day election is about, it is not about global warming or anything else of importance to Canada's nuclear industry.

C.G.H.

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~ Cover Photo ~

Historic photo of the ZEEP reactor building seen during its operational period in the 1960s.

Photo courtesy of Canadian Nuclear Laboratories.

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Editor / Rédacteur
Ric Fluke Tel. (416) 592-4110
e-mail: richard.fluke@amecfw.com

Publisher
Colin Hunt Tel./Fax (613) 742-8476
e-mail: colin.hunt@rogers.com

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CNS Hosts International Conference on Environmental Degradation in Ottawa

By Colin Hunt

More than 145 delegates attended the 17th International Conference on Environmental Degradation of Materials in Nuclear Power Systems (17th EnvDeg) at the Chateau Laurier in Ottawa during this past summer. The four-day event was held starting August 9, 2015 and was attended by scientists and researchers from dozens of nations around the world.

According to Conference Chair Peter Andresen, the attendance was so large and so diverse as to make it one of the most successful of the conferences in this series ever held. The conference is organized by volunteers from a number of companies and institutions. It is held every two years and is hosted on a rotating basis by a number of nuclear organizations and societies. In 2015, it was the turn of the CNS.

The conference opened on Sunday, August 9 with a reception for delegates and concluded with the final technical session on Thursday August 13. The conference commenced with an opening plenary on August 10, and the remainder of the conference had at least three and sometimes four parallel technical sessions each day.

The opening plenary session commenced with CNS Past President John Roberts welcoming all delegates to Canada and to the opening of the conference. For many, it was their first time in Canada and to the nation's capital. Mr. Roberts was representing CNS 2nd Vice President Daniel Gammage, Conference Host, who was unable to attend.

The first speaker was Kurt Edsinger, Director, Materials, Electric Power Research Institute (EPRI). Dr. Edsinger provided a powerful perspective on the extent of the problem posed by environmental degradation to human infrastructure. He started by noting that the annual cost of degradation in the United States is about $276 billion. Of that, the annual cost to the electricity industry is about $17 billion, of which $6.7 billion is inflicted each year on the nuclear portion.

Dr. Edsinger noted that, despite the scale of the problem, energy sectors remain one of the lowest priorities for research funding in the United States. Founded by Dr. Chauncey Starr in 1973, the bulk of such research is carried out by EPRI. Forty-five per cent of EPRI's research is devoted to nuclear power, one quarter of which is in the field of environmental degradation.

He observed that over time the electricity sector is going to continue to grow. Given the relative paucity of new construction of generation and transmission, utilities, regulators and governments are now starting to consider the prospect of 80-year life spans for nuclear power reactors.

Such an operating life is considerably longer, more than double, what was originally considered when all of these plants were built. To achieve this much longer operating life, extensive assessments of plant conditions, progress of degradation and assessment of knowledge gaps becomes essential.

Dr. Edsinger indicated that in the light of the above, EPRI was concentrating its work in a number of key areas:

- Irradiation-associated stress corrosion cracking;
- Materials fatigue, which may be the single largest problem when looking at operation beyond 60 years;
- Steam generator performance;
- Welding lightly irradiated materials;
- Correlating irradiation damage mechanisms.

These were only the most prominent areas; Dr. Edsinger noted that there were many other important areas of research beyond these top priorities.

The second plenary speaker was Dr. Peter Andresen, Principal Scientist, GE Global Research Centre and Conference General Chair. Dr. Andresen looked at the past half century of research and development in nuclear science. Dr. Andresen commenced by noting the enormous leverage provided by research in nuclear energy.

For each $1 million in research invested, $1 trillion in plant investment had resulted.

Dr. Andresen noted that science and technology development is in large measure the result of the power of negative thinking.

"The way we get better is through the things we don't do well."

By way of illustration, Dr. Andresen noted that in 1852, 50,000 people died from steam boiler explosions with a further two million injuries. The near absence of such injuries today on an annual basis shows just how much progress has been made in the intervening century and a half.

Dr. Andresen observed that environmental degradation has been and continues to be a growing problem. It is exacerbated by a tendency to perceive failure episodes as unique and not systematic.

Another large aspect of the problem of degradation is the inadequacy of the ASME codes. Dr. Andresen characterized these as largely the result of mechanical engineering which did not take environmental factors into account.

ASME, the American Society of Mechanical Engineers, is one of the principal standard setting bodies worldwide. ASME sets standards like the Canadian Standards Association (CSA) for materials, fabrications, and processes. All standards are voluntary unless incorporated into a binding contract or embodied in regulation.

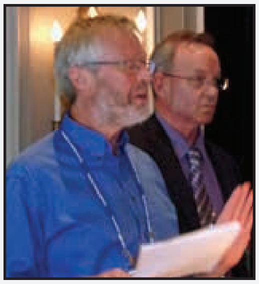
"There is a tendency now to think that policies and guidelines are a substitute for knowledge and experience," Dr. Andresen said. He noted that plant management had become too much preoccupied with meeting regulatory requirements and deeming that sufficient for effective long term plant operation.

Dr. Andresen further noted that standards are not keeping pace with changes in the metal processing industry. Taken all together, these structural and management problems posed difficulties for greatly extended operation of nuclear plants beyond 60 years if not addressed.

The conference was concluded on Wednesday, August 12 with a closing banquet and poster session and reception. A final half-day parallel technical session was held on Thursday, August 13.

The banquet was organized as an informal meet and greet with no fixed seating, an arrangement welcomed by delegates.

The student poster winners were Jian Xu, Tohoku University, Nathan Johnston, University of Birmingham, and Kevin Daub, Canadian Nuclear Laboratories.



Mike Wright and Dr. Peter Andresen.

The conference was organized with Mike Wright, CNL, Technical Program Chair; John Jackson, Idaho National Laboratories, Assistant Technical Program Chair; and Conference Treasurer Tracy Lapping, CNL.

Dr. Andresen credited the CNS and Conference Administrator Elizabeth Muckle-Jeffs for the flawless execution of the conference and the great, positive experience had by all the delegates.

Pictured are the student poster winners. Left to right Kevin Daub, Nathan Johnston and Jian Xu.

Scenes from the Conference: Opening Reception

Seventy Years in the Nuclear Age

by JEREMY WHITLOCK, PhD, FCNS

Seventy years ago Canada became the second country on the planet to control nuclear fission – the nation barely seventy years old itself, with a well-earned reputation for punching above its weight class.

In September 1945 we were still getting used to the idea that the war was over, and the Atomic Age had begun. Two American bombs of unimagined power had ended the hostilities, followed shortly by a statement from the Canadian government that Canada had proudly played an “intimate” role in their development.

Post-war hubris aside, it was true that Canada had participated in the Anglo-American atomic bomb program, and had, by accident of geology and geography, come out of the war with the world’s second largest nuclear infrastructure. The time would soon come to decide what to do with it, but for now, a month after the war’s biggest secret was out, the focus was still very much on getting the job done.

Here, in a clearing on the wooded Ontario shoreline of the Ottawa River about two hours west of Ottawa, Canada would become the second nation to construct a working nuclear reactor. It was Sept. 5, almost a month to the day after the Hiroshima bombing.

For Lew Kowarski it was a moment of personal closure. Five years earlier the burly Russian-born scientist had escaped France aboard a collier on the eve of Nazi occupation, with almost the world’s entire supply of “heavy water” – about 200 litres in 26 cans. Three months before that the precious scientific cargo had been spirited out of Norway, just ahead of the German invasion of that country. Once safely on English soil, Kowarski and fellow refugee scientist Hans von Halban continued their experiments with uranium and heavy water that they had pioneered in France.

By an extraordinary convergence of history, the most spectacular scientific discovery of the century, the splitting of the atom (or fission), had been discovered just prior to the outbreak of the largest global conflict in history, and the discovery was made in Germany. Furthermore, many of the practical advances in studying this new energy source were made in France, and now all of that was in German hands.

All, that is, except Kowarski, Halban, and their heavy water. It was known that uranium fission could generate a lot of heat, and that heavy water (a rare form of regular water) could help achieve this. Increasingly, the British government became convinced that they possessed the energy source for a new weapon of immense destructive power, and if that were true, then so did the Nazis. One outcome of this suspicion was a 1943 commando raid on the Norwegian hydro plant that generated the heavy water.

Meanwhile, across the Atlantic in Ottawa, deep within the gothic laboratories of the National Research Council on Sussex Drive, Canadian scientist George Laurence closely followed Kowarski and Halban’s work against the descending secrecy of WW II. By day, Laurence was responsible for teaching radiography to Canada’s wartime aircraft industry, but in his spare time he worked towards building one of the world’s first nuclear reactors.

Instead of heavy water, Laurence opted for carbon, a less efficient but cheaper and more available substitute. With 10 tonnes of the black, messy stuff (in the form of petroleum coke), and 450 kilograms of black uranium powder borrowed from Eldorado Gold Mines Ltd. in the Northwest Territories, Laurence conducted his experiments from 1940-42. In the summers he had help from Professor B.W. Sargent of Queen’s University in Kingston, Ont.

The Holy Grail of this type of work was a self-sufficient nuclear reaction; that is, one in which uranium atoms continuously split each other in a chain reaction that requires no outside help. With purer materials and a full-time effort, Laurence might have been the first in the world to achieve this, but that honour went to Enrico Fermi on Dec. 2, 1942, in Chicago.

The Americans had awoken to the grim prospect of a German atomic bomb, and were now putting their fullest wartime machinery behind the task of getting there first. All agreed that if the Germans won this race, they’d win the war, regardless of their standing elsewhere in the conflict.

Britain and the United States, each with its own cadre of dispossessed European scientists, formed a top-secret nuclear alliance that in demographic, scope and intent could only have been conceivable during WW II. The world’s most brilliant minds were locked in a macabre race to build the perfect weapon.

But there was more to it. Nuclear fission was an energy source of almost unlimited potential, both good and bad. In a Faustian twist, the scientists were also building the energy source of a postwar industrial boom, or so many thought.

Developing concerns over security and industrial patents strained the Anglo-American relationship, and when the British offered to move their group to America to escape the European theatre of war, they were flatly refused. This is where Canada came in. A British colony with an abundance of both water and uranium, plus skilled workers, open space, natural resources, energy and (not least in importance) proximity to the American effort, the choice was clear.

With a characteristic "Okay, let's go!" by Minister of Munitions and Supply, C.D. Howe, a decision was made to host the British project in the fall of 1942. It was a defining moment for Canada, shaping the future direction of its science and technology infrastructure and thrusting it directly onto the world stage.

The British group was assigned to the National Research Council, and was joined by a number of Canadians led by Laurence. Space was found in a building at the University of Montreal, in a suitably cosmopolitan city. The Montreal Laboratory, as it became known, had the task of designing a pilot heavy-water nuclear reactor for producing plutonium. Prior to the war, plutonium had only existed in trace amounts. Now it held a place alongside uranium as the miracle fuel of the future. Interestingly, plutonium could only be created in great quantities within a nuclear reactor, one example of which was now the Montreal lab's focus.

The task had military significance, but the greatest concentration of scientific minds in Canadian history set about its task with an eye on the other edge of the sword: NRC President C.J. Mackenzie later commented that the deciding factor in taking on the Montreal lab was the obvious long-term social and economic significance of atomic energy. Canada was getting in "on the ground floor of a great technological process for the first time" in its history. Mackenzie never expected the project to be finished in time to contribute to the war.

Indeed, it was July 1944 – a month after D-Day – when a site for the pilot plant was chosen about two hours west of Ottawa, seven kilometres north of the village of Chalk River on the shores of the Ottawa River. In utter secrecy a complete scientific lab was built from scratch, along with a town site–Deep River–for its workers a few kilometres to the west. Both sites were built by Defense Industries Ltd., with the familiar white and green colour scheme of Canadian military installations. Petawawa Works, as it was known during construction, looked like nothing more than an extension of nearby Canadian Forces Base Petawawa. This was, of course, the intention.

Chalk River Nuclear Laboratories was to host a 20-million-watt reactor called the NRX, for National Research X-Metal (X-Metal being the wartime code for uranium; later the name was changed to National Research Experimental, but it would always be known simply as NRX). First, however, a smaller test reactor needed to be built, and this assignment went to Kowarski.

Kowarski was one of the last of the British team to come to Canada, now lured by the chance to complete the quest he had begun five years before in France: construction of a heavy-water reactor. He named his reactor ZEEP, for Zero Energy Experimental Pile. The "zero energy" was due to the reactor producing barely any heat; "pile" was the jargon for reactors in those days, after Fermi built the first one in Chicago literally out of a pile of graphite (carbon) blocks.

The construction of ZEEP dragged on through the final days of the war, which ended in Europe in May 1945. Germany, it turned out, was never close to building an atomic bomb. In July the Americans had made enough plutonium of their own to secretly test the world's first atomic bomb in New Mexico. The world's second and third atomic bombs were dropped, less secretly, on Hiroshima and Nagasaki in August 1945, and that ended the hostilities with Japan.

Canada's first reactor, and the first one outside the U.S., started up a month later. Born out of military expediency within a larger American context, Canada's nuclear lab was suddenly a leftover wartime gift, fully staffed and ready to go.

On the books was the NRX reactor, already under construction. Never designed solely as a plutonium-producing reactor, the NRX came fully equipped for scientific experiments, including a number of "beam tubes" that permit streams of subatomic particles to leave the reactor and impinge on test materials.

When completed in 1947, NRX was the most powerful research reactor in the world. Canadian nuclear science defined the forefront of the art, and the little Canadian Pacific Rail station in Chalk River welcomed the world's greatest scientists and other VIPs to the heart of the Canadian Shield.

Significantly, Canada did not pursue the development of atomic weaponry, despite being one of the three countries on Earth at the close of WW II with the know-how to do so. Canadian research reactors at Chalk River did turn out a relatively small amount of plutonium for the American market until well into the Cold War, but the broader foresight of NRX's designers, and the scientific vision of the National Research Council, put Canada soundly on a path to peaceful nuclear research and development.

One thing the NRX could do better than any other reactor was make radioisotopes; that is, materials that give off radiation for industrial, medical, or scientific purposes. In 1949, Dr. Harold Johns of the University of Saskatchewan asked the NRC to make some radioactive cobalt for use in cancer therapy. The idea was novel at the time, and Johns led the field: the powerful energy from radioactive cobalt could be harnessed to kill cancerous cells, without unduly affecting the surrounding non-cancerous tissue. Elsewhere in Canada, Roy Errington of Eldorado Mining & Refining Ltd., made a similar request to the NRC at about the same time. The race for the "cobalt bomb" (as the media dubbed it) was on.

It was a slow race, since even the most powerful reactor in the world took a full two years to make sufficiently potent radioactive cobalt. The media was nevertheless intrigued. In 1951, the cobalt for both parties was extracted from NRX, but the Eldorado therapy unit was the first to be ready for clinical use. On Oct. 27, 1951, Dr. Ivan Smith's cancer clinic at Victoria Hospital in London, Ont., was the first in the world to treat a patient with radiation, using the Eldorado unit. The Saskatchewan team followed with its first treatment 12 days later (the Saskatchewan unit had an illustrious career, treating almost 7,000 patients over the next 21 years).

From those humble beginnings, Canada became a world leader in the production of medical radioisotopes and radiation therapy devices. In time, a fleet of massive electricity-generating reactors would follow, and eventually power half of Ontario and one-third of New Brunswick. The CANDU reactor, with a heavy water lineage directly to Lew Kowarski and ZEEP, today operates on four continents with a reputation for safety and efficiency.

This is a remarkable achievement for a largely empty country with a largely resource-based economy, and equally remarkable is its link to a single decision of wartime expediency and vision.

ZEEP: Canada's First Nuclear Reactor

By R.E. GREEN and A. OKAZAKI[1]

Ed. Note: The following is the text version of the presentation by Ralph Green at the Plenary Session III of the 26th CNS Annual Conference held in Toronto, Ontario, June 2005. A replica of ZEEP has been constructed at the Canadian Museum of Science and Technology in Ottawa.

Abstract

In 1905 Albert Einstein published his historic paper on special relativity, which contained the equation E=mc 2. The significance of this mass-energy relationship became evident with the discovery of nuclear fission in 1939, when it was realized that large amounts of energy would be released in a fission chain reaction. Canadian scientists were involved in this field from the beginning and their efforts resulted in the startup in September 1945 of the ZEEP reactor at Chalk River, the first reactor to go critical outside the USA. In this paper we recall some of the events that led to the construction of ZEEP, and describe the role it played in the development of the Canadian nuclear energy program.

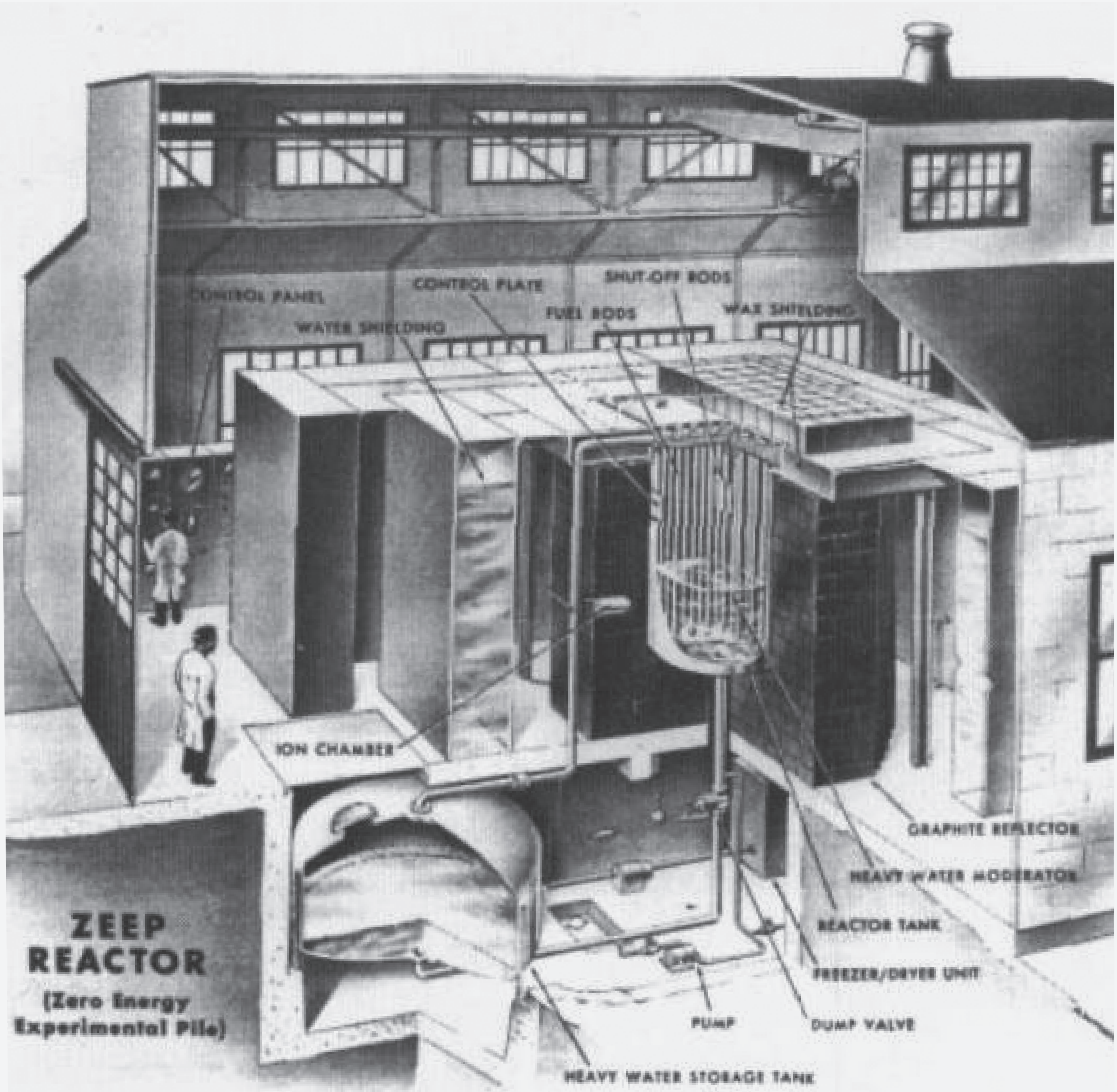
Introduction

One hundred years ago, Albert Einstein took the world of physics by storm when he published three outstanding papers on widely different areas of physics. In one of these papers he formulated his special theory of relativity which contained the now famous mass-energy relationship E = mc 2.

During the next three decades the work of Rutherford, Bohr, Heisenberg and others revealed the structure of the atom. The discovery of the neutron in 1932 by Chadwick provided Fermi and others with a means for probing the nucleus, which resulted eventually in the discovery of nuclear fission in 1939. With this discovery, the real significance of Einstein's mass-energy relationship became clear, since scientists now realized that large amounts of energy would be released in a nuclear chain reaction.

Canadian scientists were involved in this field right from the beginning and their work resulted in the startup of ZEEP (Zero Energy Experimental Pile) on September 5, 1945, the first nuclear reactor to operate outside the USA. In this paper we recall some of the events that led to the construction of ZEEP, and describe the role it played in the development of the Canadian nuclear program.

1 Drs. Ralph Green and Al Okazaki worked for Atomic Energy of Canada Limited. Ralph Green lives in Ottawa; sadly, Al Okazaki passed away on December 2, 2009 at Deep River, at the age of 80.



A schematic drawing of ZEEP.

ZEEP: Conception To Criticality

The first attempt to achieve a self-sustained nuclear chain reaction in Canada was made by George Laurence, assisted by B.W. Sargent, working at the National Research Council in Ottawa during the years 1940-42. Their pile consisted of sacks of uranium oxide interspersed with sacks of powdered coke. Their attempt failed mainly because of impurities in the materials they were using, although it would have been very difficult to achieve a critical assembly using natural uranium oxide and graphite, even with pure materials.

In 1942 it was decided to move the UK nuclear-energy program to Canada, and a joint Canada-UK laboratory was set up in Montreal in the fall of 1942. The work in Montreal, described in a pamphlet entitled "Early Years of Nuclear Energy Research in Canada", by George Laurence, led to the decision, in mid-April 1944, to build a natural-uranium-fuelled, heavy-water-moderated reactor, what we know today as NRX. The design of NRX was based on theoretical calculations, backed up by subcritical experiments in the Montreal laboratory using lattice arrangements of natural-uranium metal rods immersed in heavy water.

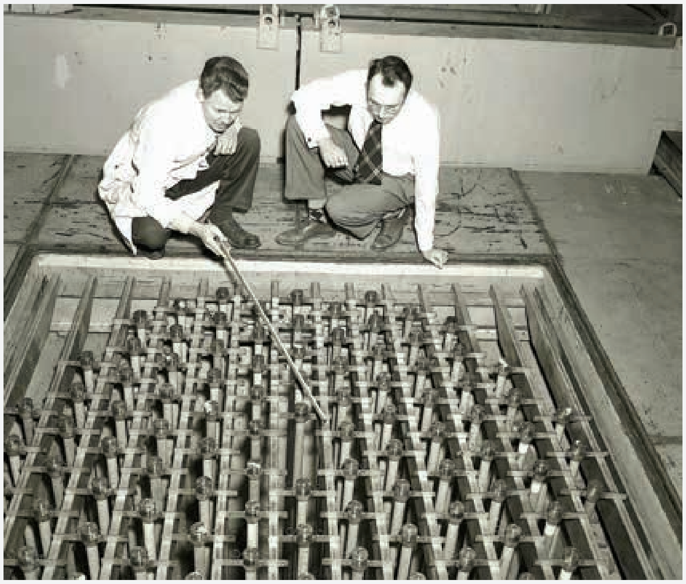
The original control room.

In late April 1944 John Cockcroft came to Canada to lead the Canada-UK program. In May 1944 Cockcroft decided it would be desirable to have some operating experience with a low power reactor like NRX before the latter was built, and to have the capability to alter the reactor core to investigate the effect of changes to the lattice arrangement. The main reasons for building such a reactor were that it could be constructed quickly and the experience gained during the construction and operation would be valuable for NRX. It could also be used to measure some materials properties and to test control, safety and radiation-protection equipment.

So, in July 1944 Cockcroft asked two of his staff to look at the possibility of building a low-power reactor without seriously impeding the NRX project. In August 1944 approval was received to proceed with the design, and Lew Kowarski, newly arrived from the UK, was asked by Cockcroft to manage the project. Charles Watson-Munro was Kowarski's second in command, and they were assisted by A.H. Allan, F.W. Fenning, G.J. Fergusson, C.W. Gilbert, E.P. Hincks, H.F. Freundlich and H. Carmichael. The chief designer was George Klein from the NRC Mechanical Engineering division in Ottawa. He was ably assisted by Don Nazzer, also of NRC.

During the design phase there was pressure from the research staff for a reactor power of 1 kilowatt, rather than 1 watt, because this would provide neutron fluxes high enough for good cross-section measurements, for the chemists to prepare good radioisotope sources, for the engineers to study material properties and for significant radiation protection work to be done. However, such a power level would require more shielding to protect the operators, and would preclude the rapid rearrangement of the core to study different lattice configurations. So, the power level was kept at 1 watt.

Final approval for the construction of ZEEP was given on October 10, 1944. Construction was complete by September 4, 1945, and the reactor went critical on September 5, 1945 at 3:45 p.m., only 16 months after



A view of the original top of the reactor.

conception and only 11 months after approval of construction. One might wonder how long it might take to achieve that today. Of course, this was before the creation of the Atomic Energy Control Board (now the Canadian Nuclear Safety Commission).

The height of the heavy water in the ZEEP reactor tank at criticality was 132.8 cm, compared to the calculated value of 128 cm. This excellent prediction was made by John Stewart, a long-time AECL employee, working with George Volkoff, who later went to the University of British Columbia.

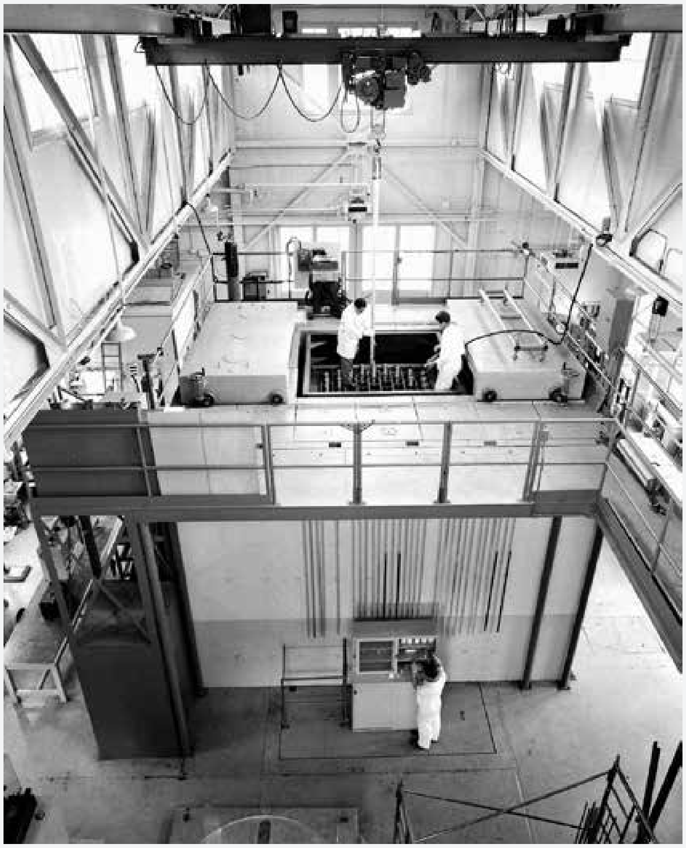
As noted above, ZEEP was the first reactor in the world to operate outside the USA, and it was a great achievement for the Canada-UK team. However, it is important to acknowledge the contribution made by the U.S., in providing key materials, and information from the operation of the CP-3 heavy-water research reactor at Chicago.

Early Operation Of ZEEP: 1945-47

Once criticality had been achieved, a busy schedule of experiments commenced, and continued up until early 1947, when ZEEP was shutdown so that its heavy water could be used in NRX.

Space limitations preclude our listing all of the experiments done during this initial operating period, but the major ones were as follows:

- measurement of the buckling, or overall reactivity, of the ZEEP lattice
- measurement of relaxation and doubling times for various subcritical and supercritical conditions, to determine heavy-water reactor kinetics
- measurement of the temperature coefficient of reactivity
- measurement of intensities and lifetimes of delayed neutrons and delayed photoneutrons, important for reactor control and safety



- calibration of ion chambers for the NRX control and safety systems
- measurement of the reactivity effects of various control-rod configurations, including interference effects between rods
- measurement of the neutron absorption of various nuclear materials, e.g. samples of graphite and uranium for the UK reactors, and thorium for the NRX J-rod annulus, where it was planned to produce uranium-233
- various nuclear-physics experiments, e.g. the measurement of gamma rays emitted during fission, and a search for the negative proton
- determination of eta (the number of neutrons emitted per neutron absorbed) for U-233
- neutron activation of various samples for radiochemical studies. (One of these experiments determined the radioactivity produced in Ottawa River water, which enabled an estimate to be made of the activity to be expected in the NRX cooling water.)

The people involved in these first experiments were: J.G. Bayly, S.W. Breckon, A.J. Cruikshank, F.J.M. Farley, F.W. Fenning, G.J. Fergusson, K.D. George, C.W. Gilbert, H.E. Gove, M.W. Johns, L. Kowarski, B. Kinsey, D.J. Littler, B.W. Sargent, L. Siminovich, A.G. Ward, C. Watson-Munro and D.H Wilkinson.

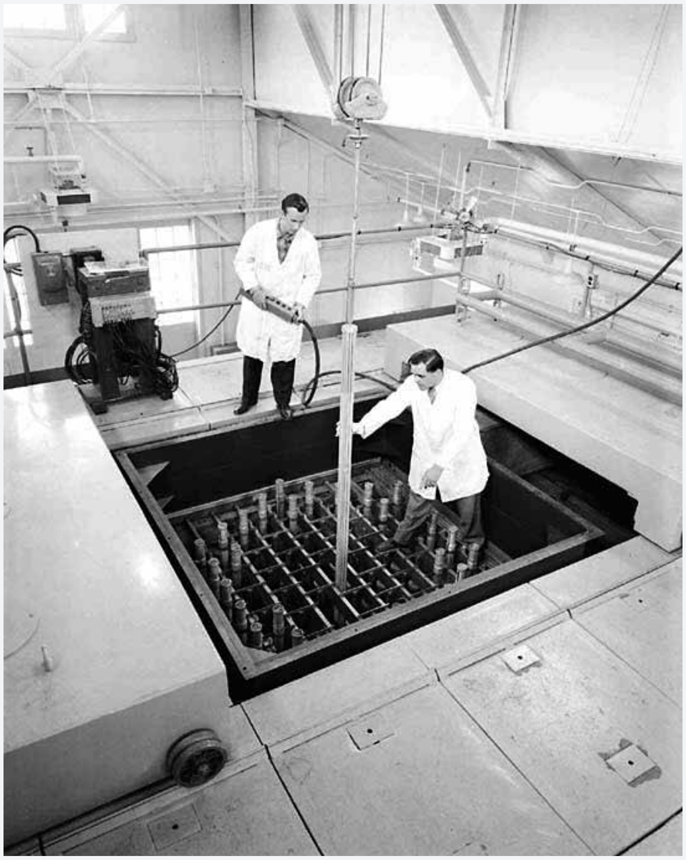
Since ZEEP initially had no shielding outside the graphite reflector, it had to operate at first at a fraction of a watt, to protect the operators. Later on, tanks of ordinary water were stacked around the reactor, wood was placed on top and a small room of masonite and steel blocks was built to house the operators. In this way the power could be raised to 50 watts for brief periods. During this first phase of operation ZEEP operated around the clock, except for Sundays, when the reactor was shut down at 7:30 am, presumably to give the staff time to get to church, or to go sailing, or play tennis!

ZEEP was shut down in April 1947, and its heavy water was transferred to NRX. Much was accomplished during this first period of operation, and much of it was relevant to the operation of NRX. However, no experiments were done to study the effect of changing the lattice arrangement, one of the original reasons for building ZEEP. Perhaps there were too many other important experiments to be done, and since the ZEEP critical size had been accurately predict-ed, it may have been decided that the more time-consuming lattice experiments were not required at that time. These would come in the next phase of operation.

Second Period Of Operation: 1950-56

The ZEEP program started up again during the period April-August 1950, under the leadership of A.J. Pressesky. During the shutdown new side shielding had been provided so the reactor could now operate at higher power levels, and improvements had also been made to the control system.

The focus for the experimental program now was support for the new reactor NRU, then being planned. Experiments were done with different numbers of NRU rods and the results were used to optimize the lattice spacing and overall core size for NRU. Other experiments were done to measure the reactivity effects of empty fuel channels and the split lattice used in NRU



to provide horizontal through tubes for neutron-beam research. Other NRU-related studies involved measuring reactivity effects and neutron flux perturbations due to the insertion of guide tubes and various control devices.

At this stage in our power-reactor development it was believed important to extract the maximum amount of energy from natural uranium fuel, and to do this would require recycling the plutonium produced in the original fuel. This led to experiments in ZEEP with close-packed lattices that might be used as a blanket around a reactor core to produce plutonium.

There was also interest in power-reactor cores with fuel rods containing large amounts of uranium, so experiments were done with 3-rod clusters of ZEEP rods to investigate this concept.

In another experiment the temperature coefficient of reactivity for the ZEEP core was measured by heating the reactor to 80 degrees Celsius. Measurements of the temperature coefficient of uranium were also made, using the "swing" method, in which samples of heated and unheated uranium were alternately inserted into equivalent positions in the reactor core.

Other experiments were done with Pu-Al rods prepared by John Runnalls and co-workers. This type of fuel was being considered for use in NRX and NRU.

ZEEP was also used during this period by scientists from the UK to measure the properties of fuel rods to be used in a proposed UK heavy-water power reactor.

Near the end of this period lattice experiments were done with 19-rod clusters of uranium metal, similar in size to those used later in NPD and Douglas Point. This fuel was produced before it was clear that uranium oxide would be the eventual fuel for CANDU reactors.

The key players during this period of operation were D.H. Allen, W. Dickerson, D.W. Hone, J.H. Moon, A. Okazaki, R.M. Pearce, L. Pease, A.J. Pressesky and D.H. Walker.

The second period of operation was now coming to a close as plans had been made to shut the reactor down for another upgrade. There were several weaknesses in the system that needed fixing. One was that there was no way to drain heavy water from the reactor at the control desk. The reactor was normally started up by pumping heavy water into the reactor tank to a level at which the power would increase at a fixed rate. When the desired power level was reached water had to be drained from the tank to achieve operation at steady power. However, the drain valve was located at the side of the reactor, 10 to 15 feet from the control desk. So, one operator had to manipulate this valve on instructions from a colleague watching the power meter at the control desk. (It should be noted here that the scientific and technical staff were also the operating staff.)

The shielding for the top of the reactor was also primitive compared to today's standards. There were tanks of boron-loaded paraffin that could be placed on the reactor lid, for operation at high power, but since lifting these was no fun the tendency was to operate as much as possible at low power, or for short periods at higher power.

Once when ZEEP was operating without the shielding in place the NRX reactor tripped due to high neutron flux in the NRX reactor hall. After that, we were asked to inform the NRX operating staff when ZEEP was going to operate.

There was also a problem with the ZEEP shutoff rods. These were attached to cables wound on drums mounted on the rod-support beams. Sometimes when these rods were dropped to shut the reactor down the cables would jump off their drums. While this wasn't a safety concern, it did delay the experimental program.

There is one anecdote from that period that readers might find interesting. To pump water into the reactor tank one had to push a button at the control desk to start the pump. However, the pump ran only for a fraction of a minute at a time, and then stopped. So an operator had to repeatedly push the button to keep the pump running. Since this was rather tedious, one of the operators made a block of wood that could be used to jam the pump button so the pump would run continuously.

One day, a couple of researchers were on the top of the reactor inserting flux detectors, and an operator was at the control desk pumping up the heavy water, with the pump button jammed. Suddenly, the telephone rang at the other side of the building and the operator left the control desk to answer it, leaving the pump running. The call took longer than expected and the next thing the researchers heard was the shutoff rods dropping into the reactor. The reactor had tripped on overpower. No one knows how much radiation the researchers received since they had left their film badges in their coat pockets on the floor below! However, it couldn't have been too much since the wife of one of the researchers later had a healthy baby. One might deduce from this that "a little neutron flux never hurt anyone". This incident was never reported to senior management.

So ZEEP was shutdown for several months at the end of 1956. A new rolling shield for the top of the reactor was installed, as well as new control and safety equipment. The latter was similar to the instrumentation to be used in NRU, so once again ZEEP was used as a test bed.

Third Period Of Operation: 1957-68

ZEEP started up again during the April-June 1957 period. The first series of experiments involved a core of 55 19-rod clusters of uranium oxide. Although the density of the oxide was lower than that used later in the power reactors, it nevertheless enabled us to obtain the first lattice physics data for uranium oxide fuel.

One experiment involved heating the whole reactor to 65 degrees Celsius to determine the overall temperature coefficient.

Later we acquired a full loading of 7-rod clusters of the original NPD uranium-oxide fuel for another series of experiments. This fuel was in the form of 50-cm long bundles, another first for ZEEP.

Tests were done with heavy water and air coolants, which gave valuable information on the reactivity effect of a loss of coolant, information important for the design of CANDU safety systems.

In September 1960 the ZED-2 reactor started up, and from that time forward most of the full-scale lattice experiments were done there. ZED-2 was large enough that experiments could be done with complete fuel-channel assemblies, i.e. with pressure and calandria tubes. However, the role of ZEEP was far from over. A hot loop was installed at the centre of the reactor and was used to measure detailed neutron-spectrum effects in CANDU fuel at elevated temperatures, closer to the actual conditions in the power reactors.

During this period a series of experiments was done to check the feasibility of determining lattice parameters by using a small number of fuel assemblies located at the centre of a large core of different assemblies. This substitution technique was of interest since it would, if feasible, reduce the amount of new fuel required for such work in the future.

Many other valuable experiments were done in ZEEP during this final period of operation. Some of the more significant ones were:

- measurement of the reactivity of several NRU fuel assemblies, in an attempt to explain a loss of 7 mk in reactivity when a new fuel design was introduced in NRU. (The reactivity loss was found to be due to boron contamination of the aluminum coolant tubes.)
- measurement of flux peaking at the gaps between the ends of adjacent CANDU fuel bundles. (The fuel engineers were concerned about fuel overheating at the bundle ends.)
- a comparison of the neutron absorption of samples of Zircaloy, Zr-Nb and ozhennite, prospective pressure-tube materials
- irradiation of sulphur capsules for the Commercial Products Division of AECL (now MDS Nordion), to explore ways to enhance the production of phosphorus-32
- tests of self-powered flux detectors being developed by J.W. Hilborn
- the reactivity of Douglas Point-type fuel bundles for the CANDU reactors in India

We are now up to the end of 1968, and from here on ZEEP was used only sporadically, as all of the lattice physics work was being done in ZED-2. From this point until its final shutdown the reactor was used mainly by university students for post-graduate projects.

ZEEP was shut down for good on July 27, 1970, after almost 25 years of outstanding service.

The major players in this last phase of operation were D.H. Allen, G.A. Beer, C.B. Bigham, D.S. Craig, B.G. Chidley, W. Dickerson, R.E. Green, K.J. Hohban, D.W. Hone, B.A. Maciver, A. Okazaki, R.J. Patterson, D.J. Roberts, L.P.Robertson, K.J. Serdula, P.R. Tunnicliffe, R.W. Turner, D.H. Walker and S. Yewchuck.

Conclusion

In this paper we have tried to take you back in time to the early days of the Canadian nuclear program, and to give you a summary of the history of ZEEP, whose 60th anniversary we are celebrating this year. We hope you will agree that while ZEEP was a small reactor, it was a very versatile one, and made a large contribution, out of all proportion to its size, to the Canadian nuclear program.

It represented the first self-sustained nuclear chain reaction in Canada, the first outside the USA, and launched us on the road to CANDU, the best power-reactor system in the world.

However, the ZEEP story is not yet complete, for the reactor is currently being reassembled at the Museum of Science and Technology in Ottawa, and it is hoped to have the reactor open for public viewing this fall (2005).

Natural Uranium Equivalent Fuel
An Innovative Design for Proven CANDU Technology

by F. PINEIRO[1], K. HO1, A. KHAIAL[1], M. BOUBCHER[1], C. COTTRELL[1], S. KURAN[1], Z. ZHENHUA[2] and M. ZHILIANG[2]

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Abstract

The high neutron economy, on-power refuelling capability and fuel bundle design simplicity in CANDU® reactors allow for the efficient utilization of alternative fuels. Candu Energy Inc. (Candu), in collaboration with the Third Qinshan Nuclear Power Company (TQNPC), the China North Nuclear Fuel Corporation (CNNFC), and the Nuclear Power Institute of China (NPIC), has successfully developed an advanced fuel called Natural Uranium Equivalent (NUE). This innovative design consists of a mixture of recycled and depleted uranium, which can be implemented in existing CANDU stations thereby bringing waste products back into the energy stream, increasing fuel resources diversity and reducing fuel costs.

1. Introduction

With the continuous growth of the energy industry, there is an increasing worldwide demand for nuclear power. To secure the long-term availability of nuclear fuel resources that such demand requires, several countries are engaged not only in the improvement of current technologies, but also in the development and implementation of alternative technologies. The implementation of recycled uranium (RU)-based fuels in CANDU reactors is proposed as a viable, efficient alternative to ensure resources availability as well as reducing fuel costs and bringing otherwise waste products back into the energy stream.

Candu, in collaboration with its Chinese partners, has developed an advanced fuel called Natural Uranium Equivalent (NUE). NUE fuel consists of a mixture of RU and depleted uranium (DU), designed to have similar neutronic characteristics as natural uranium (NU), which allows for its implementation in the proven CANDU reactor without the need for modifications. Currently, CANDU 6 reactors operate successfully in five countries, delivering over 22,000 MW of clean air energy.

2. The CANDU Reactor Advantage

The proven CANDU 6 reactor, with over 150 reactor-years of safe operation and ranked among the world's top performing reactors, has unique characteristics which make it the perfect candidate for the use of advanced fuels. These attributes include:

- Inherent high neutron economy
- On-power refuelling capability that enables power shaping in the reactor core
- Versatile design of reactor core components
- Simple fuel bundle design.

The features of the CANDU reactor enable the use of NU fuel as well as advanced fuels such as RU- based fuels, low-enriched uranium and thorium (LEU/Th) fuel and plutonium-thorium (Pu/Th)- based fuels. In addition to the full-core implementation of these alternative fuel cycles, advanced fuels can be tested through irradiation testing in selected channels of operating CANDU reactors, thereby providing a technological low-risk approach for fuel evaluation and implementation. CANDU reactors' advanced fuels utilization capability promotes the development of closed fuel cycle technologies, which take advantage of otherwise waste products and effectively re-introduce them into the energy stream for clean power generation.

3. NUE Fuel Design and Manufacturing

NUE fuel is an innovative fuel design that works in synergy with current and planned light water reactors (LWR) reprocessing technologies around the globe by blending recycled resources (i.e., RU) with waste products (i.e., DU). The mixture is used for the fabrication of fuel pellets that are inserted into the standard 37-element fuel bundle assembly (Figure 2).

NUE fuel takes advantage of the large worldwide stocks of RU, which are mostly kept in storage. About 90,000 tonnes of RU have been thus far reprocessed from commercial power reactors, and the current global fuel recycling capacity is of about 4,000 tonnes per year [1]. The isotopic compositions of RU used in NUE fuel varies depending on its initial enrichment, fuel exit burnup, type of fuel used and subsequent processing.

The world stocks of DU are estimated to be 1.2 mil-

1 Candu Energy Inc., Mississauga, Ontario, Canada
2 Third Qinshan Nuclear Power Company, Haiyan, Zhejiang, China

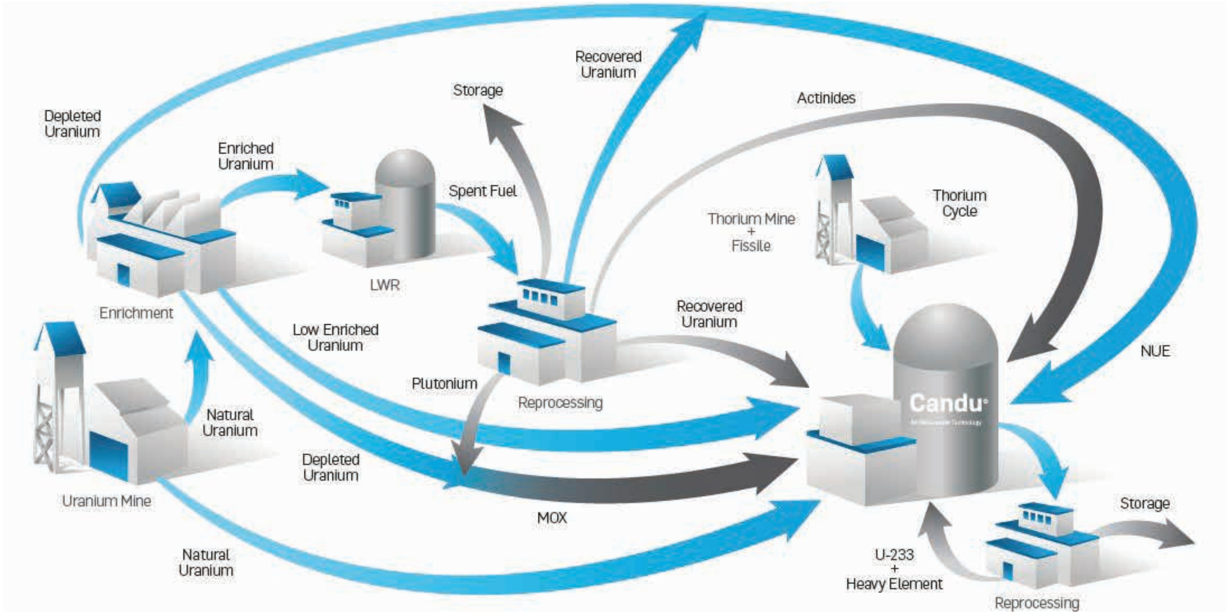

Figure 1: CANDU Reactor Technology's Fuel Cycle Capability.

Figure 2: CANDU Reactor Standard 37-Element Fuel Bundle.

lion tonnes [2] and are expected to grow further with the continuous increase of nuclear power capacity.

The use of RU and DU in existing CANDU reactors increases the uranium utilization rate, relieves recycling facilities from the burden of high storage and monitoring costs and provides an environmental benefit by reducing the volume of spent fuel. In addition, NUE fuel provides a significant economic advantage over NU, since RU is generally priced lower than NU and DU costs are almost negligible [3].

4. NUE-fuelled CANDU Reactor Core Behaviour

NUE fuel behaves similarly to NU fuel, and can hence be used for full-core implementation in existing CANDU reactors. Comprehensive technical analyses have been

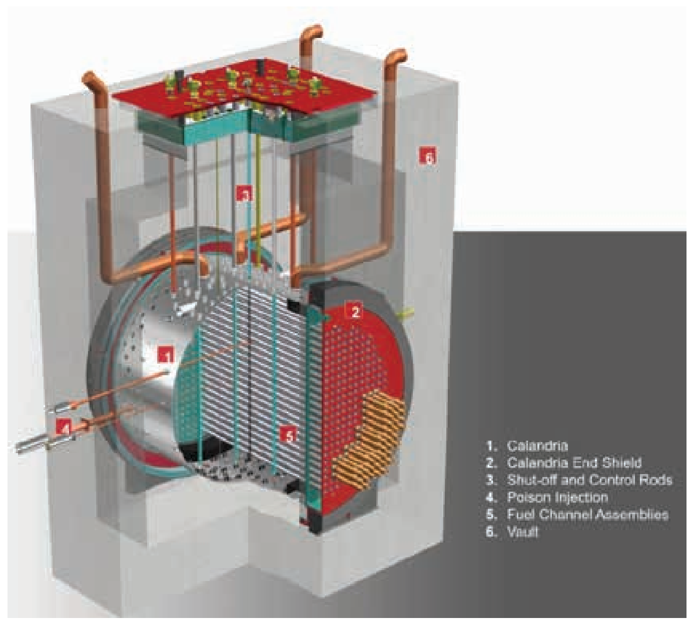

Figure 3: CANDU Reactor Core.

carried out to ensure that the behaviour of the reactor core remains unchanged when fuelled with NUE, and thus little or no changes are required to the reactor design, safety parameters and licensing case. The analyses' results showed that an NUE-fuelled CANDU reactor behaves equivalently to an NU-fuelled CANDU reactor such that all core components including reactivity devices, fuel channel assemblies and safety systems (Figure 3) remain adequate and do not need to be modified.

4.1 Radiation Physics

The only minor changes to the nuclear power plant required for the implementation of NUE fuel are related to radiation physics. The current CANDU pro-

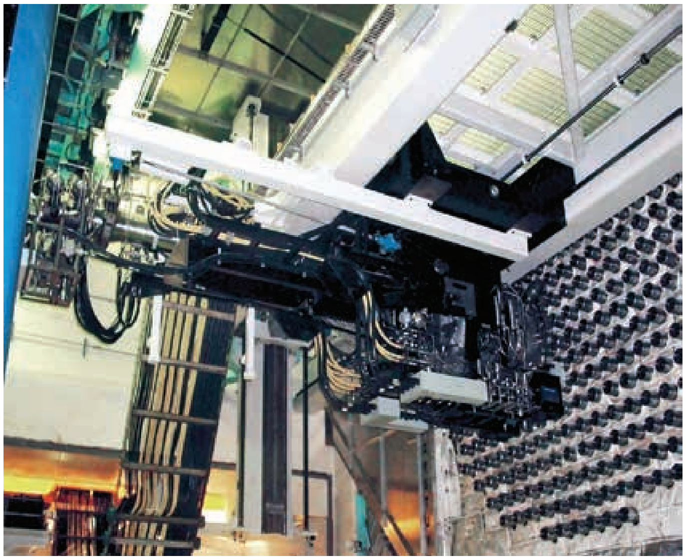

Figure 4: CANDU Reactor Fuelling Machine.

cedure allows for fresh NU fuel bundles to be handled by hand and to be visually inspected prior to fuelling by the operators. Due to gamma activity arising from the presence of ^{232}U daughter products in RU, the dose rates on contact with NUE fuel are about six times higher than those with NU fuel. The implementation of minor localized shielding features, however, is sufficient to maintain radiation exposure of operators below the regulatory limits. These minor enhancements are required for the new fuel storage room and the new fuel loading room. The spent fuel handling and spent fuel storage only require minor procedural changes, since the decay heat of NUE fuel upon core discharge is equivalent to that of NU fuel and is only slightly higher after long decay times (~6 years).

4.2 Refuelling

Refuelling simulations were carried out to ensure that the CANDU reactor could be fuelled with NUE fuel within the current envelope for safe operation. Analyses were performed to prove that a CANDU reactor can transition on-power (i.e., without the need to shut down the reactor) from NU to NUE fuel and vice-versa. The maximum channel and bundle powers found in the transition analysis and during normal NUE refuelling operations did not exceed current operational limits, and the reactivity devices in the core remained within normal operating conditions. Other refuelling parameters such as the eight bundle shift refuelling scheme, were kept the same in the NUE-fuelled core as those for the NU-fuelled core, due to the large similarities between the two fuels. No changes to the CANDU reactor fuelling machines (Figure 4) are required.

4.3 Regional Overpower Protection

The Regional Overpower Protection (ROP) system

Figure 5: Qinshan CANDU Reactors in Haiyan, China.

in CANDU reactors is designed to detect and prevent overpower conditions that could impact fuel integrity by initiating a timely reactor shutdown. The ROP system of the NU-fuelled CANDU reactor was shown to be adequate for the NUE-fuelled CANDU reactor. The ROP margins to trip are not affected by the implementation of NUE fuel in the entire core.

4.4 Safety Systems

Several safety analyses were carried out for the limiting cases of the NUE-fuelled CANDU reactor to confirm that the impact of its full-core implementation is negligible. The assessments included the limiting accident scenarios such as a Large Loss-Of-Coolant Accident (LOCA) with 100% pump suction break, a small LOCA with 2.5% reactor inlet header break, loss of forced circulation: single pump trip for initial core power of 90% full power, and steam and feedwater circuit event: loss of feedwater pumps. The results remained similar to those obtained for the NU-fuelled core and thus showed that there is no significant impact arising from the use of NUE fuel in the CANDU reactor. Sufficient margins to the safety limits are always maintained, and hence the current safety case is not affected.

5. NUE Test Irradiation

Based on the comprehensive technical analyses that demonstrate the negligible impact of implementing NUE fuel in a CANDU reactor as well as manufacturing activities to determine how to best fabricate the fuel, TQNPC obtained the necessary licensing from the Chinese regulating body to carry out a test irradiation of NUE fuel bundles in selected channels of the

Qinshan CANDU reactors located in Haiyan, China (Figure 5).

Following the successful manufacture of 26 NUE fuel bundles in the CNNFC fuel manufacturing facility, which meet pre-established fuel technical specifications, 24 bundles were used for irradiation testing and two were retained for archiving. Irradiation testing started in March 2010, in Qinshan Unit 1, where the selected 24 NUE fuel bundles were inserted into two high-power fuel channels. All NUE fuel bundles were removed from the reactor in spring of 2011.

Continuous monitoring was done during the test irradiation of the NUE fuel bundles to ensure that their performance was as predicted, and that it met pre-established acceptance criteria. The resulting data was compared to that of regular operation with NU fuel and proved the irradiation testing to be successful. In particular, the liquid zone controllers (LZC) remained within normal operation ranges and the bundle and channel powers remained under the licensing limits. There were no indications of any abnormal behavior in the channels that contained NUE fuel relative to those containing NU fuel.

Following the irradiation testing, the irradiated NUE fuel bundles were visually examined for defects or anomalies in an in-bay inspection. This examination consisted of the inspection of both NU and NUE fuel bundles, as well as bundle disassembly and element inspection. The reference NU fuel bundles were directly compared to the NUE fuel bundles as they were retrieved from similar locations of the reactor core. No anomalies or defects were found in the inspection, which suggested that the NUE fuel bundle performed the same as the NU fuel bundle: all fuel element sheath-to-endcap welds were clean and defect free, pellet interface circumferential ridging was distinct and no sheath swelling was observed.

A Post Irradiation Examination (PIE) was carried out to further confirm that the performance of the NUE fuel bundles was adequate and as expected. Twelve elements separated from two NUE fuel bundles were shipped from TQNPC to NPIC (the hot-cell facility). The PIE confirmed that NUE fuel behaved similarly to NU fuel. The conclusions were the following:

- Overall appearance of NUE fuel was consistent with that of NU fuel.
- No anomalies were found on the bundle elements' sheaths.
- Normal strains on the pellets and ridge heights were found.
- NUE fuel element elongation (due to irradiation growth) was consistent with typical NU fuel bundles.
- No indication of potential sheath failure due to fission gas release or gas over-pressure was found.
- Thermal behavior was as expected since grain sizes of both NUE and NU fuels were similar. This also indicates that homogeneity of the NUE pellet was well maintained from the mixing of RU and DU during manufacturing. No thermal hot spots were found.
- Sheath microstructures were consistent with those typically found for CANDU fuel operation.
- Burnup results were consistent with predicted values, NUE fuel operated as designed and maintained similar CHF behavior as NU Fuel.

6. NUE full-core implementation

Based on the successful NUE fuel demonstration irradiation, TQNPC signed a commercial contract with Candu to pursue a full-core implementation of NUE fuel in their Qinshan reactors. A licensing application was submitted to the Chinese nuclear regulator for conversion of the Qinshan reactors to NUE fuel, providing comprehensive technical analyses, which demonstrate that NUE fuel does not cause any changes to the CANDU reactor performance and that the current NU-based safety case remains applicable.

7. Conclusions

The world-wide growing demand of nuclear power has given rise to an increasing interest in the development of alternative technologies that are capable of utilizing unconventional resources for nuclear power generation.

CANDU reactors are an excellent option for the utilization of advanced fuels. NUE fuel, a mixture of RU and DU, is a feasible alternative which can be implemented in existing CANDU reactors. This advanced fuel forms a strong synergy with LWRs, improves the overall uranium utilization rate, allows for the re-introduction of waste products into the energy stream, and reduces fuel costs.

The successful irradiation testing of NUE fuel bundles in the Qinshan CANDU reactors has demonstrated the feasibility of the fuel's utilization in the proven CANDU reactor design. This low- risk technological approach is a breakthrough in the path towards the development of closed fuel cycle technologies. As a result of the NUE project's success, Candu in co-operation with its Chinese partners has developed the Advanced Fuel CANDU Reactor (AFCR), which is capable of utilizing a high burnup RU-based fuel and LEU/Th fuel. The NUE and AFCR projects are part of a strategic plan to further reduce the dependency of countries like China on NU, while providing significant performance and economic advantages [4].

8. Acknowledgments

The authors wish to acknowledge colleagues at CNNC (TQNPC, CNNFC, NPIC), Candu Energy, and

Atomic Energy of Canada Limited (AECL) for their contributions to the NUE project.

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Probabilistic Seismic Hazard Assessment for Point Lepreau Generating Station

by DEREK MULLIN[1], ALEXIS LAVINE[2], JOHN EGAN[3]

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Abstract

A Probabilistic Seismic Hazard Assessment (PSHA) has been performed for the Point Lepreau Generating Station (PLGS). The objective is to provide characterization of the earthquake ground shaking that will be used to evaluate seismic safety. The assessment is based on the current state of knowledge of the informed scientific and engineering community regarding earthquake hazards in the site region, and includes two primary components–a seismic source model and a ground motion model. This paper provides the methodology and results of the PLGS PSHA. The implications of the updated hazard information for site safety are discussed in a separate paper.

1. Introduction

A site-specific probabilistic seismic hazard assessment (PSHA) was performed by AMEC Environment & Infrastructure, Inc. (AMEC), for the Point Lepreau Generating Station (PLGS) in New Brunswick, Canada [1] in response to seismic safety concerns following the accident at the Fukushima Dai'ichi power plant in Honshu, Japan, caused by the March 11, 2011, Tohoku, Japan, earthquake, and as part of the 2012 Canadian Nuclear Safety Commission decision for renewal of the operating license for the PLGS. The purpose of this assessment is to provide an update of the seismic hazard characterized for the PLGS site based on numerous geologic and seismic hazard studies that have been conducted in the site region since the previous seismic hazard analyses for the site were performed in the 1970s and 1980s (e.g., [2] and [3]). The approach to this assessment was to conduct a site-specific PSHA to characterize ground motion hazard at the site in terms of peak horizontal ground acceleration and response spectral accelerations at selected structural response frequencies (periods) and for a range of probabilities of exceedance appropriate for evaluating seismic safety during the design life of the PLGS.

The PSHA involved compilation of an earthquake catalog for the region surrounding the site and identification and characterization of regional seismic source zones and local seismic sources. The results of paleoseismic studies in the region were incorporated in the seismic source characterization. Ground motion models applicable to the hard rock conditions of southeastern Canada were selected using the most recent published literature and through discussions with experts. Probabilistic hazard analyses were conducted for peak ground acceleration (PGA) and response spectral accelerations (S_a) covering the frequency range of importance to nuclear power plant design and performance.

1 New Brunswick Power Corporation, Point Lepreau Generating Station, Canada

2 AMEC Foster Wheeler Environment & Infrastructure Americas, Oakland, California, USA

3 SAGE Engineers, Oakland, California, USA

2. Geologic and Tectonic Setting

Understanding the geology, structure, tectonic setting and seismicity of a region facilitates the identification of potential seismic sources and provides a context for developing tectonic models of crustal deformation that can be used to characterize the seismic potential of individual geologic structures and source zones. The PLGS site is located in the Northern Appalachian Orogen, which extends from the Gulf of St. Lawrence to the Atlantic Ocean, and is an area that has experienced a long and complex geologic and tectonic history. The PLGS site is located on the northwestern edge of the Fundy Basin, one of numerous rift basins of early Mesozoic age on the continental margin of eastern North America. The site is underlain by Triassic bedrock of the Lepreau Formation, consisting primarily of sandstones and conglomerates, with minor thin lenses of shale [4]. The geologically most recent, and unequivocal evidence for major tectonic activity in the region is Late Triassic to Late Jurassic normal faulting along the Atlantic margin related to continental rifting and the subsequent opening of the Atlantic Ocean. However, historical seismicity along the St. Lawrence rift system and in other concentrated zones such as Passamaquoddy Bay, local geologic evidence of Cenozoic reactivation of faults, evidence of paleoseismicity, and geologic and geodetic data are all indicative of regional and local crustal deformation and suggest continuing neotectonic activity, albeit at much lower rates than during the last episode of major tectonic deformation.

3. Seismicity

An earthquake catalog of seismicity from 1568 to 2011 for the region surrounding PLGS was developed for this study. The primary source of data for the project catalog is the Central and Eastern United States Seismic Source Characterization (CEUS SSC) for Nuclear Facilities Project catalog [5] that includes earthquakes from 1568 through the end of 2008. The CEUS SSC catalog is appropriate to use for this project because it merged all the relevant continental, regional, and local catalogs for instrumental and historical earthquakes, and was compiled for a Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 study. Preparation of the catalog involved extensive research of literature on specific earthquakes, use of uniform moment magnitude that is consistent with ground motion models, and formal treatment of uncertainties in estimates of moment magnitude. For the portion of the CEUS SSC catalog that lies within Canada, appropriate regional and local catalogs (i.e., Geological Survey of Canada [GSC] catalogs for events that occurred in Canada) were identified as preferred sources. The CEUS SSC catalog has been supplemented for this study by earthquake data within the bounds of the project catalog for the 2009 through 2011 timeframe that were obtained from the GSC National Earthquake Database [6], the United States Geological Survey (USGS) National Earthquake Information Center database [7], and the Weston Observatory [8]. Since the end of 2011, no significant earthquakes have occurred in the region surrounding PLGS that would require consideration in the project catalog.

The CEUS SSC earthquake catalog [5] utilizes a uniform moment magnitude estimate, expected moment magnitude (E[**M**]), and includes earthquakes as small as E[**M**] 2.2. The catalog is composed of independent earthquake events with all foreshocks and aftershocks, or dependent events, removed. Assessment of earthquake occurrence rates requires an evaluation of the completeness of the earthquake catalog. For this study the completeness regions and associated completeness periods for each region were adopted from the CEUS SSC model [5].

To the west-southwest of the PLGS site, an increased level of historical seismicity has been recognized in the area of Passamaquoddy Bay (Figure 1). The project earthquake catalog includes 33 earthquakes within this area. The largest earthquakes that have occurred in the Passamaquoddy Bay area are the October 22, 1869, E[**M**] 5.47 earthquake and the March 21, 1904, E[**M**] 5.73 Eastport earthquake [9]. The 1869 event was located approximately 61 km west-southwest of the site based on felt intensities. This earthquake displaced furniture in St. Stephens and glass was reportedly broken in St. John [10]. A study of felt effects for historical earthquakes by [10] indicates that the PLGS site is in an area that experienced an estimated Modified Mercalli Intensity (MMI) of IV to V following the 1869 earthquake. The 1904 Eastport earthquake was located 55 km west-southwest of the PLGS site. Reported damage associated with this event included toppled chimneys and broken windows in the town of St. Stephens, 65 km southwest of the site, and in Calais and Eastport, Maine, and cracked plaster and walls that were found in St. John, 39 km northeast of the site [10]. The PLGS site is located in an area that experienced Rossi-Forel intensity of VI to VII [3], which corresponds to MMI of V to VI [10].

4. Paleoseismicity

Because the record of historical and instrumental seismicity only represents several hundred years of earthquake history in the region, a paleoseismic evaluation was performed by M. Tuttle & Associates [12] for the PLGS site region. The paleoseismic study was performed to help constrain the source area, magnitude, and recurrence times of large regional earthquakes in the late Quaternary (in particular, the past 10–12 kyr [thousand years]) in the region.

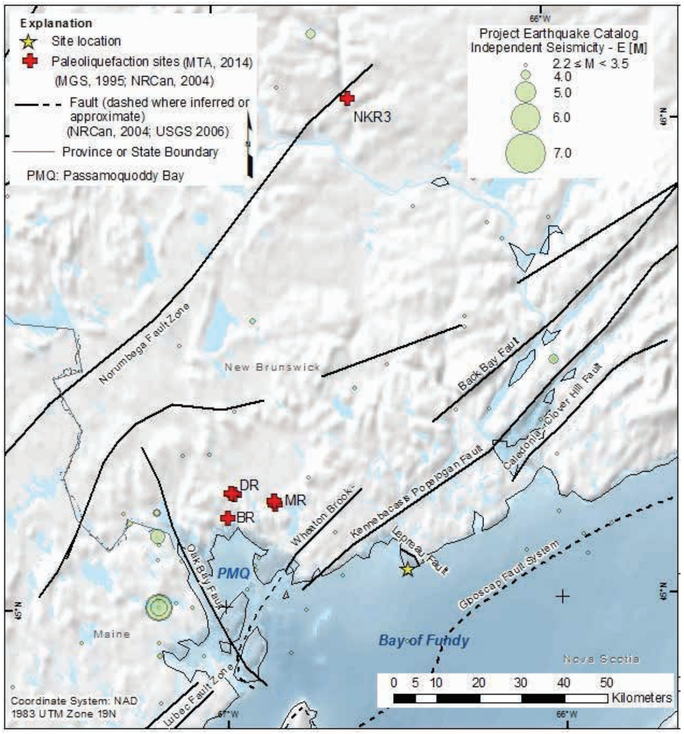

Figure 1: Faults, Seismicity, and Earthquake-Induced Paleoliquefaction Features in the Site Region.

Based on the distribution of observed earthquake-induced soil liquefaction features (Figure 1), the preferred interpretation of [12] is that three earthquakes occurred about 1 ka (thousand years ago), 4 ka, and 12 ka in the Passamaquoddy Bay area, centered near the epicenter of the 1904 event, that were responsible for triggering the formation of sand dikes and soft-sediment deformation structures on the Bocabec, Digdeguash, and Magaguadavic Rivers. This suggests a recurrence interval ranging from 1.8 to 4.5 kyr, with an average recurrence time of 3.15 ± 1.35 kyr. The liquefaction potential analysis performed by [12] predicts that earthquakes of M 6.5–7 generated by a source near the epicenter of the 1904 earthquake would produce the distribution of liquefaction features observed, as well as where such features were not observed.

The results of the paleoseismic investigations are incorporated in the PSHA through: 1) adjustment of the Passamaquoddy Bay seismicity-based source zone geometry to include the potential locations of the paleoearthquakes; 2) adjustment of maximum magnitude distributions for the seismic source zones within which Passamaquoddy Bay area seismicity and the identified earthquake-induced paleoliquefaction features lie; and 3) adjustment of the probability of Oak Bay fault being seismogenic.

Calculated magnitude-recurrence relationships for the Passamaquoddy Bay seismicity-based source zone (M 6.0 every ~1,000 years, M 6.5 every ~5,000 years, and M 7.0 every ~10,000 years) agree well with recurrence estimates of late Quaternary M 6 to 7 earthquakes based on earthquake-induced paleoliquefaction features (approximately 1,000 to 5,000 years with an average of 3,000 years) [12].

5. Seismic Source Characterization

A key objective of this study is to identify and quantify the uncertainties associated with seismic source characteristics, thus incorporating the current knowledge and uncertainties into the hazard analysis. The uncertainty assessment in this study is performed using a logic tree methodology. The seismic source model developed for this assessment encompasses a region having a radius of more than 300 km surrounding the PLGS site. This region was selected to ensure that all sources, including regional and local aerial source zones and local faults, that could potentially contribute to ground motion hazard at the site are incorporated ino the analysis.

5.1 Regional Seismic Sources

Earthquakes that cannot be attributed to mapped active fault zones are modeled as occurring in areal seismic source zones, shown as polygons on Figures 2 and 3. The size and extent of the areal source zones were delineated based on prominent geologic structures and tectonic provinces and consistent patterns of seismicity. Our model includes two types of seismic source zones: (1) Regional seismotectonic source zones based primarily on geologic and tectonic characteristics (Figure 2); and (2) Seismic source zones based on observed seismicity (Figure 3).

A key difference between these methodologies is the degree to which the spatial pattern of observed seismicity (both historical and instrumentally recorded earthquakes) provides an indication of the locations of future seismicity. Because the distribution of seismicity is not uniform within the large regional seismotectonic zones, seismicity was smoothed to evaluate the spatial density variations (clustering) of seismicity within each zone. The methodology used for spatial smoothing of seismicity in the regional seismotectonic source zones is one that smooths the rate of activity within each zone. The regional seismotectonic basis for source zonation is strongly favored (0.8) over the seismicity-based alternative (0.2) because it subdivides the region into zones with more uniform crustal characteristics, as well as taking into account the spatial variability of seismicity within each zone, rather than characterizing the entire zone as having a uniform rate.

The regional seismotectonic model includes four source zones that extend more than 300 km from the site (Figure 2). These are the Mesozoic Rifted Basin

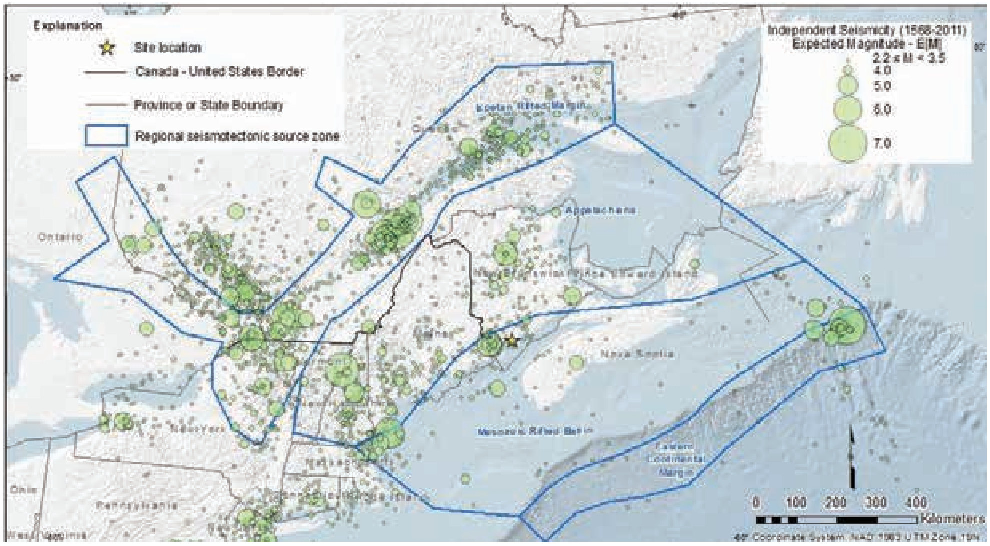

Figure 2: Regional Seismotectonic Source Zones (Alternative A).

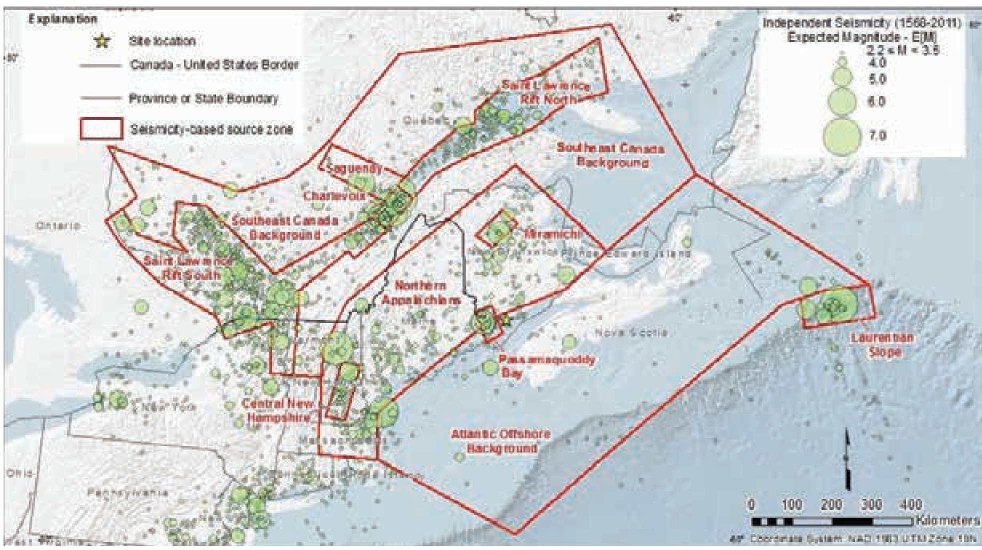

Figure 3: Seismicity-Based Seismic Source Zones.

(MRB), Northern Appalachian (APL), Iapetan Rifted Margin (IRM), and Extended Continental Margin (ECM) zones. The geometry of these zones are based on [5], [13], and other geologic maps and publications. Three alternative geometries for these source zones were considered to incorporate the uncertainty of source zone boundaries, especially in the vicinity of the PLGS site (i.e., the MRB/APL boundary).

The seismicity-based source zones modeled in this study generally follow the GSC 5th generation historical seismicity (H2) zones [13]. The seismicity-based source zone model includes 11 crustal areal seismic source zones that cover the region extending at least 300 km from the site as shown on Figure 3. These zones were constructed to encompass areas of relatively uniform seismicity and the rate within each zone, regardless of geographic extent, is characterized as uniform. Two alternative source zone geometries are considered to take into consideration the uncertainty in the boundary of the Northern Appalachians/ Atlantic Offshore Background (NAN/AOB) boundary, which is located near the PLGS site (Figure 3); these alternatives are given equal weight in our model. The northeastern boundary of the Passamaquoddy Bay (PMQ) zone was modified from [13] to include paleoliquefaction features identified by [12].

The primary approach used for assessing the maximum magnitude for a seismic source zone is the Bayesian approach as described in [5], which was based on the approach initially outlined in Johnston et al (1994). For zones that contain the paleoliquefaction features identified by [12], the maximum magnitude distribution was adjusted to account for the paleoearthquakes being the largest observed earthquakes in the zone. The frequency of occurrence of earthquakes associated with a source was computed from the statistics of the earthquake catalog for the source. For source zones, the standard truncated exponential magnitude distribution was used to define the relative frequency of various sizes of earthquakes. Earthquakes in the seismic source zones are modeled as occurring on planar fault sources distributed throughout the source area at a uniform spacing of 5 km for all distant source zones and spacing of 1 km for the Northern Appalachian, Passamaquoddy Bay, and Mesozoic Rifted Basin zones. Orientation and style of faulting of the modeled planar fault sources are based largely on the CEUS SSC model [5], with some modifications based on more local studies. Maximum depth of seismogenic rupture for modeled pseudo faults is based on the seismogenic depth of the crust used in CEUS SSC model [5] with modification to the ECM zone based on the depth of the 1929 Grand Banks earthquake.

5.2 Potential Local Fault Sources

Active faults for this assessment are generally defined as those that have had displacement or seismic activity during the Quaternary period (i.e., 2.6 million years before present [Myr BP] to the present). Several faults within 100 km of the PLGS site were considered in evaluating local seismic sources; however, based on a thorough literature review and conversations with local experts, we found no evidence of faults within 100 km of the site that may unambiguously be considered to be active. Although there is no firm evidence to associate any particular fault with the occurrence of earthquakes in southern New Brunswick [14], several authors have postulated that seismicity in the Passamaquoddy Bay area may be associated with the Oak Bay fault (e.g., [15], [16], [17]). Additionally, seismicity and potential earthquake-induced paleoliquefaction features in the area of the Norumbega fault, suggest that it may have been active in the Quaternary. Faults within 100 km of the site that were considered in our evaluation are the Oak Bay fault, the Glooscap fault system in the Bay of Fundy, the Lepreau fault, and the Norumbega fault (Figure 1). Each of these faults was evaluated for seismogenic potential following the methodology of [18]. "Seismogenic" in this context is defined as capable of generating moderate-to-large earthquakes (M > 5) in the present tectonic environment and worthy of being represented as a fault source in the PSHA. The evaluation takes into account the association of the fault with seismicity, seismogenic crustal extent of the fault, whether slip is favourable in the current stress regime, and evidence for multiple episodes of reactivation. The Oak Bay fault was included as a fault source in the PSHA with a 0.47 probability of being seismogenic.

6. Ground Motion Model

A key input to the probabilistic seismic hazard model for the PLGS site, as in most PSHAs, is specification of earthquake ground motions through implementation of ground-motion prediction equations (GMPEs). There are two necessary components of a GMPE. The first is a relationship for the median amplitude (mean log amplitude) of peak ground motions as a function of earthquake magnitude, source-to-site distance, and spectral frequency of interest, as well as other explanatory variables that may be appropriate. The second and equally important component is a relationship for the aleatory variability (random variation) of peak ground motions about the median amplitude. For Central and Eastern North America (CENA), however, recorded strong-motion data is very limited. As a result, the available ground-motion models are primarily based on theoretical/numerical modeling approaches that have been calibrated using comparisons with recorded data from more active regions, in addition to the relatively sparse CENA data.

To address uncertainty in the GMPEs, four alternative GMPEs that have been developed based on different approaches are used in the PSHA. The models utilized were developed to represent ground surface motions on generic CENA hard rock sites. The GMPEs used in this PSHA are: 1) Pezeshk et al. (2011) [19]; 2) Atkinson (2008) [20], with the Atkinson and Boore (2011) [21] revision; 3) Atkinson and Boore (2006) [22], with the Atkinson and Boore (2011) [21] revision; and 4) Silva et al. (2003) [23]. These are a very similar set of GMPEs to those on which the ground motion model being applied to seismic hazard maps for the 2015 edition of the National Building Code of Canada [24] are based. The four GMPEs are given equal weight and are all implemented for hard rock site conditions present at the PLGS site, on which the reactor and other safety elements at the site are founded. The sigma values of [24] are used to incorporate the aleatory variability in ground motion models.

7. PSHA Analysis Approach

The methodology used to conduct a PSHA was developed first by [25] and has undergone substantial development since that time. Current practice is described in detail in several publications, such as [26], [27], [28], [29], [30], and [31]. The basic formulation involves computing the frequency at which a ground motion parameter exceeds a specified level at the site. The procedure for computing the frequency of exceedance involves assessing the following parameters and probability distributions: (1) the frequency of earthquake occurrence; (2) given an earthquake occurrence, the distribution of possible earthquake sizes (magnitudes); (3) given an earthquake of a particular size, the distribution of the possible distances from the site to the rupture; and (4) given an earthquake of a particular size and location, the distribution of possible ground motions at the site. Items (1) and (2) are specified by earthquake recurrence relationships developed for the seismic sources; item (3) is specified by the locations and geometries of the seismic sources relative to the site; and item (4) is specified by ground motion prediction equations.

The site-specific PSHA conducted in this evaluation utilized proprietary in-house seismic hazard codes (software programs) developed by AMEC, and qualified under AMEC's Nuclear Quality Assurance (NQA-1) Program. These programs have also been used for U.S. Nuclear Combined Operating and Licensing (COL) applications, recent design-related evaluations for clients in Canada and worldwide for nuclear facilities, as well as for buildings, dams, oil and gas facilities, mines, and other civil facilities.

8. Results and Conclusions

The results of the PSHA are presented in terms of site-specific uniform hazard response spectra for annual frequencies of exceedance in the range of 10^{-2}

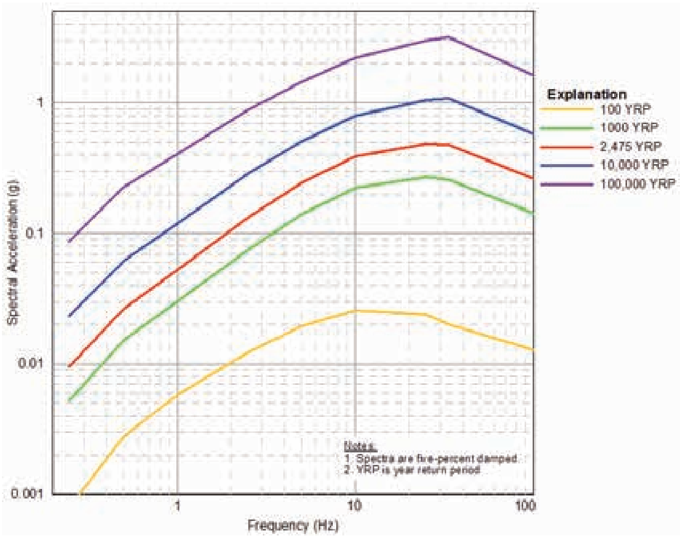

Figure 4: Uniform Hazard Response Spectra Based on Mean Hazard Results.

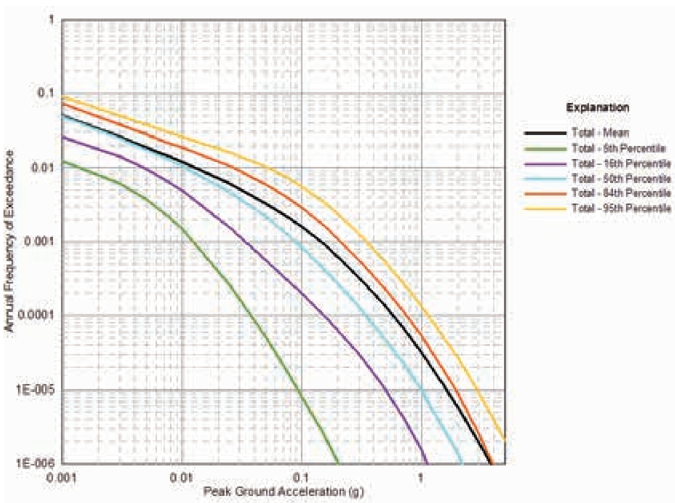

Figure 5: Mean and Fractile Total Hazard Results at Peak Ground Acceleration.

to 10^{-5} (equivalent return periods ranging from 100 years to 100,000 years) (Figure 4). Ordinates for these response spectra are given for PGA and over the spectral frequency range of 40–0.25 Hz at a damping ratio of 5 percent. The probabilistic seismic hazard results indicate that the seismic hazard at the PLGS site is dominated by seismic activity in the Passamaquoddy Bay area, which is located approximately 25–30 km west-southwest of the site, and has been the source of earthquakes with magnitudes estimated as large as M 5.7 during the historical period and earthquakes potentially as large as M 7.0 during the late Quaternary based on interpretation of earthquake-induced paleoliquefaction features [12]. The Passamaquoddy Bay seismicity lies within several seismic source zones in the different model alternatives (i.e., the Passamaquoddy Bay zone in the seismicity-based alternative models, and the Mesozoic Rifted Basin [Alternatives A and B] and Northern Appalachian [Alternative C] zones in the regional seismotectonic alternative models). The largest contribution to the hazard is from the Mesozoic Rifted Basin zone in the regional seismotectonic model alternative A. Ground motion values associated with the 10,000-year return period mean total hazard level for spectral frequencies of 1 Hz and 10 Hz are S_a = 0.12g and S_a = 0.80g, respectively, and for PGA is 0.58g (Figure 5 illustrates total hazard results for PGA); for the 10,000-year return period median total hazard level, the ground motion values for 1 Hz, 10 Hz, and PGA are, respectively, S_a = 0.07 g, S_a = 0.53 g, and PGA = 0.34 g.

The regional seismotectonic source zones were found to be the dominant contributors to the hazard. The contribution of individual assessments to the uncertainty for various components in the seismic hazard computation was also examined. The results indicate that alternative geometries of regional seismotectonic source zones are the largest contributors to the uncertainty in seismic hazard at the site. Other significant contributors to uncertainty are the estimation of the b-value of the Gutenberg-Richter magnitude-frequency relationships, selection of the appropriate ground motion models, and the maximum magnitude assessments.

Comparison of peak ground accelerations from this project with other studies conducted for, or applicable to, the PLGS shows that median values for uniform hazard response spectra from the present assessment (mean values are not reported for the previous studies) are similar to those previously reported (e.g., [3] and [32]) Median PGA at the 10,000 year return period hazard level is 0.34 [this study], 0.33 [32], and 0.25-0.43 [3]. The slightly higher PGA values determined for the site in this study are primarily due to incorporation of new data regarding the size and location of earthquakes in the site region, particularly recently identified earthquake-induced paleoliquefaction features in the Passamaquoddy Bay area, and the incorporation of more recent GMPEs.

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Hybrid Laser Arc Welding of a Used Fuel Container

by CHRIS BOYLE[1], PATRICK MARTEL[2]

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Abstract

The Nuclear Waste Management Organization (NWMO) has designed a novel Used Fuel Container (UFC) optimized for CANDU used nuclear fuel. The Mark II container is constructed of nuclear grade pipe for the body and capped with hemi-spherical heads. The head-to-shell joint fit-up features an integral backing designed for external pressure, eliminating the need for a full penetration closure weld. The NWMO and Novika Solutions have developed a partial penetration, single pass Hybrid Laser Arc Weld (HLAW) closure welding process requiring no post-weld heat treatment. This paper will discuss the joint design, HLAW process, associated welding equipment, and prototype container fabrication.

1. Introduction

The Nuclear Waste Management Organization (NWMO) is implementing Adaptive Phased Management [] for the long-term care of Canada's used nuclear fuel. The program's objective is to create a socially acceptable, environmentally responsible, and economically feasible used fuel solution. The creation of a Deep Geological Repository (DGR) was proposed and accepted. The used nuclear fuel is encapsulated in long-lived Used Fuel Containers (UFC), then emplaced at a reference depth of 500m underground in a suitable rock formation, and surrounded with bentonite clay, as shown in Figure 1. The DGR method is consistent with the preferred approach from many countries around the world [2, 3, 4, 5].

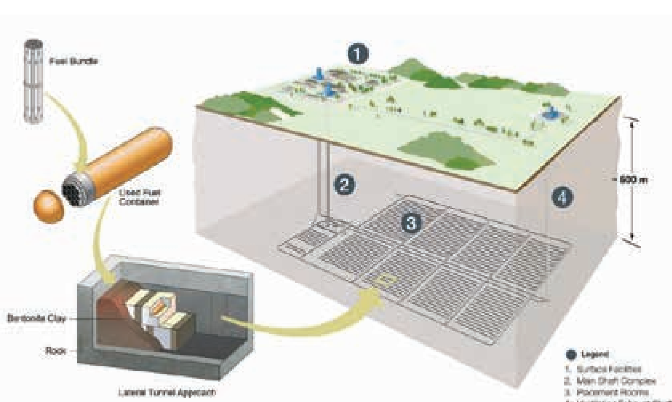


Figure 1: NWMO Deep Geological Repository (DGR) Concept.

The DGR represents a multi-engineered barrier system designed to prevent radioactive material from reaching the biosphere. The container is a unique component of that system, as it is the only one designed specifically for containment. There are several different container concepts internationally. The KBS-3 repository container, developed by the Swedish (SKB) and Finnish (POSIVA) nuclear waste management organizations, is a dual-vessel design []. It consists of a cast-iron structural insert, with channels to separate and emplace the used fuel. This insert is contained within a large 50mm thick copper overpack corrosion barrier. The Swiss (NAGRA) and French (ANDRA) organizations are investigating the use of large steel containers [,]. A common element of all these programs is the size of the containers; measuring over 4 metres in length and 1 metre in diameter. This large size is necessitated by the use of large, enriched uranium, light water reactor fuel bundles. The resulting containers weigh more than 25 tonnes with fuel.

In contrast to light water reactors, Canada's CANDU pressurized heavy water reactors use natural uranium fuel bundles, which are significantly smaller. A CANDU bundle measures approximately a half metre in length and weighs 25kg. The NWMO has developed a container specifically designed for CANDU fuel, shown in Figure 2, with several novel design features:

1. Constructed using standard nuclear pressure vessel grade materials and sizes
2. Hemi-spherical heads for uniform distribution of external pressure loads
3. Smaller sized container, weighing less than 3 tonnes when loaded with fuel
4. Copper coating corrosion barrier integrally bonded to structural steel container
5. Partial penetration Hybrid Laser Arc Weld (HLAW) for container closure

The partial penetration HLAW seal weld is a departure from the international designs. The SKB/POSIVA dual-vessel container features a bolted lid inner container, which provides temporary containment via elastomeric seal. The long-term containment boundary is the copper overpack vessel, which is welded closed using

1 Nuclear Waste Management Organization, Toronto, Ontario, Canada
2 Novika Solutions, La Pocatière, Québec, Canada

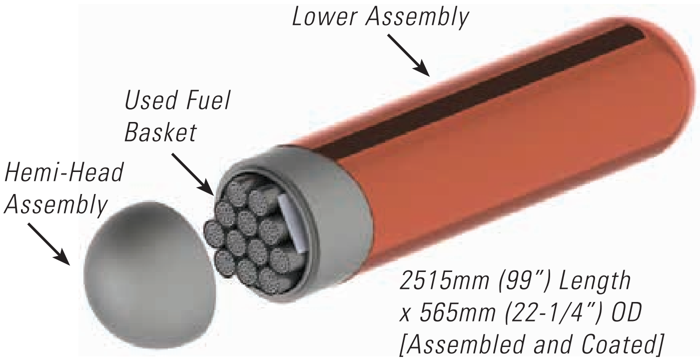


Figure 2: NWMO's Mark II Used Fuel Container.

full-penetration, single pass Friction Stir Welding (FSW). The NAGRA/ANDRA steel containers also propose full-penetration welds requiring multi-pass arc welding or high-penetration Electron Beam Welding (EBW).

2. Method

2.1 Hybrid Laser Arc Welding

Conventional arc welding processes such as Shielded Metal Arc (SMAW) and Gas Metal Arc (GMAW/MIG) operate on a similar principle. Electric current creates an arc between the base metal and filler wire. The arc plasma heats the base and filler metal reaching the materials melting point resulting in a weld pool. The penetration depth and welding speed is limited due to the low energy density; that is, the arc and weld pool quickly lose heat to the surrounding base materials limiting weld depth. In order to create deep welds, groove joint preparation and / or multiple passes are required.

Alternatively, high energy density welding processes such as Electron Beam Welding (EBW) and Laser Beam Welding (LBW) use focused energy on very small areas to both melt and vaporize the metal. The beam is focused on the joint and vaporizes the surface material creating a vapour cavity, known as the keyhole. Once the keyhole develops, the beam can penetrate deep into the joint, displacing the molten metal at the joint surface. This allows for deep single pass welds up to 16mm for LBW and 150mm for EBW [10]; however, joint preparation, position, and tolerances are critical for weld quality.

Hybrid Laser Arc Welding (HLAW) combines both LBW and GMAW into a single process, as shown in Figure 3. The laser beam is aimed at the leading edge of the weld pool and is closely followed by the GMAW, which move together simultaneously. The hybrid process uses the advantages of each individual process: laser provides deep penetration and high-speed single pass welds. Joint tolerance sensitivity is eliminated as the GMAW produces a wide and shallow bead filling any residual gap.

2.2 Joint Design for Used Fuel Container

Partial penetration welds are not suitable for conventional, internally pressurized nuclear vessels and containments. As a result, they are not permitted by relevant design codes and standards, such as CSA N285.0 and the American Society of Mechanical Engineers Boiler and Pressure Vessel Code Section III [] under most circumstances (the code will be referred to as ASME for the reminder of the paper). The NWMO is following industry best practice and all applicable design codes and standards; however at this time, no national or

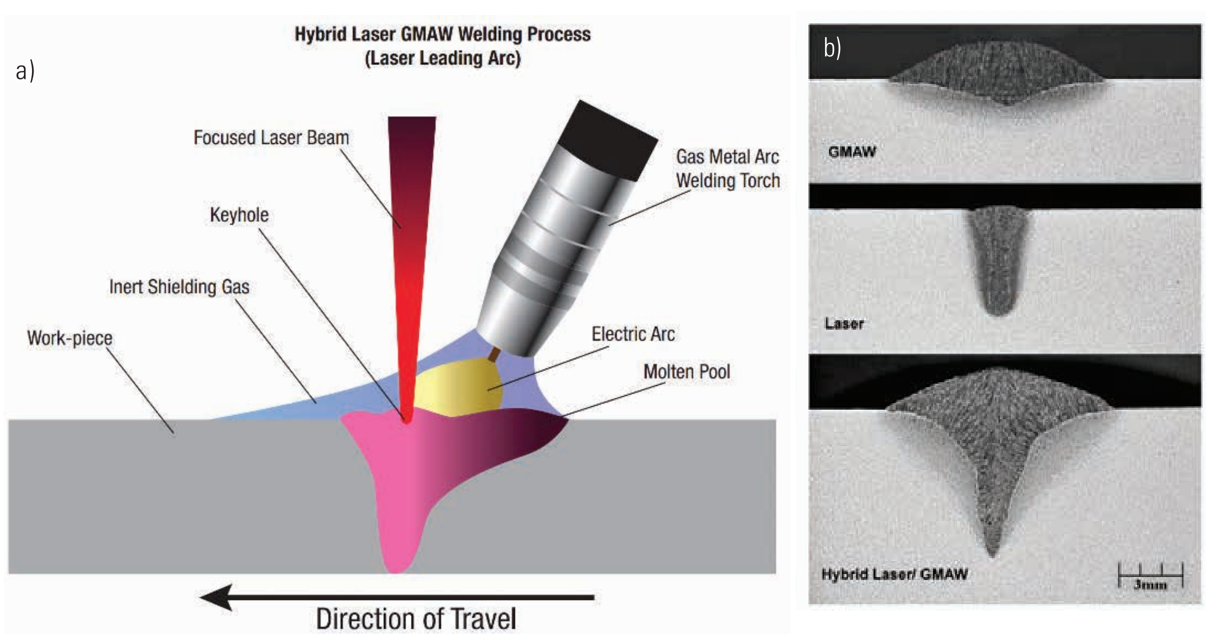


Figure 3: (a) Hybrid Laser Arc Welding Process Schematic [] (b) Weld cross-sections from Gas Metal Arc Welding, Laser Beam Welding, and Hybrid laser Arc Welding [10]

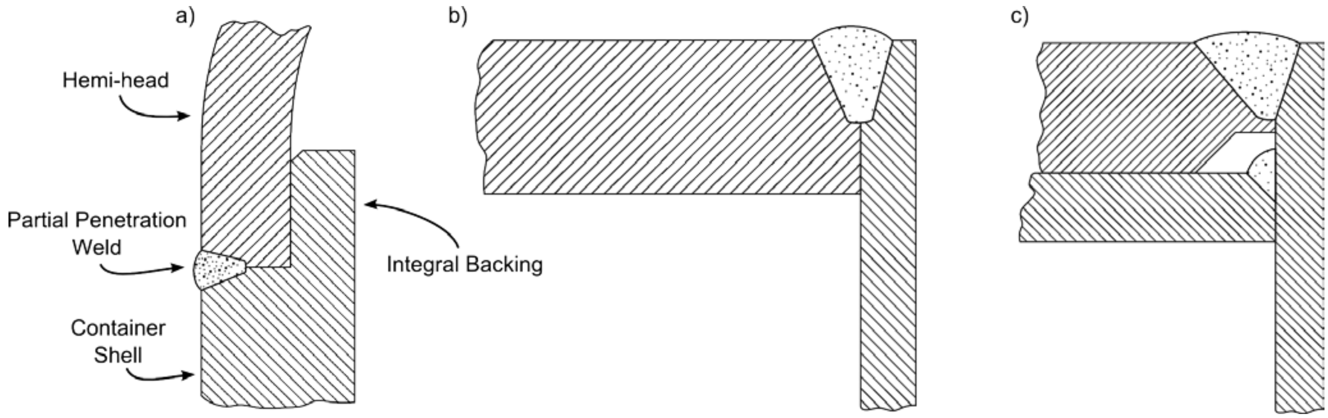


Figure 4: Partial penetration joint designs (a) NWMO's Mark II container with hemi-spherical heads (b) Typical ASME BPVC Class SC containers with single closure flat head (c) Double closure flat heads (adapted from [11])

international standard exists for the requirements on used fuel disposal containments. The closest appropriate code is the ASME Section III, Division 3, "*Containments for the Transportation and Storage of Spent Nuclear Fuel and High Level Radioactive Material and Waste*". Sub-section WC provides rules for interim used fuel storage containments only (Class SC vessels). A key difference with sub-section WC is that partial penetration welds are permitted for vessel closure for flat head designs, as shown in Figure 4 (b) and (c). NWMO's current approach is to follow the intent of ASME Section III Division 3, augmented as required for disposal containments.

Used fuel containers, whether interim or disposal, are designed to withstand external loads – internal pressurization is limited and a non-issue. The Mark II container joint design utilizes an integral backing in the cylindrical shell, as shown in Figure 4 (a). This backing supports the thinner hemi-spherical head and provides a locating feature suitable for automation in a radiological environment. With this design, the weld experiences limited tension and shear under external pressure. The weld's role in structural integrity is vastly diminished and its core function is reduced to an air-tight seal. The NWMO's current structural analysis shows that an 8mm partial penetration weld is more than sufficient for long-term containment.

2.3 HLAW Process Development and Demonstration for the Used Fuel Container

The NWMO investigated several different methods for welding the container based on the following weld requirements:

1. Metallurgy and Mechanical Properties
   a. Tensile strength and ductility equivalent to base material properties
   b. No martensite present (Hardness <22 Rockwell C as preliminary target)
   c. Must meet ASME Section III impact toughness at lowest service temperature of -5°C
   d. Weld penetration > 8mm
2. Quality
   a. Must meet ASME Section III ultrasonic inspection requirements with more restrictive criterion (3mm max flaw length)
   b. Cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length
   c. High repeatability
3. Manufacturability
   a. No post-weld heat treatment
   b. Ability to perform localized weld repair
   c. Suitable for remote welding using automated equipment (nuclear application)

After completion of the feasibility and scoping studies, summarized in Table 1, HLAW emerged as the preferred technology. NWMO and Novika Solutions [] began a comprehensive HLAW process development and demonstration program for the Mark II container closure weld. The work program involved investigation and proof testing of:

1. Weld joint design and preparation
2. HLAW procedure, parameters, and draft qualification
   a. Weld pre-heat
   b. Laser (power, spot size, weld speed, ...)
   c. GMAW (current, voltage, angle, wire feed rate, ...)
3. Metallurgical and mechanical properties testing to meet ASME Section III requirements
4. Non-destructive Examination
5. Defect repair

As mentioned, the NWMO is following the intent of the ASME code including applicable fabrication rules. Specific weld qualification rules are required for compliance. The primary objective of weld qualification is to ensure that materials and techniques being utilized

Table 1: Scoping Study: Comparison of Welding Processes

Welding Process	Process Advantages	Process Disadvantages
Arc-Welding (GMAW, GTAW)	- Low Equipment Cost - High Reliability - Well-understood - Rough joint position and fit-up required	- Lower penetration - Groove joints and multi-pass required for thick welds
Laser Beam Welding (LBW)	- Low distortion - Small Heat Affected Zone (HAZ) - Fast Weld Speed - No filler metal - Flexible fiber optic cables for beam delivery from laser source - Easily automated, robot friendly	- Accurate joint position and fit-up required - High equipment costs - Beam alignment and focus critical
Electron Beam Welding (EBW)	- Low distortion - Small Heat Affected Zone (HAZ) - Fast Weld Speed - No filler metal - Highest Penetration	- Very accurate joint position and fit-up required - High equipment costs - Beam alignment and focus critical - Requires vacuum (chamber or local seal) - X-rays generation (safety hazard) - Larger electron gun unit required for beam delivery
Friction Stir Welding (FSW)	- Low distortion - Small Heat Affected Zone (HAZ) - No filler metal - Solid state process	- Very accurate joint position and fit-up required - High equipment costs - Weld termination (exit hole) requires run off tab - Automation difficult
Hybrid Laser Arc Welding (HLAW)	- Low distortion - Fast Weld Speed - Simple joint preparation - Easily automated, robot friendly	- High equipment costs

result in consistent, quality welds with acceptable mechanical properties. Beginning with the 2013 code edition, ASME allows the use of HLAW for fabrication of nuclear pressure vessels including storage containments.

2.4 Novika Solutions Laser System

Novika Solutions' HLAW system consists of four major components, as shown in Figure 5. The laser source is an IPG Photonics YLS-15000 15 kW fiber laser. The focusing optics encompass a 0.4mm core fiber optics process cable with a Precitec YW-50 processing head (150 mm collimator and 300 mm focal length). The GMAW system is a Lincoln Electric Power Wave 655R and a PowerFeed 10R wire feeder. Seam tracking was assured via a Servo Robot Quanta LF laser camera and Robo-Trac servo slides. A Fanuc Robotics R-2000iB 165F robot was used for handling the weld end effector system.

2.5 Used Fuel Container Rotation Equipment (ROTEQ)

To complete automated welds on full-scale Mark II prototype containers, a specialized piece of handling equipment was required. The Used Fuel Container Rotation Equipment, known as the ROTEQ and shown in Figure 6, was designed, fabricated, and tested by Novika Solutions in collaboration with the NWMO.

The container is rotated while the weld end effector remains stationary relative to the ground (1G weld position); therefore, the weld speed is directly controlled by the container's rotation speed. A conventional rotation method for welding steel pipe is to use motorized rollers

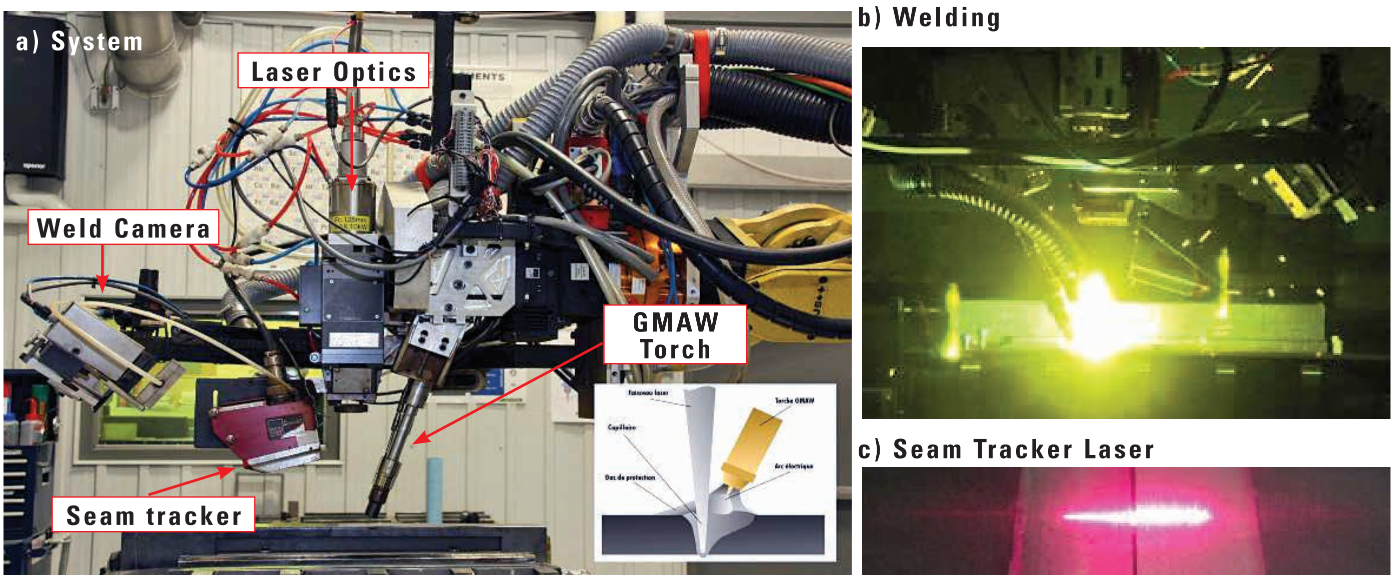


Figure 5: Novika Solutions' Hybrid Laser Arc Welding (HLAW) System.

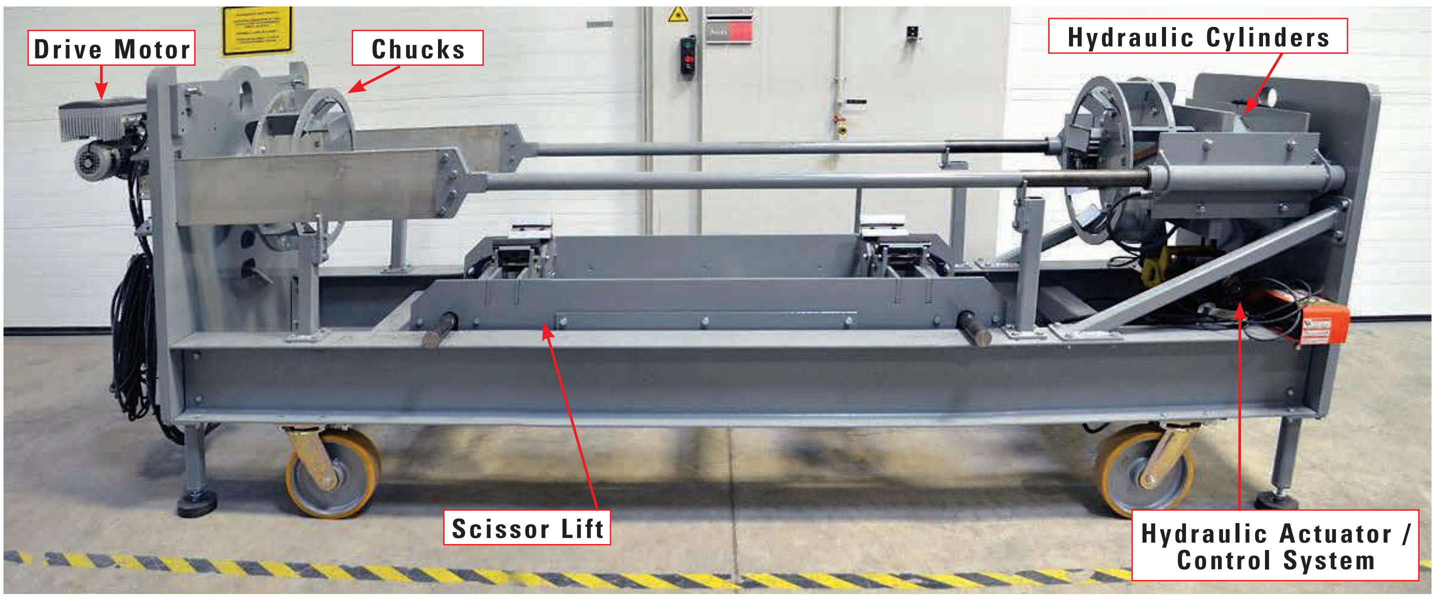


Figure 6: Rotation Equipment (ROTEQ) for Mark II Used Fuel Container welding.

in contact with the outer diameter. However, this is not suitable for the container as rollers can create high, localized contact pressures. The Mark II container is fully copper coated and a primary concern is to minimize the damage to this surface. Additionally, even if rollers were possible, the hemi-spherical head would still need to be secured in place for the welding operation.

To circumvent these issues, an end-clamping method was devised that simultaneously secures the hemi-heads and minimizes contact pressure with the container surfaces. Custom chucks, shown in Figure 6, were designed to clamp directly onto the two hemi-spherical heads and drive the rotation. This design provides several advantages over rollers:

1. The unwelded hemi-spherical head is securely clamped into place with over 27,000N force
2. Larger contact areas on the end chucks keep pressures low, eliminating damage from indentation
3. Limited potential for slippage compared to rollers. Allowing precise rotation positioning for circumferential welding.
4. Limited potential for vertical displacement (e.g. bouncing / vibration on rollers), which is critical for post-weld machining operations

3. Results

3.1 HLAW Process Development and Demonstration for the Used Fuel Container

3.1.1 Joint Design and Preparation

An initial study investigated NWMO's proposed integral backing joint design by determining the

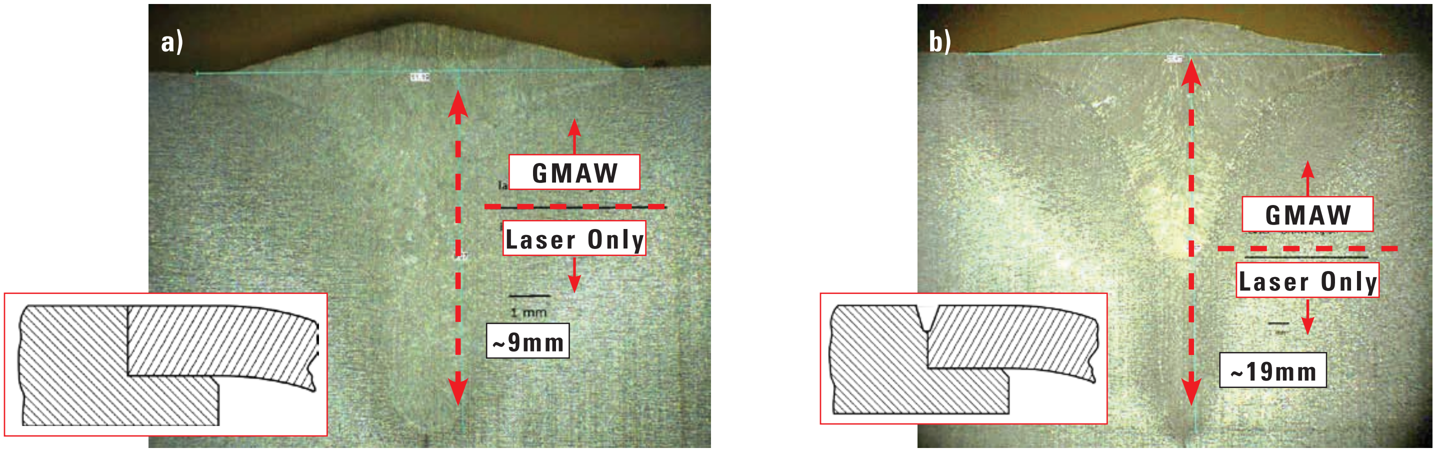


Figure 7: Typical Hybrid Laser Arc Weld Micrographs (a) Butt joint (no preparation) (b) ~8mm V-groove joint preparation.

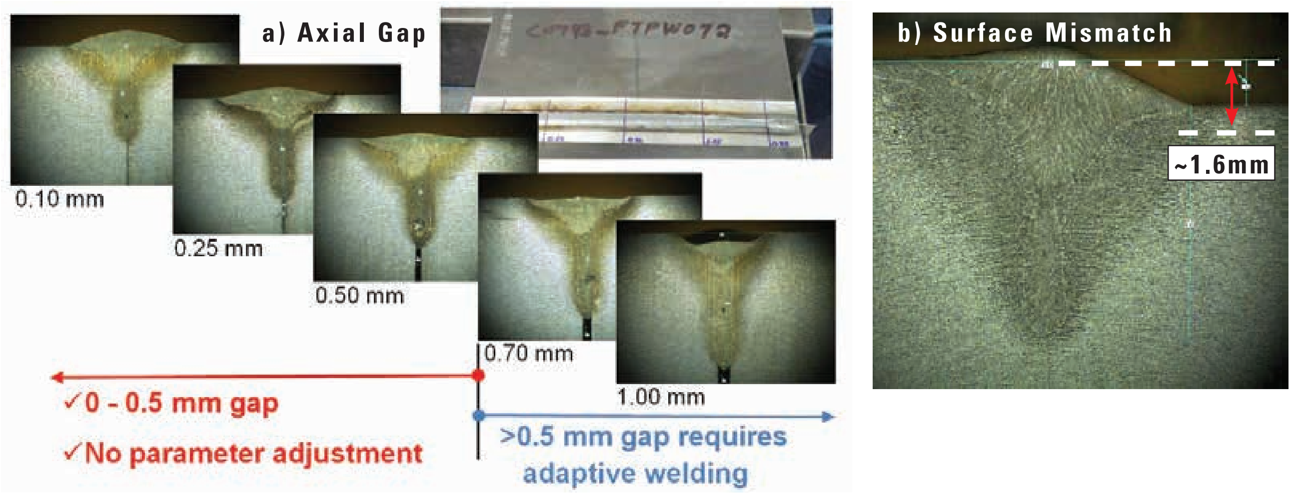
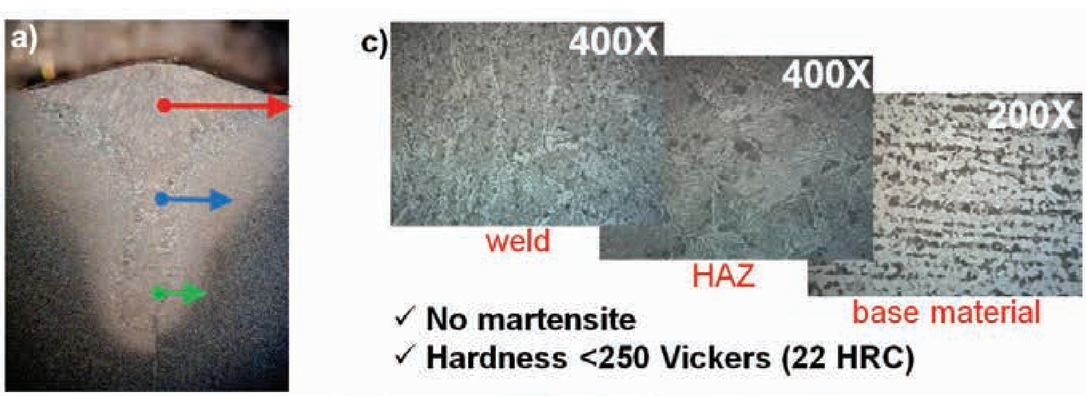


Figure 8 Joint tolerance for acceptable welds (a) Axial gap < 0.5mm (b) Surface mismatch < 1.6mm.



b) Base Metal | HAZ | Weld | Intersections

Sample W006C

1 mm below surface base metal	206	201	210	213	210	225	210	213	207	182	178	172	156	151	151
Center of weld	198	201	198	189	177	168	169	169	173	154	149	145			
1 mm from bottom of weld	204	215	192	183	156	151									

Figure 9: Metallurgical Analysis (a) Micrographic cross-section (b) Hardness measurements < 250 Vickers (22 HRC) (c) Micro-structure of weld, Heat Affected Zone (HAZ), and base material - no martensite visible.

Table 2: Mechanical Properties Analysis

Property	**Requirement**	**Result**	**Comments**
Tensile Strength	≥ 483 MPa	496 MPa avg.	All specimens passed. Ductile failure in base material, except for one specimen in weld at 502 MPa.
Ductility (side bend test)	No open discontinuities	No open discontinuities	All eight specimens passed
Charpy Impact Toughness @ -5°C	≥ 27J	105J avg.	All six specimens passed.

achievable penetration depth while maintaining weld quality using various preparation techniques. As shown in Figure 7 (a), a simple square butt joint achieved quality welds of 8mm-11mm depth (averaging 9mm). Depths of >13mm were achieved; however, root cracking occurred. To achieve quality welds at greater depths, a V-groove joint prep was added. This allowed depths up to ~20mm, as shown in Figure 7 (b), in a single pass with the filler metal providing ~10mm of penetration.

The sensitivity of joint position and fit up was also examined. The axial gap between the head and shell were varied from 0.0mm up to 1.0mm. The surface mismatch was tested up to ~1.6mm. As shown in Figure 8, the GMAW weld filler metal accommodates for up to 0.5mm of gap and 1.6mm of mismatch while still producing quality welds. The NWMO has set preliminary tolerances that ensure that the maximum gap and mismatch are below these values.

3.1.2 Metallurgical and Mechanical Properties

A key metallurgical requirement is no untempered martensite after welding; additionally, the NWMO wishes to avoid a post-weld heat treatment operation. Novika Solutions determined that pre-heating was necessary to achieve these requirements and performed parameter trials at 100°C to ~500°C. The study concluded that a minimum pre-heat of 400°C produces hardness less than 22HRC (250 Vickers); measurement values and locations are summarized in Figure 9. To consistently ensure low hardness, a reference pre-heat value of 450°C is applied and maintained on the container prior to and during welding. The key mechanical properties were also tested on the qualification samples. All specimens exceeded the ASME Section III requirements, summarized in Table 2.

3.1.3 Non-destructive Examination

Non-destructive examination was completed by ultrasonic inspection using both phased array and pulse echo methods. These methods provide a full volumetric examination of the weld and HAZ zone detecting porosities, lack of fusion, and penetration depth.

The inspection procedure followed applicable ASME Section III Division 3 and Section V methodology. All imperfections which produced a response greater than 20% of the reference level were investigated to determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below.

a. For weld procedure development purposes, unacceptable imperfections are those indications which exceed the reference level amplitude and have lengths exceeding 3 mm.
b. Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

All qualification welds passed ultrasonic examination using both phased array and pulse echo methods; all indications were less than 20% of the reference standard signal (i.e. non-relevant).

3.1.4 Weld Repair

Weld repair was performed on several different types of intentional defects including porosities, lack of penetration, missed joint, and lack of filler material.

Repair was completed by re-applying the welding procedure in the affected area with an additional ~20mm overlapping start and stop regions in existing "good weld". In these regions, the laser power is ramped from zero to full welding power (or vice versa) to prevent abrupt collapse of keyhole / weld pool. Ultrasonic examination was completed before and after the weld repairs to confirm successful repair of all weld defects.

The largest challenge for weld repair is re-locating the weld joint. Once the weld cap is machined flush, there is no identifying feature on the surface of the container for the seam tracker to locate the joint. To overcome this limitation, the weld system records the weld joint positions during the initial weld. All subsequent repair welding is completed in "playback" mode, where the positioning corrections are made on an elapsed-time basis or as a function of container radial position.

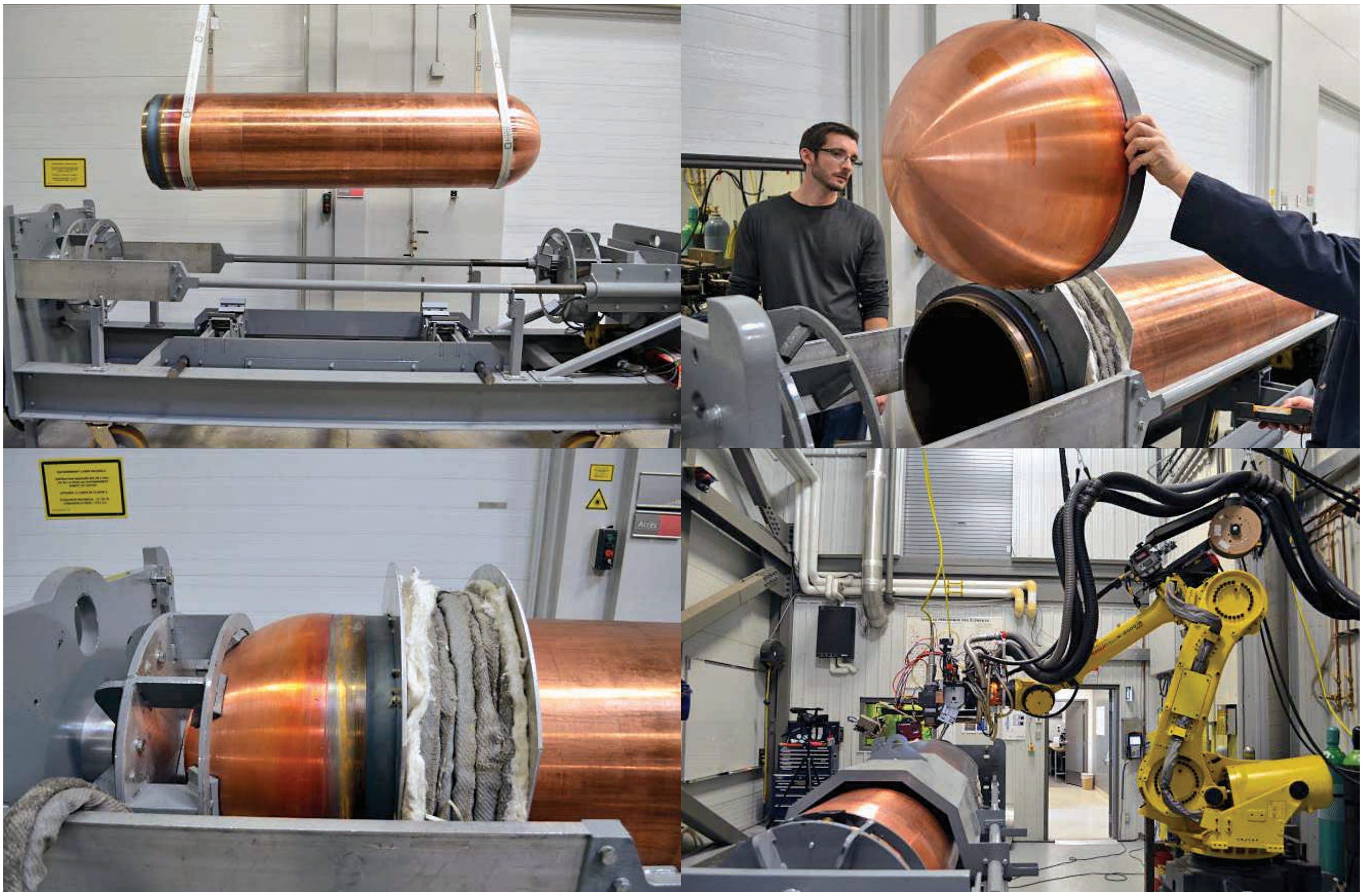


Figure 10: Mark II Used Fuel Container Welding (a) Loading container into scissor lift (b) Loading upper hemi-head into position (c) End-clamping of container and positioning of non-contact induction heater (d) Welding with splatter guards in place.

3.2 Leading Container Welding and Machining

The ROTEQ successfully welded and machined the prototype Mark II container. The operation of the ROTEQ is summarized below with key steps shown in Figure 10 and Figure 11:

1) The container is loaded into the moveable scissor lift for initial positioning of the container
2) Once located, the upper hemi-spherical head is positioned onto the container shell integral backing.
3) Two linear hydraulic cylinders securely clamp the hemi-head and container shell. A hydraulic accumulator is used to prevent loss of pressure and clamping force. The scissor lift is retracted and the full container weight is supported solely by the end chucks.
4) A circular induction heating coil slides over the container weld zone with a uniform ~1/4" stand-off distance and begins pre-heating.
5) An encoded, high torque gear motor rotates the container ensuring uniform pre-heat at all locations.
6) Once the pre-heat temperature is reached, the induction coil is moved directly beside the weld zone on the shell side. It continues operating during welding to maintain the pre-heat temperature.
7) The Fanuc robot with Novika Solution' custom weld end effector moves into position above the weld zone.
8) The rotation begins and the tacking sequence is initiated. A laser-only tack weld is completed every 45 degrees. After all 8 tacks are completed, the position is reset.
9) The rotation begins and the final welding sequence is initiated. The seam tracker leads the hybrid laser-GMAW and follows the position of the joint. The weld is completed in less than 3 minutes.
10) After cooling, the induction coil is moved out of the way and the weld cap machining attachment is installed.
11) The weld cap machining is initiated and the cap is removed in one or two passes.

4. Conclusions and Future Work

NWMO and Novika Solutions have demonstrated that Hybrid Laser Arc Welding is a viable process for closure welding of the Used Fuel Container. It is a fast,

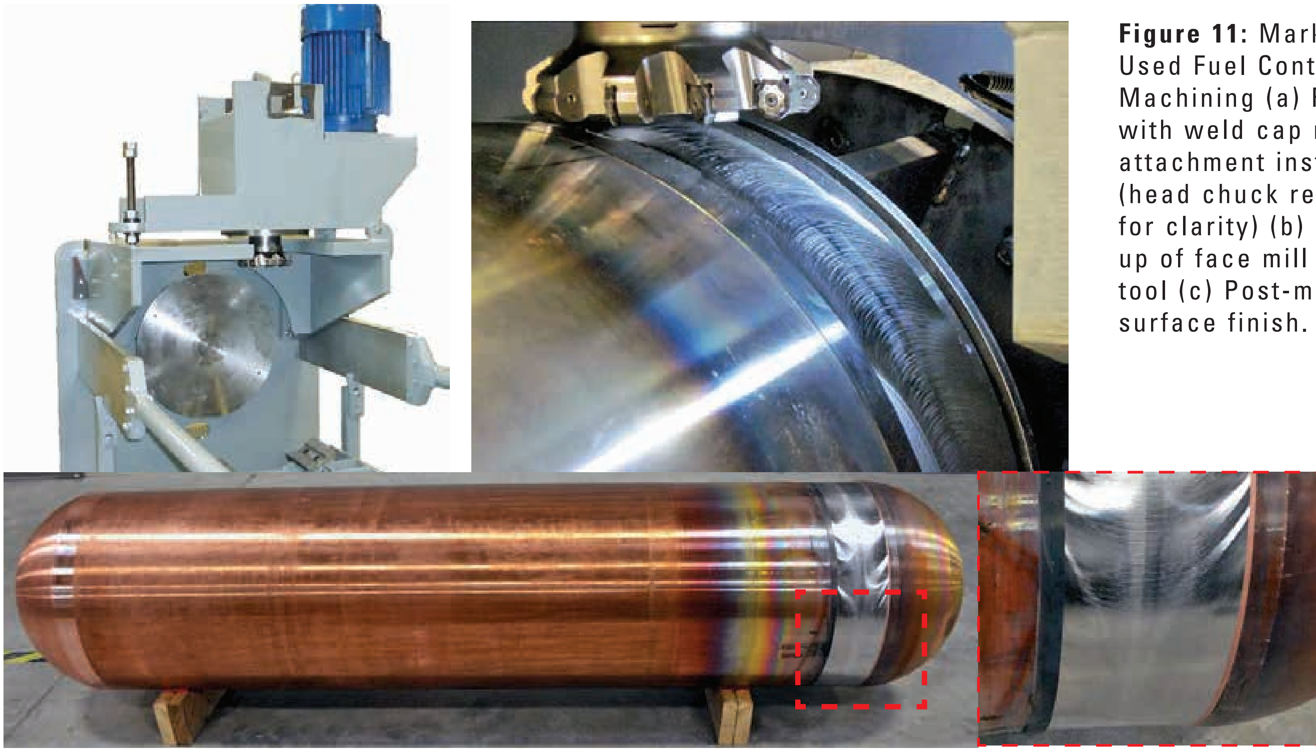


Figure 11: Mark II Used Fuel Container Machining (a) ROTEQ with weld cap removal attachment installed (head chuck removed for clarity) (b) Close-up of face mill cutting tool (c) Post-machining surface finish.

repeatable, and repairable process meeting all NWMO requirements. A draft weld procedure specification has been produced, tested, and analyzed on plate and pipe specimens with all metallurgical, strength, and quality properties meeting the ASME Section III requirements. A custom piece of equipment for welding the Mark II container was designed, fabricated, and tested successfully on full-scale Mark II container prototypes.

As part of future work, Novika Solutions is investigating weld parameter sensitivity and its effect on weld quality. After this investigation, a final weld procedure specification will be created for the normal and repair weld scenarios. The ROTEQ equipment will be upgraded to incorporate automation features, such as non-contact pre-heat temperature control and rigid coil induction heating system that does not need to be manually re-positioned prior to welding.

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Industry-University Collaboration for Research and Education

by B.A. SHALABY, V.G. SNELL, B. ROUBEN[1]

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Abstract

University Network for Excellence in Nuclear Engineering also known as UNENE is a joint partnership between the nuclear industry and thirteen universities. UNENE has been legally registered as of 2002 as a not for profit organization. The establishment of this network was prompted by industry to address anticipated retirement of a large number of professionals from industry starting in early 2000 onwards and thus the loss of nuclear knowledge and experience within industry. UNENE was created to provide a sustainable supply of highly qualified personnel to industry, support nuclear research within various universities and provide a course based Master's Degree in nuclear engineering to enhance the knowledge of young professionals within the industry in the science and technology of the CANDU nuclear power system. The paper describes the current UNENE, its research objectives, key outcomes of research programs to date and its contribution to industry needs in maintaining an economic and safe power plant performance of its nuclear fleet. The paper addresses achievements within the education program and the new 4-course diploma program recently introduced to enhance core expertise of young industry professionals. Also publications and national and international collaborations in various aspects of research have significantly contributed to Canada`s position in nuclear science and research worldwide. Such collaborations are also addressed.

1. Introduction

The start of the new millennium prompted the nuclear industry to review its intellectual and technical capability and plan for the future to meet its business priorities. The operating utilities' priority is maintaining their core capabilities to secure support of the design and licensing basis of the current CANDU Nuclear Power Plant (NPP) fleet. Along with this priority, design and vendor organizations plan to maintain their core technical capabilities for the support of their current design and refurbishment contracts, as well as the medium and long term need for the continuous evolution of the technology in keeping with new market and regulatory requirements. This became the impetus for the establishment of an industry-academia collaborative framework called UNENE; University Network for Excellence in Nuclear Engineering.

To date, more than a decade in existence, this partnership has grown and steadily progressed to become a mature and well respected partnership with notable achievements. These are in both program areas, Research and Education, and are discussed further in the paper under

- Leveraged funding
- Research outcomes and advances in knowledge
- New Equipment and Research facilities established under UNENE
- Education Program ; Knowledge transfer mechanisms to enhance nuclear competencies within young industry professionals
- Training and development of Highly Qualified Personnel for industry and other scientific agencies within Canada
- Publications by UNENE funded researchers

2. Leveraged Funding

Industry research funding is 100% leveraged by NSERC to the level of \$1.67M per year. Additional leveraging of research funds continues amounting to an additional \$1M through individual efforts by researchers at various UNENE universities (e.g. McMaster, RMC, UWO etc.). In addition a number of one-time grants totalling \$43M were secured through multi UNENE university submissions during the two year period 2007-2009. These grants were mainly from provincial and federal sources such as Ontario Research Funds (ORF), NSERC and Canadian Fund for Innovation (CFI), and some Universities. These additional funds enabled new facilities to be established, hence sustaining an increased scope of research and number of graduate students. The new equipment and research facilities established are discussed further in this paper.

3. Research Outcomes

To date research outcomes have been mostly advances in knowledge in support of continued safe and economic performance of plants and/or development of a meth-

1 University Network of Excellence in Nuclear Energy

Figure 1: Schematic of the Reactor Material Test Lab (Queen`s University).

odology, software or hardware for potential application to plant operation and safety margin enhancements or towards optimization of inspection and maintenance practices. Some of the notable outcomes are:

1- Severe accident phenomena modelling and analysis with validation through experimental results. This work continues and is in support of substantiating limits of In Vessel Retention (IVR) for CANDU cores. The IVR is the basis of severe accident mitigation for current and future CANDU plant designs and licensing. Along with the ongoing research in this area, an optimized heat sink mitigation strategy is formulated crediting and confirming current plant heat sinks.

2- Operating margin quantification and restoration through the application of advanced thermalhydraulic modelling and experiments. These are undertaken to substantiate margins in plants that are close to refurbishment. Experimental CHF (Critical Heat Flux) facility for full characterization of CHF under high pressure and high temperatures are also being used covering reactor conditions to improve modelling in support of margin quantification.

3- Application of a probabilistic based methodology to derive a risk based inspection and maintenance program for critical NPP equipment. This methodology is developed under the UNENE Research Chair program at the University of Waterloo. It has been applied successfully to other key plant components industry wide in support of a risk based inspection and maintenance program for some of these components. This methodology integrates actual component inspection data and mechanistic models on component degradation mechanisms into a probabilistic based methodology to derive a risk based approach to component replacement or maintenance.

4- Research data from the Nuclear Materials Program of Queen`s University research chair, is used by industry for validation of the Fitness For Service Guidelines (FFSG) codes used for Fuel Channel Inspection.

5- Fuel-channel creep models are also updated by industry based on new understanding developed by the Nuclear Materials IRC.

Other ongoing research that will result in advances in knowledge and of potential benefit to future operation and refurbishment are:

a) Improved understanding of long-term radiation impact on non-human biota. This is based on current research on fish species undertaken by the Research Chair on Radiation Physics and Environmental Safety at UOIT.

b) ALARA (As Low As Reasonably Achievable) improvements for equipment maintainability is expected based on an ongoing development of a robot (at UOIT) equipped with radiation detectors and 3D mapping of rooms/areas along with a capability of identifying hot spots in such areas to reduce/optimize dose and durations during maintenance.

c) Recommendation on the corrosion susceptibility of Steam Generator Tubing (Alloy 800 and 600) under various operating and shutdown conditions for avoidance of potential corrosion during various conditions.

d) Development of a Transient Eddy Current (TEC) probe technology for inspection of equipment internals with tight configurations such as those of SG tube-tube support area, Pressure Tube/ Calandria Tube gap (PT/CT gap) and CT/ LISS (SDS2) nozzle gap.

4. New Equipment and Research Facilities

Leveraged one-time funds from federal and provincial agencies have been used towards the establishment of new research facilities in universities and the acquisition of modern equipment to sustain an increased scope of research and number of graduate students. Some notable facilities are

- The Reactor Material Testing Lab (RMTL) at Queen`s University

This new facility now built and operational has a 4 MV tandem proton accelerator, two new electron microscopes and other testing equipment. The proton accelerator will be used to introduce degradation into fuel channel materials at the microstructure level, simulating radiation and stress introduced as a result of in-reactor conditions and to further characterize key degradation mechanisms experienced in materials, as well as investigating potential modification and improvements of materials. These results will be used to expand our understanding of CANDU fuel channel materials, and increase our capability to characterize their irradiation induced degradation mechanisms. Funding to establish the facility was obtained from the Canada Foundation for Innovation (CFI), the Ontario Ministry of Research and Innovation (MRI) and Queen's University.

- A new Centre for Advanced Nuclear Systems (CANS). This $24M regional facility provides a unique world-class capability to advance research in three focus areas:

1) Nuclear materials,
2) Nuclear safety thermalhydraulic behaviour, and
3) Health physics.

Funding to establish the facility was obtained as grants awarded in 2009 by the Canada Foundation for Innovation (CFI) – New Infrastructure Fund (NIF) and the Ontario Ministry of Research and Innovation (MRI).

CANS is comprised of four primary facilities, namely:

1. Post Irradiation Examination of Nuclear Materials (McMaster University)
2. Nuclear Materials Characterization Facility (McMaster University)
3. Thermal Testing Facility (McMaster University)
4. Health Physics Dose Response Facility, located at the University of Ontario Institute of Technology (UOIT) and made fully operational by the IRCs and their team.

These facilities provide a suite of irradiated material handling and testing facilities and equipment; a thermal testing laboratory (at McMaster); and a radiation dose laboratory (at UOIT). This infrastructure, together with the McMaster Nuclear Reactor and the Canadian Centre for Electron Microscopy, provides a world class materials and thermal testing centre unique in North America. The project was supported by a majority of Canadian nuclear energy related companies (OPG, Bruce Power, AECL, and Kinectrics) as well as a number of leading international organizations (EPRI, EdF, Bechtel).

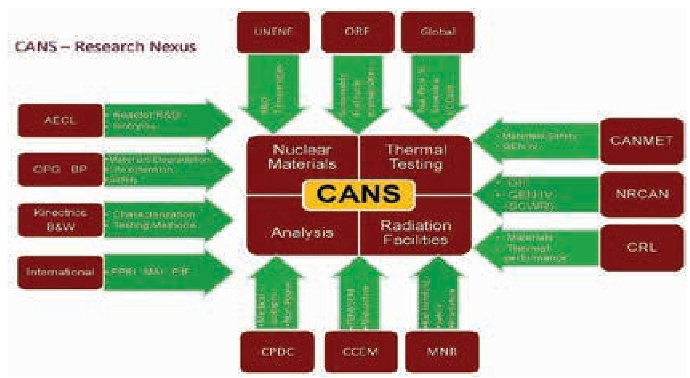

Figure 2: Centre for Advanced Nuclear Systems.

5. Education Program

To meet the set objectives for UNENE an education program was initiated 2 years after the establishment of the partnership and following the formal accreditation of the program. The program consists of a course-based M.Eng. in Nuclear Engineering offering graduate level courses from various UNENE universities under the UNENE umbrella. The degree is geared to young industry professionals for enhancing their knowledge of the design and licensing basis of the CANDU technology. Courses cover the entire spectrum of the technology and are offered via different universities with Instructors, mainly UNENE research Chairs that are well recognized scientists in their field with most of them with significant experience in industry as well.

Lectures are delivered in a classroom setting on weekends and use distance-learning tools (Blackboard – Collaborate) to accommodate students at various sites and weather conditions. Since the start of the M.Eng. Program, a total of ninety three (93) students have graduated upon successful completion of the 10-course program or an 8-course plus a project. Figure 3 below provides further details.

A new Diploma program is now introduced under UNENE, starting April 2015. This was the outcome of a strategic planning session of the Board of Directors in March 2011. Its intent is to increase the student base and provide another shorter track in nuclear education. The Diploma is a four (4) graduate-course program enabling young industry professionals to acquire focused knowledge in a given core competency area needed by the individual in his/her current area of responsibility.

Another notable highlight in education is the development of a CANDU Textbook documenting the scientific basis of the CANDU-HWR technology. This was initiated in 2012 under a Joint Project funded under COG (CANDU Owners Group) with contributions from CANDU utilities in Canada and offshore and UNENE. Many chapters of the textbook are now available at www.unene.ca/publications.

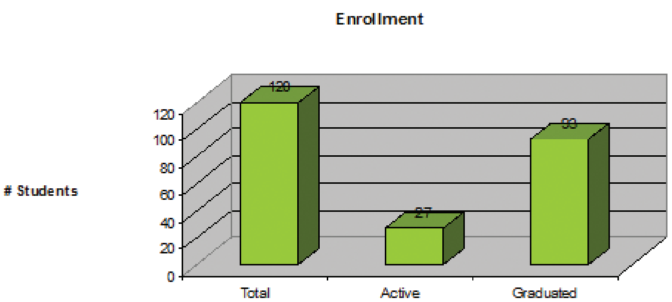

Figure 3: Student throughput of the UNENE M.Eng.

6. Development of Highly Qualified Personnel (HQP)

Training and development of HQP for potential deployment by industry is one key objective of UNENE. The complement of graduate students in the various UNENE research programs grew from the early years to a typical level of nearly 130 students who are at various phases of their research programs. Some of the past graduates have been successfully recruited by industry, national laboratories, government and academia within Canada. The bar chart below (Figure 4) depicts a typical distribution of HQP in different research programs.

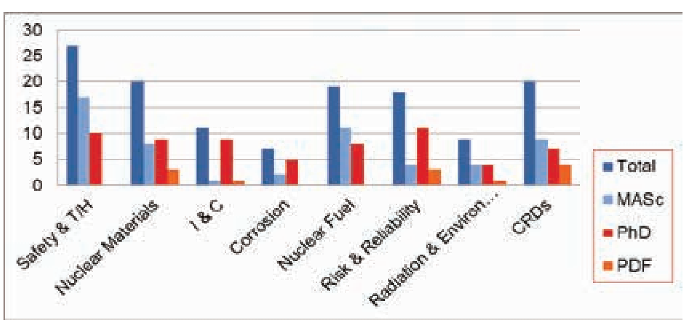

Figure 4: Distribution of HQP across Research Programs (Typical).

7. Publications

Advances in knowledge and technology are documented in Ph.D. and M.A.Sc. theses, as well as journal publications and conference papers. Over 100 publications a year are published in journal papers, conference proceedings, academic /industrial presentations and /or chapters in technical books. These advance knowledge in all aspects of the technology and showcase Canadian nuclear research. These outcomes are also documented nationally through the research Chair participations on various COG technical committees and internationally through various exchanges of students, sabbaticals, etc.

Conclusion

The UNENE Industry-University partnership has steadily grown over the last eleven years, thriving and achieving the following attributes:

1 - Research of relevance and impact in nuclear science and technology and for the benefit of the CANDU design, licensing and operations.

2 - A pool of university-based nuclear experts who are well respected and have a strong research culture of scientific enquiry/innovation.

3 - M.Eng. & Diploma degrees catering to young industry professionals and geared to enhancing core competence.

4 - Extensive national and international collaborations

5 - New research infrastructure (equipment/labs) through leveraged grants from government agencies.

Acknowledgments

The successful partnership of UNENE hinges on the annual financial support of industry members, National Science Engineering and Research Council (NSERC), and on the one-time grants from government agencies such as Ontario Research Funds (ORF), New Infrastructure Fund (NIF), the Ontario Ministry of Research and Innovation (MRI), the Canadian Fund for Innovation (CFI), and some Universities.

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[1] B. Shalaby, V. Snell, B. Rouben, "UNENE; An Update on Nuclear Education and Research", in Proceedings of the 31st Canadian Nuclear Society Conference, 2010 June, Montréal, Québec, Canada, 2010 May 25-28

[2] http://www.unene.ca/

A WORLD TO COME HOME TO - Ending Global Warming in Our Lifetime

Author: Craig R. Hover is a licensed professional engineer (retired), a former member of the Nuclear Engineering Group at the San Onofre Nuclear Generating Station in California, and experienced in other areas such as financial services.

Reviewed by Ric Fluke

A WORLD TO COME HOME TO is about ending global warming by putting a stop to burning fossil fuels (coal, oil and gas). This must be done quickly, and completed by 2050. If we don't, 2050 is the year Hover cites as "The Point of No Return". Beyond that point it will not be possible to curtail global warming, even if we all wake up and decide to stop immediately all emissions of CO_2. That is because other GHG emissions (CH_4, a much stronger GHG than CO_2) will take over from decomposition of thawing permafrost. And as the planet's temperature increases, so will the amount of atmospheric water vapour, which is another GHG (H_2O). (Water vapour pressure increases exponentially with temperature.) It is seen then that failure to curtail CO_2 emissions will result in a positive runaway in global warming and the planet will become too hot to support human life, according to Hover. He dubs this scenario as "The Disaster Movie".

Hover presents an alternative to the Disaster Movie: a future that is prosperous and sustainable. Furthermore, the needed technology already exists.

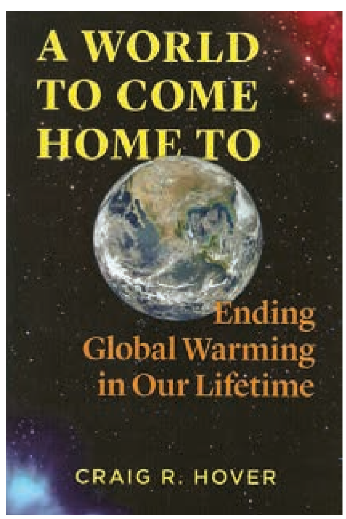
He outlines the three essentials - electricity, fuel and water. These essentials can be achieved without fossil fuels. Solar, wind and hydro can be used to generate electricity, which can be used to produce water (desalination of sea water) and fuel (hydrogen). Using simple first-order mechanisms Hover explains how this can be done.

CNS members are probably asking "Why not nuclear?" Good question! According to Hover, it would take too long. Perhaps true, given the history of nuclear build projects, but in my opinion, a much shorter build schedule could be achieved if the need is there.

Hover explains the problems with Biofuel such as depleting the aquifers, excessive land area and delivery. Hydrogen, on the other hand, is an energy currency that can be used for heating and motive. Battery-electric vehicles are not practical for typical needs (short range, long recharge). However, a hydrogen fuel cell can move an electric vehicle as fast and far as a conventional gasoline vehicle with similar refill times. The problem: lack of hydrogen "filling stations". The solution: off-the-shelf electrolysers installed at conventional filling stations, corner stores or the shed in your back yard.

There are, of course, barriers to overcome. These include the mainstream media, politicians, big banks, big business and big oil. They are controlled by what he refers to as "the entrenched interests". Overcoming the control of the entrenched interests begins with awareness, and a small number of people taking actions that catalyze others to follow suit. As Hover suggests, obtain information from other than mainstream media (newspapers, radio, TV and Internet are controlled by a few elite); elect someone other than the incumbent (Republicans, for example, receive enormous campaign contributions from big oil, but electing a non-incumbent gives politicians the notion that it is the public they serve, not big oil); switch to a credit union (banks make big money from big business, big oil and user fees); shop local (the big box stores with absentee owners take more money out of the community than is returned via jobs and local taxes); and, probably the most difficult, boycott brand-name gas stations and seek out hydrogen alternatives.

I found *A WORLD TO COME HOME TO* to be interesting, enlightening, informative and perhaps overly alarmist. Hover's explanations, written in layman's language, appear to be scientifically sound and he provides several scientific references. Although I am sceptical of some of his contentions (e.g. the "Disaster" scenario), I would recommend Hover's book to anyone who is concerned about global warming.



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GENERAL news

(Compiled by Colin Hunt from open sources)

Federal Appeal Court Upholds Darlington Environmental Assessment

In a 2 to 1 decision the Federal Court of Appeal on September 10, 2015 overturned Judge Russell's decision which would have sent the environmental assessment for the proposed Darlington Nuclear New Build Project back to the Joint Review Panel and invalidated approvals rendered by the Governor-in-Council, the Canadian Nuclear Safety Commission, the Department of Fisheries and Oceans and Transport Canada. Judge Russell had concluded that the Canadian Environmental Assessment Act S.C. 1992, c.37 requirements had not been met in three instances:

1. the Panel failed to fully consider the environmental effects of hazardous substance emissions, in particular liquid effluent and storm-water runoff and the sources, types and quantities of non-radioactive wastes to be generated by the project.
2. the Panel failed to consider radioactive waste management and more particularly the management of spent nuclear fuel off-site
3. the Panel failed to consider the effects of a common cause accident involving both the existing and proposed nuclear reactors, but left this issue to be addressed by the nuclear regulator prior to the actual construction some 8 years down the road.

The appeal court was unanimous in deciding that the waste management issue and the common cause accident had been adequately addressed by the Panel. The Terms of Reference did not require consideration of spent nuclear fuel off-site and the improbability of a common cause accident supported the Panel's deferral of the issue to a later date as a reasonable conclusion.

The Court disagreed on the question of whether the effects of hazardous substances emissions had been properly considered. The majority found that there had been a reasonable consideration and that was all that was required. The reasonableness of the consideration was found in the acceptance by the panel of the plant parameter envelope or bounding approach under which the proponent did not propose one design or technology but four separate ones. The distinct characteristics of each design giving rise to the greatest adverse effects set the boundaries for the environmental impact assessment. Without any firm design selection the full suite of effects could not be predicted fully at the assessment stage but the majority of the court found that the approach was reasonable when accompanied by recommendations for further regulatory action if and when the project proceeded.

CNEA Formally Takes Control of Canadian Nuclear Laboratories

The Canadian National Energy Alliance Ltd. (CNEA) entered into a long term contract with Atomic Energy of Canada Limited (AECL) on September 13, 2015 to manage and operate Canadian Nuclear Laboratories Ltd.(CNL). The agreement marks the completion of the project to transform AECL facilities from operation by a crown corporation to one by private corporate management.

The announcement came in the wake of the decision by the federal government in June 2015 that CNEA had been selected as the preferred bidder. AECL will continue to own the land, facilities, assets and intellectual property. AECL will now be focused on oversight of the contractual arrangement with CNEA on behalf of the federal government.

CNL will remain responsible for the day-to-day operation of the nuclear laboratories, and it holds all the licences and other regulatory responsibilities for undertakings at the sites.

L-3 MAPPS to Upgrade Embalse Simulator

L-3 MAPPS announced on July 16, 2015 that it had received a contract from Nucleoeléctrica Argentina S.A. (NA-SA) to upgrade the Embalse full scope simulator. Work will commence immediately and the upgraded simulator is expected to return to service in the third quarter of 2016.

"L-3 MAPPS has enjoyed an excellent relationship with NA-SA since we first took on the development of the Orchid®-based Embalse full scope simulator in 2010," said Michael Chatlani, vice president of marketing & sales for L-3 MAPPS Power Systems and Simulation. "We are honored that NA-SA continues to place their trust in us to further develop the simula-

tor, the most modern CANDU* plant simulator in the world."

"NA-SA and L-3 MAPPS put the Embalse full scope simulator into service in 2013 and we have experienced very positive training results since then," said Rubén Semmoloni, Embalse NPP life-extension project director for NA-SA. "The simulator plays a key role in the ongoing training of our operators and will continue to be important as we extend the life of the plant for another 30 years."

Since the full scope simulator was put into service in the first quarter of 2013, the Embalse plant has been through numerous design changes in response to NA-SA's ongoing plant refurbishment. The simulator upgrade is intended to reflect these design changes, including updates to the shutdown control systems, introduction of larger emergency diesel generators, improvements to the emergency core cooling system, addition of a new turbine control system, and a power uprate involving several thermal-hydraulic systems to increase the gross capacity of the plant from 648 MWe to 683 MWe. The project will also see an update to the Digital Control Computer emulation provided by L-3 MAPPS.

The simulator's main control room panels will also be updated with numerous modifications, including the addition of simulated human-machine interfaces for the ABB Symphony Harmony turbine controls and ABB UNITROL 6800 Automatic Voltage Regulator (AVR) control terminal.

The simulator's instructor booth will be enhanced to include L-3 MAPPS' revamped audio-visual recording and playback system, Orchid Multimedia Manager. Orchid Multimedia Manager will be used to record inputs from six new high-zoom digital cameras and six digital microphones to be added overhead in the simulator main control room. Orchid Multimedia Manager's advanced features and professional surveillance-grade interface will make it easy to monitor and follow Embalse trainees during simulator training sessions. The audio and video recordings, synchronized with the simulator, will make debriefing sessions much more informative and aid instructors to explain what actions and/or behaviors should be corrected.

L-3 MAPPS to Deliver Full Scale Simulator for Westinghouse Project in Japan

L-3 MAPPS announced today that it has won an order from Westinghouse Electric Company to deliver a full-scale 1,000 MWe class pressurized water reactor (PWR) simulator equipped with severe accident simulation capability as part of a larger project that Westinghouse is fulfilling for a customer in Tokyo, Japan. The simulator will be used to teach operators plant responses ranging from normal operations to severe accidents and is scheduled to be in service in the first quarter of 2016.

"Westinghouse and L-3 MAPPS have a rich and long history of working together to enable Westinghouse control systems with L-3 MAPPS-developed plant simulators in the U.S. and in Europe," said Scott Roberts, director, operator interface for Westinghouse. "We are pleased to collaborate with L-3 MAPPS on this important endeavor."

"L-3 MAPPS is committed to making a contribution to nuclear safety with this new project," said Michael Chatlani, vice president of marketing & sales for L-3 MAPPS Power Systems and Simulation. "The project is L-3 MAPPS' first sale into the Japanese market and we look forward to further developing our relationships in this region."

The simulator will be based on L-3's latest fully integrated Orchid® simulation environment and will operate within a virtual control room implemented using the Orchid Touch Interface and Orchid Sound System solutions, providing a full-scale training environment. The virtual panels and Orchid Instructor Station will be made available in Japanese to facilitate operation of the PWR simulator.

L-3 MAPPS will also connect the Electric Power Research Institute's (EPRI) Modular Accident Analysis Program (MAAP5) to the simulator. The simulator models will include support for the connection of external power and water sources, part of the diverse and flexible (FLEX) response strategy developed by industry to address challenges experienced at the Fukushima Daiichi power station following the earthquake and tsunami on March 11, 2011. MAAP5 is a software program that performs severe accident analysis for nuclear power plants, including assessments of core damage and radiological transport. The simulator will also be equipped with new two-dimensional and three-dimensional animated, interactive visualizations of the reactor vessel, containment building and spent fuel pool to provide trainees with additional insight into the behavior of the plant during severe accidents. With severe accident simulation capabilities, the PWR simulator will support training scenarios relating to degraded reactor core conditions that result in fuel melting, including cladding oxidation and hydrogen generation, vessel failure, containment failure and fission product release.

OPG Applies for 13-year Renewal of Darlington NGS Operating Licence

Ontario Power Generation (OPG) appeared before the Canadian Nuclear Safety Commission (CNSC) on August 19, 2015 for the first portion of its request to renew the operating licence of the Darlington nuclear power station. OPG has requested that the renewed licence be valid to 2028.

Covering 13 years, the new licence if granted would cover the entire period of the refurbishment of the Darlington station. Starting in 2016, each of its units will in sequence be fully refurbished to allow another 30 years of operation. When completed, it is expected that Darlington would be fit for service to approximately 2058.

The second portion of the public hearing will be held in Courtice, Ontario, November 2-5, 2015 with submissions from intervenors. It will be followed by a decision by the commissioners of the CNSC.

The Canadian Nuclear Society (CNS) will be participating in the public hearing in November.

On August 20, the CNSC gave Darlington its highest rating of "Fully Satisfactory" for the seventh year in a row.

OPG Names Jeffrey Lyash as New President & CEO

Ontario Power Generation (OPG) has named Jeffrey Lyash as its new President and CEO. Mr. Lyash comes to OPG from CB&I Power where he headed one of the largest US power engineering, procurement and construction firms.

Mr. Lyash's appointment became effective on August 21, 2015. In making the announcement, OPG Board Chairman Bernard Lord indicated that Mr. Lyash's talents and knowledge will be important to carrying out the refurbishment of the Darlington NGS.

Bruce Power Receives Its Best Ever Safety Report from CNSC

Bruce Power received its highest marks from the Canadian Nuclear Safety Commission (CNSC) on August 20, 2015, with an Integrated Plant Rating of Fully Satisfactory for its Bruce B nuclear power station.

The CNSC provides grades in 15 different safety categories. Bruce A received 3 fully satisfactory ratings, and 12 satisfactory ratings, while Bruce B received four and 11, respectively. Bruce Power President and CEO Duncan Hawthorne noted that these are the best ratings the company has received in its 14-year history of operating the station.

"We have worked very hard to continuously improve our safety performance," Mr. Hawthorne said, "And we are seeing those efforts reflected in the CNSC report card." He added that the credit for this performance goes to the hard work of Bruce Power employees.

Cigar Lake Celebrates Official Opening

Cameco Corporation and Areva celebrated the official opening of the Cigar Lake uranium mine in northern Saskatchewan on September 24, 2014. Mining at Cigar lake began in March 2014, nine years after construction of the mine commenced. The first packaged uranium concentrate from Cigar Lake was produced at the McClean Lake mill in October 2014.

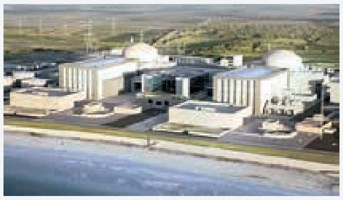
Cigar Lake is the site of 90,400 tU of proven and probable reserves averaging over 17% U_3O_8. It is therefore the world's second largest high-grade uranium deposit after the McArthur River mine, also in northern Saskatchewan.

The ore is removed by jet boring using a high pressure water jet to mine out cavities of frozen ore. The resulting slurry is then pumped to underground grinding and processing circuits. Finally it is then moved to the surface and transported 70 km. to the McClean Lake mill where it is processed into uranium concentrate.

Cigar Lake is owned by Cameco (50.25%), Areva Resources Canada (37.1%), Idemitsu Canada Resources (7.875%) and Tepco Resources (5%). The mine is operated by Cameco. It is expected that Cigar Lake will produce six to eight million pounds of uranium this year. At full production, 18 million pounds can be expected annually.

UK, China to Fund Jointly a New Nuclear Research Centre

The United Kingdom and China have announced a joint funding of a new $78 million nuclear research centre to be headquartered in the United Kingdom. The UK's National Nuclear Laboratory will jointly lead



the new UK-China Joint Research and Innovation Centre with the China National Nuclear Corporation (CNNC).

The announcement came on the same day that UK Chancellor George Osborne announced the the UK government would provide up to $3 billion in support of the planned Hinkley Point C nuclear power project.

Georgia Power Takes Delivery of Large Components for Vogtle

Large components for Vogtle Unit 4 were delivered to the site in September 2015. Vogtle 4 is one of two units being built at the Vogtle nuclear power station owned and operated by Georgia Power.

Delivered to the site were two core makeup tanks (135 tonnes each) and a 610 tonne steam generator. The makeup tanks were manufactured in Italy, and

the steam generators were produced in South Korea. Overseas equipment is being delivered by rail from the port of Savannah.

Vogtle is the site of two Westinghouse AP1000 PWR type reactors under construction. The two units began construction in March and November of 2013, and they are expected in service in 2019 and 2020.

Swiss Parliament Rejects Limits on Nuclear Reactors

Switzerland's Council of States has refused to put legal limits on the operating lives of the country's nuclear power reactors. It also rejected a proposal to require operators to submit a long term operating concept every 10 years once a reactor reaches 40 years of service.

In addition, it voted to impose a time limit on the federal renewable energy feed-in tariff subsidy scheme. It also authorized the switching of some of the funds supporting wind and solar power to support existing hydropower stations.

The Council is the upper chamber of the Swiss parliament. The decisions noted above will then go through a reconciliation process with the lower house National Council. These proposals originated in the search for a new national energy policy after the accident at Fukushima Daiichi. An initial policy of exiting nuclear power was followed by a rejection of a Green Party proposal to limit nuclear reactor operating life. Instead, the government put forward a new draft energy policy, subsequently being reviewed and amended by the two houses of parliament.

Evacuation Order Lifted for Fukushima Town

The evacuation order for the town of Naraha in the Fukushima prefecture was lifted on September 5, 2015. Naraha was one of seven towns evacuated completely by the accident in March 2011, and it is the first to have the order removed.

Naraha is located less than 20 km from Fukushima Daiichi. The Japanese Ministry of Economy, Trade and Industry announced that following decontamination and reconstruction work, residents of Naraha were free to return to their homes. The government intends to lift all evacuation orders by March 2017 except for certain specific areas were radiation levels are expected to remain high.

Meet the President

by FRED BOYD

By the time you read this Paul Thompson will have been in the office of President of the Canadian Nuclear Society for several months. He moved from 1st vice-President /President Elect automatically at the Society's Annual General Meeting held May 31, 2015, in Saint John, New Brunswick, immediately before the CNS Annual Conference. His term runs until the 2016 AGM.

This is actually Paul's second term as CNS President. He was elected in 1998 but his term was cut short by a tragic accident in December of that year. (See note appended to this article.)

At the two meetings of the Council of the Society that have been held since he became President, Paul has demonstrated his ability as a chairman and shown sensitivity to the number of new members. As chief executive officer he has increased the frequency of meetings of the CNS Executive and improved its decision-making process.

Paul brings to these challenging roles (president and chairman) a broad experience which has included various challenging technical roles, management, planning and advisor to senior management, primarily at the Point Lepreau NGS in New Brunswick.

Biography

Paul was born in Belleville, Ontario in1957. His family moved in 1966 to the brand new community of Kanata built just beyond the "greenbelt" surrounding the city of Ottawa. Originally a separate municipality, Kanata is now a large suburb of the amalgamated city.

He attended Queen's University in Kingston, Ontario, obtaining, in 1979, a B.Sc. (Honours) in Applied Mathematics, specializing in thermal sciences and nuclear engineering. Following graduation he joined what was then called Atomic Energy of Canada Limited, Power Projects (now SNC Lavalin Nuclear) in suburban Toronto. Seven years later, in 1986, he joined New Brunswick Power at its new Point Lepreau Nuclear Generating Station located south-west of the city of Saint John.

Two years later, in September 1988, he married Sue Bastock who had emigrated from England. Over the years they had three children and now one granddaughter.

They live in what Paul describes as a "live-in cottage" at Woodmans Point at the confluence of the Saint John and Nerepis rivers north of Saint John city. Paul states that in support of his wife's love of horses they have another piece of property near-by with a barn housing a number of horses and goats.

In what limited time his work and CNS role permits Paul pursues a number of athletic activities such as canoeing, kayaking, hiking, skiing and hockey. This is augmented with his intellectual interests in fields such as astronomy, archeology, history and paleoanthropology.

Professional Background

During his period at AECL Power Projects, 1979 – 1986, Paul initially worked on CANDU 6 fuel channel behaviour at high temperatures. This involved a number of analyses which were important for the licensing of the Point Lepreau and Gentilly 2 stations. That led to his appointment as AECL Licensing Supervisor for those two units. From 1983 to 1986 he was project manager for the nuclear safety work conducted at AECL Power Projects for NB Power and Hydro Quebec. During that period he led the restructuring of the CANDU 6 Safety Report that has served as the basis for the current reports.

In 1986 Paul joined NB Power at Point Lepreau in a supervisory role of safety analyses, reactor physics and fuel. That expanded to include reliability analysis and licensing.

In late 1999 he was appointed Safety & Licensing Manager in the newly created Point Lepreau Generating Station Refurbishment Project. That included responsibility for licensing, environmental assessment, and oversight of the integrated safety review, safety analysis, and probabilistic Safety Assessment aspects of the project.

Paul became a member of an Advisory Panel created to oversee the Plant Condition Assessment Evaluation that was being performed to determine the scope of the refurbishment activities. Under his direction, the Safety & Licensing scope for the project was defined and the Integrated Safety Review was performed. Through extensive consultation with staff of the Canadian Nuclear Safety Commission the licensing framework for the refurbishment was developed and agreed upon by the CNSC. The approach subsequently formed the basis of CNSC Regulatory Document RD-360.

In 2006, he was appointed Manager of Health, Safety and Environment at PLGS. That position included responsibility for Radiation Protection, Health Physics, Environment, Waste Management, Emergency Preparedness, Security, Nuclear Safety and Regulatory affairs.

He continued in that role during the refurbishment program for the Point Lepreau station which began in March 2008 and, after a number of delays, ended when the reactor was restarted in the fall of 2012.

Since early 2010, Paul has been an authorized alternate Station Director and qualified to hold the Incident Commander position within the emergency response organization.

In 2013, he was appointed manager of Performance Improvement and Regulatory Affairs, with responsibility for programs involving: corrective action; operating experience; human performance; self-assessment; and safety culture. This involved him in working closely with public affairs in support of meetings with the community liaison committee.

His current role is Senior Strategic Advisor at the Point Lepreau Generating Station which involves him having close relations with senior station and company executives.

In late 2014 he was appointed as the NB Power representative on the CANDU Owners Group Board of Directors, and to the advisory board for the Centre of Nuclear Energy Research, a research institute within the University of New Brunswick.

CNS Involvement

Paul has been an active member of the Canadian Nuclear Society since 1987 at both the local and national level. He has been chairman of the New Brunswick Branch; the Nuclear Science and Engineering Division; the Program Committee; and the Honours and Awards Committee. As noted earlier he was elected President of the Society in1998 but his time in that role was cut short by a very serious accident. That background gives him an in-depth knowledge of the workings of the Society.

In recognition of his contributions to the Canadian Nuclear Society and the Canadian nuclear program he was designated: "Fellow of the Canadian Nuclear Society" in 2001.

Paul's Views on the Canadian Nuclear Power Program and CNS

In addition to providing considerable personal information in response to the Bulletin's proposal for this article Paul added some views on the Canadian nuclear power program and the Canadian Nuclear Society, as follows:

- *This is a fantastic industry to work in. I really enjoy my work. I have had the honour of working with many talented and hard-working people over the years, most of whom have been or are members of our society. All of that had a positive influence on my career and life. I also had the good fortune to interface with many different aspects of the extensive Nuclear Power Program.*
- *I believe the CNS provides much value to the industry as a whole, and to its membership through its many conferences and courses as well as through Branch activities. This advances institutional learning and individual technical development of people. The Student Conferences provide great opportunities for students to present papers and meet influential people in the industry. The Honours and Awards program allows individuals to be recognized by their peers for their achievements and a great way to demonstrate the appreciation of the membership for their contributions. I believe we have also made important strides related to communication and education.*

Postscript – Paul's tragic accident

(Following is a condensed note in Paul's own words of the very severe accident he had in December 1998.)

In December of 1998, while driving back home after a long day at work; I was involved in a head-on motor vehicle accident. I was hit by a drunk driver who was driving on the wrong side of the highway. Although dazed for a few moments after impact, I was very aware of the situation and have vivid memories of my extraction, transport to hospital and early tests up until the point they put me under for surgery. My injuries included a broken neck (C1 &C2 – the so called hangman's break), two shattered lower legs and feet, a broken right wrist, and had part of the door embedded into the back of my left upper leg.

I was kitted out with a halo (who would have ever imaged!), external fixator on my left leg, and a number of casts. My biggest concern at the time was the impact this was having on my family and work. I believe the overwhelming encouragement, prayers and support I received from family, friends and colleagues had a great deal to do with my recovery, and I am extremely appreciative of that as well as the fine efforts of the medical staff at the Saint John Regional hospital and the support from NB Power. While I will always have issues stemming from the accident, I look at myself as being extremely fortunate.

From the President September 2015

We have a new council, representing a good mixture of seasoned and new members from across the industry, all of whom are ready to take on new challenges and work hard to provide member services and meet the objectives of the CNS. To that end, we have had a very busy last few months with three very successful conferences. The list includes:

- The 35th annual CNS conference and student conference
- The first technical meeting on Fire Safety & Emergency Preparedness
- The17th International conference on Environmental degradation of materials

I would like to extend my appreciation to the organizing committees. It takes a lot of effort to plan and orchestrate a successful conference, and these are key to providing service to our members and the industry and to bring in needed revenue.

Looking forward, we have an exciting upcoming year of courses and conferences covering a broad range of topics. Specifically in the next few months we have;

- The Candu Fuel Technology course Oct 5-6, 2015
- The 7th International conference on modelling & simulation methods, held in conjunction with the Canadian workshop on Fusion energy Science & Technology Oct 18-21, 2015
- The International Nuclear Components Conference, Nov 1-4, 2015

In addition to the courses and conferences, we have a number of active branches holding a variety of interesting presentations, and we have committees working diligently behind the scenes to deliver on the objectives of the society.

This year we also want to focus on assisting a few of the branches whose membership numbers are relatively low and are not as active as they could be.

I would also like to take this opportunity to thank Jacques Plourde and the previous council for their excellent efforts and achievements last year and their support in the transition to the present council.

In closing, I am honored to be able to serve as President of the Canadian Nuclear Society this year and I look forward to getting out to visit the various branches and to partake in the activities of this great vibrant society.

CHALK RIVER Branch – Laura Blomeley

In **June, Samy El Jaby from** the CNS Chalk River branch was on hand to present the CNS award to two students graduating from the Radiation Safety program at Algonquin College.

CNS Algonquin College Liaison Samy El Jaby with the two award recipients, Mitch Finlayson and Murray Hyatt

Over the summer months, the Chalk River Branch of the CNS has been again involved with the Deep River Science Academy (DRSA). The DRSA allows high school students to be paired with undergraduate researchers in scientific projects in the Deep River area, including with Canadian Nuclear Laboratories and Algonquin College. This year, the CNS co-sponsored a series of evening lectures, also open to the public, to help the students get even more flavour for the science world. These were:

- **Jeremy Whitlock, "Splitting Atoms - Canadian Style"**
- **Morgan Brown, "Fukushima: When Shutdown's Not Enough"**
- **Nick Priest, "The toxicity of Radiation and the Development of Radiological Protection: "Röntgen to Litvinenko"**
- **Bill Diamond, "Accelerator Production of Medical Isotopes"**

In addition to the well attended talks, the Chalk River Branch presented two DRSA students with an award for excellence in nuclear research. This year's recipients were **Harriet Chen** and **Alexandra Symonds.**

SHERIDAN PARK Branch – Raj Jain

CNS Sheridan Park Branch organized a **tour to McMaster Nuclear Reactor** on **June 24, 2015**.

A presentation titled "**HOPE's Fusion Concept – Theory and Simulation**" by **Dr. Henry Zheng** is planned for **September 15, 2015**.

The 2015 graduating DRSA Program Students

TORONTO Branch – Andrew Ali

On **Wednesday, August 5th, 2015** the CNS Toronto Branch hosted a seminar by **Dr. Victor G. Snell** entitled **"Risk and Fear". There were over 70 people in attendance and there was excellent participation by the audience. I received very positive feedback from the attendees and they were keen on looking further into the research that Dr. Snell had done.**

WESTERN Branch – Matthew Dalzell (Interim Chair)

General

The Western Branch held the second executive election in its history. A call for nominations was held between July 1 and July 15, resulting in no contested positions. As a result the following executive members were acclaimed, with the exception of the position of Education and Outreach Coordinator which currently stands vacant:

Chair:	**Matthew Dalzell*, Saskatoon (*subject to ratification by CNS Council)**
Vice-Chair:	David Malcolm, Inuvik
Past Chair:	Jason Donev, Calgary
Treasurer:	Duane Pendergast, FCNS, Lethbridge
Secretary:	Sara Ho, Saskatoon
Membership Coordinator:	Rob Varty, Edmonton
Technical Coordinator:	Cody Crewson, Saskatoon
Education and Outreach:	VACANT
Members at Large:	Duane Bratt, Calgary; Denise Chartrand, Calgary; Ashok Khanna, Khanpur (India); Ron Matthews, Victoria; Vince Natomagan, Pinehouse SK

We were extremely pleased with the wide geographic representation and thank the nominees for their willingness to serve. The Branch would also like to bring to the attention of Council the contributions of Shaun Ward who served as Education Coordinator in both the Alberta and Western Branches and thank him for his service.

Branch Activities

The Branch will look at re-launching its book club initiative this fall.

Outreach Activities

Branch members **Neil Alexander, Matthew Dalzell**, **Cody Crewson**, **Ellen Lloyd** and **Jason Donev** will be presenting papers at the International Conference on Clean Energy in Saskatoon in September. Planning also continues for activities to mark Nuclear Science Week this October.

Obituary

Osborne, Richard Vincent

Retired: Atomic Energy of Canada Ltd.; Director of Health Sciences

At the Deep River and District Hospital on Tuesday September 29, 2015. Richard Osborne of Deep River at the age of 79 years. Beloved husband of Nancy Osborne (nee: Farnsworth). Loving father of Dean and his wife Cindy of Epsom, John and his wife Frances of Deep River, and Adrian and his wife Kate of Carleton Place. Cherished grandfather of Richard, Christopher, James, Nicholas, Benjamin, Sydney, and Jesse Osborne. Also survived by his sister Janet Williams and her late husband Gareth of Princeton, New Jersey. Family and friends are gathering at the Deep River Yacht and Tennis Club on Saturday October 10th from 1 to 4 pm, Celebration of Life at 2 pm. In memoriam donations to the Deep River and District Hospital Foundation would be gratefully appreciated. Final wishes entrusted to the Valley Funeral Home, Deep River.

Get engaged in YOUR Society!

It's never too early to think about next year's CNS Council elections.

Jacques Plourde, who, as CNS Past President, is responsible for obtaining nominations for CNS Council, the Society's governing body, is always on the lookout for more members who may wish to stand for a position on Council.

If you are interested, or know of someone whom you think would be a good candidate, please contact Jacques, who will provide background information.

His coordinates are 905-441-2776 (cell) and jap-performance@rogers.com (e-mail).

2015-2016 CNS Council • Conseil de la SNC

Executive / *Exécutif*

President / ***Président***	Paul Thompson 506-659-6234
e-mail	pthompson@nbpower.com
Past President / ***Président sortant***	Jacques Plourde 905-441-2776
e-mail	jap-performance@rogers.com
1st Vice-President / ***1ier Vice-Président***	Peter Ozemoyah 289-288-0490 x249
	pozemoyah@tyne-engineering.com
2nd Vice-President / ***2ième Vice-Président***	Daniel Gammage 519-621-2130 x2166
e-mail	dgammage44@gmail.com
Treasurer / ***Trésorier***	Mohamed Younis 416-592-6516
e-mail	mohamed.younis@amecfw.com
Secretary / ***Secrétaire***	Colin G. Hunt. 613-742-8476
e-mail	colin.hunt@rogers.com
Financial Administrator / ***Administrateur financier***	Ken L. Smith. 905-828-8216
e-mail	unecan@rogers.com
Executive Director / ***Directeur exécutif***	Ben Rouben 416-663-3252
e-mail	roubenb@alum.mit.edu
Communications Director / ***Directeur des communications***	Jeremy Whitlock. 613-584-3311 x44265
e-mail	jeremy.whitlock@cnl.ca

Members-at-Large / *Membres sans portefeuille*

Parva Alavi 905-599-9534
Frederick C. Boyd 613-823-2272
Zhenhua Cui 506-458-9552
Jerry Cuttler. 416-837-8865
Ruxandra Dranga . . . . 613-584-3311 x 46856
Peter Easton 613-863-1027
Mohinder Grover. 416-499-5591
Mark Haldane 905-979-4128
Michael Ivanco 905-825-5346
Kris K. Mohan 905-332-8067
Dorin Nichita. 905-721-8668
Tracy Lapping tracy.pearce@cnl.ca 613-584-3311 x 44084
Nicholas Preston 289-200-9718
John G. Roberts 519-396-8843
Wei Shen 613-996-0192
Nick Sion 416-487-2740
Keith Stratton 506-343-4060
Ronald Thomas 613-236-3297
Pauline Watson 905-338-3032
Don Wiles 613-256-4376
John Barrett, CNA barrettj@cna.ca 613-237-4262

CNS Committees / *Comités de la SNC*

Program / Programme
Tracy Lapping . . . . .613-584-3311 x44084 tracy.pearce@cnl.ca

WiN Interface / Interface avec WiN
Jad Popovic. 905-820-7472 popovic@rogers.com

Branch Affairs / Chapitres locaux
Syed Zaidi. . . . . smh@zaidi.net

Education and Communications / Éducation et communications
Ruxandra Dranga . . . . .613-584-3311 x46856 ruxandra.dranga@cnl.ca

Membership / Adhésion
Ben Rouben . . . . 416-663-3252 roubenb@alum.mit.edu

Finance / Finances
Mohamed Younis . . . . 416-592-6516 mohamed.younis@amecfw.com

Bulletin
Colin Hunt . . . . 613-613-742-8476 colin.hunt@rogers.com

Past Presidents / Anciens présidents
Jacques Plourde . . . . 905-441-2776 jap-performance@rogers.com

Honours and Awards / Prix et honneurs
Ruxandra Dranga . . . . .613-584-3311 x46856 ruxandra.dranga@cnl.ca

International Liaison Committee / Liaisons internationales
Kris Mohan . . . . 905-332-8067 mohank@sympatico.ca
Fred Boyd. 613-592-2256 fboyd@sympatico.ca

Internet / Internet
Adriaan Buijs. . . . . .905-525-9140 x24925 adriaan.buijs@sympatico.ca
Mark Haldane. . . . . 905-979-4128 haldane.mwa@gmai.com

Inter-society Relations / Relations inter-sociétés
Peter Ozemoyah . . . . .289-288-0490 x249 pozemoyah@tyne-engineering.com

Young Generation / Jeune génération
John Roberts. . . . . 519-396-8843 alchemy@tnt21.com

Scholarship / Bourses
Mohamed Younis . . . . 613-592-2256 mohamed.younis@amecfw.com
. . . . 416-592-6516

Technical Divisions / *Divisions techniques*

- Nuclear Science & Engineering / Science et génie nucléaires
  Elisabeth Varin 514-953-9790 varine@gmail.com
- Fuel Technologies / Technologies du combustible
  To 2014 October 7:
  From 2014 October 8:
  Paul Chan 613-541-6000 x6145 paul.chan@rmc.ca
- Design and Materials / Conception et matériaux
  Daniel Gammage 519-621-2130 x2166 dgammage@babcock.com
- Environment & Waste Management / Environnement et gestion des déchets
  Parva Alavi 905-599-9534 parvaalavi@gmail.com
- Nuclear Operations & Maintenance/ Exploitation nucléaire et entretien de centrale
  Aman Usmani 416-217-2167 aman.usmani@amec.com
  Polad Zahedi 905-839-6746 x4029 polad.zahedi@opg.com
- Medical Applications and Radiation Protection/Applications médicales et protection contre les rayonnements
  Nick Sion 416-487-2740 sionn@sympatico.ca
- Fusion Science and Technology / Scjence et technologie de la fusion
  Blair Bromley 613-584-3311 x43676 blair.bromley@cnl.ca

CNA Liaison / *Agent de liaison avec l'ANC*
John Barrett 613-237-4262 barrettj@cna.ca

CNS Bulletin Publisher / Éditeur du Bulletin SNC
Colin Hunt 613-742-8476 colin.hunt@rogers.com

CNS Bulletin Editor / Rédacteur du Bulletin SNC
Ric Fluke 416-592-4110 rfluke@sympatico.ca

CNS Office Manager / Bureau de la SNC
Bob O'Sullivan 416-977-7620 cns-snc@on.aibn.com

Branches / Chapitres locaux

Bruce	John Krane	519-361-4286 jck@bmts.com
Chalk River	Laura Blomeley	613-584-8811 x 46785 laura.blomeley@gmail.com
Darlington		
Golden Horseshoe	Jason Sharpe	905-975-5122 jason.r.sharpe@gmail.com
Manitoba	Jason Martino	204-753-2311 x62229 martinoj@cnl.ca
New Brunswick	Derek Mullin	506-650-3374 dmullin@nbpower.com
Ottawa	Ken Kirkhope	ken.kirkhope@cnsc-ccsn.gc.ca
Pickering		
Québec	Michel Saint-Denis	514-875-3452 michelstdenis@videotron.qc.ca
Sheridan Park	Raj Jain	raj.jain@candu.com
Toronto	Andrew Ali	andrew.ali@amecfw.com
UOIT	Terry Price	terry.price@uoit.ca
Western	Jason Donev	403-210-6343 jmdonev@ucalgary.ca

CNS WEB Page - Site internet de la SNC

For information on CNS activities and other links – Pour toutes informations sur les activités de la SNC

http://www.cns-snc.ca

Calendar

2015

Oct. 18-Oct. 20	**7th International Conference on Simulation 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
Dec. 8-Dec. 11	**CANSAS - 2015 (CANDU Safety Association for Sustainability)** **&** **IW-NRTHS-2015 (New Horizons in Nuclear Reactor Thermal-Hydraulics and Safety)** Anushaktinagar Mumbai, India website: www.cns-snc.ca

2016

June 19-22	**36th Annual CNS Conference** **40th CNS/CNA Student Conference** Toronto, Ontario Website: www.cns-snc.ca/events/2016
August 15-18	**13th International Conference on CANDU Fuel** Kingston, Ontario Website: www.cns-snc.ca/events/2016
October 9-13	**NUTHOS-11** Gyeongju, South Korea Website: www.cns-snc.ca/events/2016

Retired Nuclear Engineer Turns Novelist

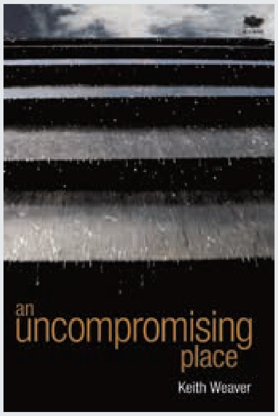
Keith Weaver, CNS member and former editor of the CNS Bulletin, retired in 2012 from his career of more than 30 years in the nuclear industry. This September, his first novel, *An Uncompromising Place*, was released by publishing company Iguana Books.

An Uncompromising Place is a historical murder-mystery packed with suspense, intrigue, bread making and wine pairings. Protagonist *Richard Gould* is a retired engineer (like Keith) who restores an old stone house in the quiet small village of Greenvale (fictional) in rural Ontario, which was renovated to be his retirement home. After moving in, Richard quickly makes friends with the three most important people in any town: the librarian, the owner of the hardware store, and the pub master. Retirement life in a small rural village easily could become mundane for someone who spent most of his life managing large engineering projects, but not for Richard, who sets out to restore an abandoned and dilapidated flour mill in the town's centre.

The mayor was delighted when he saw Richard's plans and a wonderful alternative to demolition - restoration of the mill to its former grandeur would bring new life and visitors into the village. Richard's plans included a business model of supplying different types of flour to local bakeries as well as generating electricity with the waterwheel. During renovations a mishap occurs causing a large stone in the wall to shift. Upon examining the damage, he discovered a box covered in tar. After carefully removing the tar and opening the box he finds two very rare books: an 18th century German Bible and a 16th century catechism. He decides to place them in his bank's safety deposit box and get on with his project.

That's when mysterious things start to happen. Arriving home one night he finds his helper and friend waiting for him, sitting on a lawn chair, dead. Less than satisfied with the local police he calls his friend from Toronto who is a private investigator. The investigator quickly discovers that Richard's house has been "bugged".

The mystery deepens and it appears someone wants those books and will stop at no length to get them. Events lead to a thriller of a trail that includes adventures in Germany that ultimately turn violent. But even amidst the drama Richard still finds time to prepare and enjoy fine culinary delights (described in mouth-watering detail) complete with bread and wine.



Keith leaves no doubt about the fullness of his characters - they come to life as real people. In fact, after reading his novel I thought I recognized some of his fictional characters, who in my mind had faces of people I know. But that's just me, because it's all enjoyable fiction.

Class of 1987

by JEREMY WHITLOCK

Why so glum, Nuclear?

I don't know why I come to these things...

Oh come on – reunions are fun! Chance to catch up, see who's been more successful than you...

Um, that would be everyone.

Not that again Nuclear. Look, in 1987 you were named along with all these guys as one of Canada's Top Ten Achievements of the first century of Canadian engineering. Nobody can take that away. Who cares what the others are up to today?

Did you know that the 70th anniversary of Canada's first reactor, ZEEP, came and went this year – and nobody cared. Not a word in the national media. Second country to control nuclear fission! That should mean something.

It does... it does... it just doesn't sell papers. Energy is... well... sort of a background infrastructure item, and especially nuclear energy. Albeit a $6 billion/year background infrastructure item...

Oh yeah? Look at Tar Sands over there. $60 billion/year... over half a million jobs. Look at his entourage – the fawning sycophants. Now THAT'S what a Top Ten Engineering Achievement looks like.

Lawyers and spin doctors my friend – you don't want to be him today. Just keep quietly making clean energy and you'll be fine.

You mean like High-Voltage Transmission over there? Look at the aura around him – he's got it made. That's a $30 billion/year industry in sales alone.

The bigger they are, the harder they fall – remember the 1998 ice storm in Quebec?

Oh, and here comes Microwave Telecommunications, arm in arm with Satellite Communications – those two must be worth $100 billion/year combined. Smug jerks.

Now now. You can't fault those two lads for being popular. And look, as cool as those technologies are today, who really remembers the actual "top ten engineering achievement" - the Alouette satellite and Canada being the third country into space?

Hey I don't mind people forgetting about ZEEP or NPD either – but is it too much to expect the media to bring these world-class achievements to the pubilc's attention now and then – like say a 70th anniversary..?

Well, it's just not as sexy as a satellite...

Or a train – there goes Transcontinental Railroad, still a $12 billion/year concern today. Or an aircraft – the Beaver, $24 billion/year for aerospace today. Or Mr. Bombardier's Snowmobile – there's a $7 billion/year sexy industry right there. Look at those three – they know that any Canadian asked to pick three Top Ten Achievements today would probably still name them.

Okay, well how about St. Lawrence Seaway over there? Talk about a background infrastructure item. $60 billion/year in commerce and who spares one ragged thought about him? And look who's walking in behind him – Synthetic Rubber! Nobody even sees him – they think he's Tar Sands' chauffeur. A $3 billion/year business, absolutely vital to the transportation industry, and look at him shuffling anonymously behind the punch bowl.

Hm, okay, so I'm not the most invisible of the Top Ten Engineering Achievements...

Exactly! And occasionally, when something really bad happens, why you're the most visible and most talked-about achievement of the bunch. In fact, maybe that's a strategy you could consider: next time you're looking for attention, why not spring a leak somewhere, or recycle a steam generator or something – and when the spotlight's glare is upon you, tell them about ZEEP and the good ol' days.

Now you're making fun of me.

Only as necessary. Hey look, they're taking a photograph of the ten of you. Why don't you go stand in the back behind Tar Sands, and for gosh sakes, smile!

I really hate these things...