Lorsque tu bois l'eau, souviens-toi de la source !

Mouvement Vert Mauricie

written submission to

The Joint Environmental Review Panel

for the

Environmental Assessment

of the

Darlington New Build Project

proposed by

Ontario Power Generation

February 22, 2011

Lorsque tu bois l’eau, souviens-toi de la source !

Au nom du Mouvement Vert Mauricie c’est avec beaucoup de fierté que nous rendons aujourd’hui disponible à la population canadienne le résultat d’une longue réflexion sur la pertinence ou non, pour les Canadiens, de poursuivre l’aventure nucléaire.

Le projet de construction d’une nouvelle centrale électronucléaire à Darlington Ontario aura été l’occasion pour nous, du Québec, de réunir les informations essentielles à une meilleure compréhension des enjeux politiques, économiques, sociales, environnementales et technologiques du projet. L’appropriation des données historiques qui ont motivées l’adhésion des ontariens à la filière nucléaire nous permettent maintenant de mieux saisir les immenses défis énergétiques auxquels les Ontariens sont confrontés.

Le choix d’aller de l’avant ou non avec ce projet sera lourd de conséquences non seulement pour les Ontariens mais pour l’ensemble des Canadiens et plus particulièrement pour les Québécois. ‘

Présentation du Mouvement Vert Mauricie

Avant d'aller plus avant dans l'exercice en cours, permettez nous, pour le bénéfice de ceux qui participent à cette audience publique, cette brève description du Mouvement Vert Mauricie, organisme fondée en 1986.

La charte du Mouvement Vert Mauricie convie ses membres à la protection de la vie sous toutes ses formes.

Pour ce faire le MVM a œuvré à faciliter l'acquisition, par les citoyens et divers organismes de la société civile, des informations essentielles à la compréhension des enjeux environnementaux ainsi que leur participation active et pacifique aux nécessaires débats qui découlent de leur engagement citoyen.

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Au cours des ans, le MVM a tenté d'identifier et promouvoir les changements de comportements individuels et sociaux sur des aspects variés, telle la protection de la couche d'ozone, la gestion écologique des déchets-ressources , une agriculture et une foresterie respectueuses des habitats, un monde plus pacifique etc.

Depuis quelques années le MVM œuvre plus particulièrement à la protection des espèces menacées par la création de réserves naturelles en milieu privé, par la promotion d'établissement de couloirs de la biodiversité et la désignation d'aires à protéger en territoire publique. L'approche éco systémique par bassin versant est l'approche que nous préconisons.

Contribuer à la compréhension et adoption des nécessaires changements pour assurer l'adoption d'une politique énergétique efficace et socialement responsable ont été au fil des ans une préoccupation soutenue pour l'organisme. Nous faisons la promotion de la conservation de l'énergie par une approche communautaire, de l'efficacité énergétique, d'une gestion moderne de l'énergie ainsi que, si nécessaire, de la production de nouvelle énergie par des filières renouvelables et décentralisées.

Pour nous la filière nucléaire est à proscrire parce qu'elle compromet de manière démesuré la santé et la sécurité des citoyens ainsi que l'intégrité des écosystèmes qu'ils habitent.

Notre comité expert

Notre comité expert est formé entre autres de messieurs Gordon Edwards, Ph.D., mathématicien possédant plus de trente ans d'expériences comme éducateur et consultant en matière de nucléaire, de Michel Duguay Ph.D., physicien nucléaire et actuellement professeur en génie électrique à l'Université Laval ainsi que de Frank Greening, Ph.D., qui a travaillé pendant plus de vingt ans comme expert en métallurgie pour la division nucléaire d'Ontario Hydro. Son expertise porte entre autres sur les questions impliquant l'intégrité des tuyaux au niveau du système primaire de refroidissement des réacteurs nucléaires.

À la lumière des informations mises à notre disposition par les experts que sont messieurs Greening, Duguay et Edwards, force est de constater que l'héritage de la filière électronucléaire canadienne aux générations présentes et futures en est un que l'on peut, pour l'instant du moins, qualifier de ''cadeau empoisonné''.

Les anglophones ont une très belle façon de décrire l'attitude à prendre dans des situations très difficiles… : "From a stumbling stone let us make a stepping stone."

Le défi à relever nécessitera de porter un regard non complaisant sur les choix énergétiques du passé et actuels, d'en faire un bilan réaliste et de tracer dès aujourd'hui les pistes de solution adaptées au contexte ontarien, canadien et international.

Les informations colligées par messieurs Greening, Duguay et Edwards contribueront de manière positive à la réflexion qui s'impose à nous. Leur intégrité intellectuelle est remarquable et les Canadiens auront tout avantage à considérer avec attention les documents qu'ils nous ont fournis. Au nom de tous les Canadiens, je les remercie pour leur exceptionnelle contribution et la très grande générosité qu'ils ont manifestée à la réalisation de ce mémoire.

Les motifs de notre participation au processus en cours.

Le projet de construction d’un nouveau réacteur nucléaire au site de Darlington se situe dans le bassin versant Grands-Lacs- St-Laurent. Le MVM souhaite participer à l’évaluation du projet dans ce contexte car les impacts environnementaux du projet auront inévitablement des répercussions dans l’ensemble du bassin versant.

La pollution ne connaît pas de frontière. Que ce soit par des émissions radioactives routinières, accidentelles ou par malveillance humaine (ex : terrorisme),
l’expérience du passé témoigne du fait que les centrales nucléaires comportent des risques qui dépassent les limites territoriales où sont situées les installations.

Les risques associés à la présence du nucléaire dans nos écosystèmes sont de mieux en mieux documentés. Que ce soit dans l’eau, dans l’air ou sur le sol les radionucléides qui risquent de s’y retrouver peuvent, sous certaines conditions rejoindre les organismes vivants qui y évoluent. L’humain n’échappe pas à cette réalité et il est de notre devoir d’assurer que de tels événements ne se produiront pas et que tout a été mis en place pour les éviter.

Nous espérons que les informations que nous soumettons aujourd’hui à l’ensemble des Canadiens vous permettra de prioriser, dans votre processus de décision, la sécurité des citoyens ainsi que l’intégrité écologique des écosystèmes essentiels à leur survie.

Modifier systématiquement nos façons de produire, distribuer et utiliser l’énergie est un défi que nous devons tous, personnellement et collectivement, relever. La décision que vous soumettrez de favoriser ou non la construction de nouveaux réacteurs nucléaires sur le site de Darlington aura une portée historique. Espérons que la contribution du MVM au processus facilitera votre tâche.

Merci,

Michel Fugère
Mouvement Vert Mauricie

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by Gordon Edwards – for *le Mouvement vert Mauricie*'s Intervention on the *Darlington New Build* Environmental Assessment Hearings in 2011

1. Remembrance of Things Past

In 1977 the Ontario government announced its decision to build four new nuclear reactors at Darlington. That event marked the end of an era of rapid nuclear power growth in North America. Since then, the nuclear industry on this continent has endured a three-decades-long drought in terms of domestic reactor sales.

Indeed, no orders were placed for new nuclear reactors anywhere in North America after 1977, until the year 2007. Few industries could have survived such a prolonged period without sales.

What brought the industry to a halt was a realization that the technology had been marketed prematurely, due to a number of fundamental unsolved problems that had gone unacknowledged in the early days.

The potential for catastrophic reactor accidents. The proliferation of nuclear weapons capabilities. The disposal of nuclear wastes. The need for constant subsidies. The chronic buildup of radioactive poisons in the environment. The prospect of a plutonium economy.

In retrospect, it seems clear that citizens and elected representatives did not have enough information prior to the mid-1970s to make a truly informed judgment on the environmental, security, financial and social impacts and risks of a large-scale commitment to nuclear power. Nuclear proponents presented the technology as problem-free, and people believed it to be true.

This fact makes the Environmental Assessment of the Darlington New Build Project particularly significant. It is the first time in decades that approval is being requested for new nuclear reactors to be built in Canada.

The Panel must ensure that we do not repeat the mistakes of the past. Issues must be clearly presented. Old assumptions must be challenged. Past practices must be re-examined. Potential impacts and risks must be clearly explained and frankly acknowledged.

Above all, the Panel must determine whether any of the fundamental unsolved problems of nuclear power have been resolved. Otherwise, are we not in danger of relaunching an immature and inappropriate technology?

Have reactors become inherently safe? Has the proliferation of nuclear weapons been halted? Is the nuclear waste problem now solved? Are massive subsidies no longer required? Have radioactive emissions been eliminated? Is the prospect of a plutonium economy no longer a concern?

The Mouvement Vert Mauricie believes that nothing has fundamentally changed in the last 30 years, so far as nuclear problems are concerned. Not only have those problems not been resolved, but there are renewed efforts on the part of nuclear proponents to deny that such problems even exist.

2. Reactor Accidents

The detailed technical analyses provided by Frank Greening and Michel Duguay in the last two sections of this submission clearly demonstrate that the potential for catastrophic nuclear accidents still remains. Years of effort by nuclear scientists and nuclear engineers have failed to produce reactors that are inherently safe.

As the Select Committee on Ontario Hydro Affairs reported in 1980:

> It is not right to say that a catastrophic accident is impossible…. The worst possible accident ... could involve the spread of radioactive poisons over large areas, killing thousands immediately, killing others through increasing susceptibility to cancer, risking genetic defects that could affect future generations, and possibly contaminating large land areas for future habitation or cultivation.
>
> *The Safety of Ontario's Nuclear Reactors: Final Report*
> *Select Committee on Ontario Hydro Affairs*
> *Toronto, June 1980.*

The Government of Canada officially acknowledged this fact when it recently placed before the Canadian Parliament a proposed law, the Nuclear Liability and Compensation Act, which would limit the financial liability of any nuclear reactor operator in Canada to a maximum of $650 million for offsite damages caused by a reactor accident.

This amount represents only a minute fraction of the financial losses that could be incurred by a catastrophic nuclear accident, as seen in the aftermath of the Chernobyl disaster. It raises the question: why is nuclear power the only industry that requires a special piece of legislation to limit its financial liability in the event of a damaging accident?

Since the tragic events of 9/11, it has become increasingly clear that such a catastrophic release of radioactivity could be brought about by an act of terrorism, or warfare, or sabotage, as well as by an industrial accident.

Given the existence of such an enormous risk, no matter how small the calculated probability of its occurrence, the Mouvement Vert Mauricie questions the wisdom of siting a new nuclear plant anywhere on Canadian territory. Quebec has enjoyed a moratorium on the building of any new nuclear reactors in the province since 1978, in large part due to this risk.

It seems particularly irresponsible to consider siting such a plant on the shores of Lake Ontario, given the fact that over 40 million people – Canadians and Americans alike – derive their drinking water from the Great Lakes basin. The fact that there are already reactors sited around the Great Lakes does not justify adding to and perpetuating the problem.

Darlington is dangerously close to the largest city in Ontario, and right on the doorstep of one of Ontario's most significant manufacturing centres. But as devastating as such a reactor accident would be to Ontario's industrial and financial heartland, perhaps requiring the total evacuation of the City of Toronto, it would also have crippling repercussions on Quebec.

Water laden with radioactive fallout would be carried down the St. Lawrence River past Montreal, Trois-Rivièrers, and Québec, en route to the Atlantic. Winds blowing from west to east would bring the cloud of radioactive gases and vapours over Quebec territory, depositing radioactive iodine and cesium on crops, buildings and soil.

In its 1978 Report on Nuclear Power in Ontario, entitled A Race Against Time, the Ontario Royal Commission on Electric Power Planning wrote

> Assuming, for the sake of argument, that within the next forty years Canada will have 100 operating reactors, the probability of a core meltdown might be in the order of 1 in 40 years, if the most pessimistic estimate of probability is assumed.
>
> *A Race Against Time, pp. 78-79*

In view of the devastating potential of such an accident, the Report recommended that consideration be given to building new reactors only underground – in hopes that massive radioactive releases to the environment could be prevented or minimized by this means. MVM believes that, if such reactors are to be built at all, the advice of the Royal Commission be seriously considered.

Request: The MVM asks the Joint Panel not to allow the siting of any new nuclear power plants on the shores of the Great Lakes or in proximity to large population centres or areas of vital industrial activity.

3. Proliferation of Nuclear Weapons

Without uranium, no nuclear weapons of any description could be made. The only two materials that can be used as nuclear explosives are highly enriched uranium (HEU) and plutonium.

Moat nuclear power reactors in the world today, including the AP1000, the EPR reactor, and the ACR-1000, require low enriched uranium (LEU) as fuel. But the same enrichment plant that makes LEU for reactor fuel can also be used to make HEU for bombs.

Plutonium is a man-made element that is produced in all currently operating nuclear reactors as an inevitable byproduct. It is formed when non-fissile uranium atoms in the nuclear fuel absorb stray neutrons and become transformed into plutonium atoms.

The most abundant plutonium isotope is plutonium-239, which has a 24,000 year half-life. Thus, for tens of thousands of years after a nuclear reactor has been shut down, dismantled and forgotten, the plutonium that was created inside the reactor is still available and usable for making nuclear explosives.

In fact the first reactors were built for the express purpose of making plutonium for bombs. Since the chain reaction generates a great deal of heat, it was thought that the heat could be used to boil water, raise steam, and turn the blades of a steam turbine to generate electricity.

Be that as it may, the fact remains that every reactor also mass-produces plutonium. Once created, that plutonium cannot be eliminated by any technology currently available, and remains a security risk for millennia.

Request: MVM asks the Joint Review Panel to ensure that citizens and their elected representatives are made aware of the long-term proliferation dangers associated with the operation of nuclear power reactors.

4. Management of Nuclear Waste

The human race has never actually disposed of anything. In fact the word "disposal" has no scientifically meaningful definition. In particular, we do not have any technology for disposing of nuclear waste.

What we do have is an idea, promoted by the nuclear industry, that we can "get rid" of nuclear waste by burying it in an undisturbed geological formation, thereby eliminating the risk of massive radioactive contamination caused by storing the nuclear waste at the surface.

This deceptively simple idea is fraught with difficulties and beset with contradictions. For example, the United States – one of the most technologically advanced countries in the world – has tried eight times to locate a geologic repository for high level radioactive waste, and has failed all eight times. The most recent failure was the Yucca Mountain project, which was abandoned after $10 billion and decades of research were spent.

In Canada we haven't even tried once – and we have no "contingency fund" in case our first attempt at geologic storage turns out to be a failure.

Indeed, there are some fundamental problems with the entire concept of geologic storage. How do you get the waste into an undisturbed geologic formation without disturbing it? And, once disturbed, it will never again be an undisturbed geologic formation, but an engineered facility.

For thousand of years we humans have developed and perfected mining technology. But the whole idea of a mine is to take something out of the ground, not to put something back in. In our imagination we can ´run the film backwards´ and watch a mine turning back into an undisturbed rock formation, but in reality we don't know how to return to that pristine state.

And there are even more fundamental problems with the geologic storage concept. Irradiated nuclear fuel has to be stored under circulating water for at least 7 to 10 years after extraction from the reactor, as it continues to generate a lot of heat due to the intense radioactivity of the fission products.

In fact the Nuclear Waste Management Organization has stated that irradiated nuclear fuel has to "cool off" at the surface for about 30 years on-site before it can be removed and emplaced in a geologic repository.

So as long as new reactors are being built and old reactors are being operated, there will always be a large inventory of highly radioactive nuclear waste unburied at the surface – no matter how fast the older waste is buried. The burial of the old waste does not eliminate the potential for catastrophic radioactivity releases at the surface. Hmm. We haven't solved the problem at all!

The only way that geologic storage can make the surface a genuinely safer place would be to stop building new reactors, shut down the old reactors, let the hot waste cool off for 20 or 30 years, and then put the whole lot underground once and for all. Anything else is just self-deception.

Ironically, the entire logic of the geologic storage of nuclear waste falls apart unless there is a commitment to phasing out nuclear power altogether. In the case of a nuclear renaissance with a rapidly growing fleet of nuclear reactors, the amount of hot, highly radioactive, unburied nuclear waste will grow steadily at the surface – even if the older waste is safely and securely buried as rapidly as humanly possible: problem not solved!

Request: MVM asks the Joint Review Panel to recommend against the transport of high-level radioactive waste away from the reactor site until at least 10-20 years after all the reactors on that site have been shut down.

5. Radioactive Emissions

Dozens of radionuclides are routinely released to the air and the water around every operating nuclear reactor. In most cases the amounts are quite small, although in some cases (e.g. tritium and carbon-14) the quantities released are substantial in terms of the number of becquerels.

As the Select Committee on Ontario Hydro Affairs reported in 1980,

> Carbon-14 and tritium are of comparable and special concern for similar reasons.
>
> First, they each have long half-lives: 5 730 years for carbon-14 and 12.3 years for tritium. Long half-lives allow them to accumulate in the environment around a reactor and in the global biosphere.

> Second, they are easily incorporated into human tissue. Carbon-14 is incorporated into the carbon that comprises about 18 percent of total body weight, including the fatty tissue, proteins and DNA. Tritium is incorporated into all parts of the body that contain water.
>
> Thus the radiological significance of both elements is not related to their inherent toxicity, as each is a very low energy form of radiation, but to their easy incorporation in the body.
>
> *The Safety of Ontario's Nuclear Reactors: Final Report*
> *Select Committee on Ontario Hydro Affairs*
> *Toronto, June 1980.*

The most prominent scientific bodies reporting on the health effects of low-level ionizing radiation, such as the International Commission on Radiological Protection (ICRP) and the U.S. National Academy of Sciences (NAC), have emphasized that there is no scientific basis for assuming that there is a safe dose of radiation exposure when it comes to the so-called "stochastic effects" of atomic radiation – cancer, leukemia, genetic damage.

The overwhelming consensus of independent scientific thinking on this matter is that the number of excess radiation-induced stochastic effects observed in any exposed population is directly proportional to the integrated population dose – that is, the sum of all the individual doses received by all the members of that population. A small dose to a large population can have the same effect as a large dose to a small population.

This being so, there are two ways to reduce the number of adverse health effects associated with a given radioactive release. One way is to control the individual exposure levels by containing the radioactive material and preventing it from escaping, or at least limiting the amount that escapes. The other way is to reduce the size of the population of those exposed. A prudent and responsible operator will employ both these methods.

It follows that nuclear reactors should be sited far from large populations. It is imprudent to site a nuclear reactor near large cities or on bodies of water, which serve to provide drinking water to large numbers of people.

The levels of tritium in Lake Ontario are substantially higher than the corresponding levels in Lake Superior, and this is entirely due to the tritium releases from nuclear reactors – especially the CANDU heavy water moderated reactors. Moreover, the levels of tritium in Lake Ontario are measurably increasing on a year-to-year basis.

Request: MVM asks the Joint Panel not to approve the siting of any new reactors on the shores of Lake Ontario or in the vicinity a large cities or other population centres.

6. The Plutonium Economy

Many observers, both inside and outside of the nuclear industry, believe that the future of nuclear power as an energy source depends on the eventual use of plutonium as a fuel. This is due to the fact that uranium, like petroleum, is a non-renewable resource – and if thousands of nuclear reactors are ever to be built worldwide, the uranium supply will not long outlast the oil supply. A nuclear renaissance implies a uranium shortage.

It is noteworthy that almost every country that has invested very heavily in nuclear power reactors has also invested in technology for recovering plutonium from irradiated nuclear fuel (called reprocessing) in order to use that plutonium to fabricate the reactor fuel of the future. Examples of this are France, Britain, Russia, India, and Japan.

In 1977-78, Atomic Energy of Canada Limited (AECL) made a concerted effort to secure federal funding to build one or two reprocessing plants here in Canada. That effort was unsuccessful, largely because the Carter administration (at roughly the same time) banned plutonium reprocessing in the U.S.A. due to concerns about the proliferation of nuclear weapons.

In its 1978 Report on Nuclear Power in Ontario, called "A Race Against Time", the Ontario Royal Commission on Electric Power Planning recommended against reprocessing, and also against any form of centralized storage of irradiated nuclear fuel in Canada, saying:

> We prefer on-site spent fuel storage to a centralized facility. We believe that a central facility would presuppose the reprocessing of spent fuel….
>
> *A Race Against Time, p. 95*

Earlier we recommended against the transport of irradiated nuclear fuel until all the reactors on the site in question had been shut down. We now reiterate this recommendation, based on the importance of discouraging plutonium reprocessing – due to the extraordinary long-term global security risks associated with creating stocks of separated plutonium.

Comments on OPG's Environmental Impact Statement for New Nuclear Build at Darlington NGS

by F. R. Greening – for le Mouvement vert Mauricie's Intervention on the *Darlington New Build* Environmental Assessment Hearings in 2011

Part A – Radioactive Emissions from Darlington New Build Reactors

1.0 Introduction

OPG's September 2009 Environmental Impact Statement (EIS) for the construction of up to 4800 MW of new nuclear generating capacity on the Darlington NGS site shows that the projected radioactive emissions from such a significant addition to the pre-existing nuclear facilities at Darlington are potentially very large.

This simple fact underscores the need for these emissions to be properly assessed in relation to the applicable release limits for radioactive species in gaseous and liquid discharges. Indeed, only <u>a detailed assessment of *all* such emissions</u> can ensure the new nuclear build is in compliance with these limits.

The question of the projected radioactive emissions from the proposed new nuclear build at Darlington is discussed in two Technical Support Documents (TSDs) issued as Volumes 15 and 16 of OPG's EIS:

Volume 15:
"*Radiation and Radioactivity Environment Existing Environmental Conditions*"

Volume 16:
"*Radiation and Radioactivity Environment Assessment of Environmental Effects*"

From these documents we see that OPG's approach to assessing the radiological impact of new nuclear reactors at the Darlington NGS site is to first consider the concentrations of natural and man-made radioactive species already present in the air, soil and groundwater around the site, and then to predict the *<u>expected increases</u>* in the concentrations of radioactive species emitted as a consequence of adding up to 4800 MW of nuclear generating capacity at the Darlington NGS site.

OPG's methodology for predicting the environmental emissions from the proposed reactors involves the evaluation of parameters that influence the release and dispersal of radioactive species from normal operation of the new reactors. For simplicity, and as a reasonable approximation, the reactors are considered to be one or more point sources of emission of a particular radioactive species that is subsequently traced in the near-field and far-field environments using atmospheric dispersion and water dilution factors in suitable plume-tracing models.

What is most significant about this approach is that while the air dispersion and water dilution factors of many radioactive species are well-known from studies by organizations such as the U.S. EPA and the NCRP, *the source terms* for the numerous radioactive species emitted by a newly designed, but yet to be operated, reactor tend to be quite uncertain.

Thus we need to ask the simple question: is OPG's EIS based on sound scientific principles whereby radioactive emissions are accurately predicted or is it merely a self-serving prophecy based on wishful thinking by OPG?

2.0 Issues Arising from Alternative Reactor Designs

At the present time OPG is considering four reactor designs:

- The ACR-1000, a heavy water reactor offered by AECL
- The AP1000, a PWR offered by Westinghouse
- The US EPR, a PWR offered by Areva
- A "modified" CANDU-6, based on AECL's existing CANDU-6

There are a number of issues arising from the fact that the type of reactor to be built at Darlington is yet to be selected by OPG:

(i) Modern nuclear reactors are very complex facilities that utilize a wide range of water and gaseous process streams and also generate large quantities of solid wastes. A detailed accounting of how radioactive wastes will be produced, managed and disposed of is required *for each reactor design* for a meaningful assessment of the environmental impact of these reactors to be made.

(ii) Interim storage of some effluent streams and solid wastes may (or may not) be used to delay the environmental release of relatively short-lived radioactive species; the potential for varying degrees of holdup of effluents *for each reactor design* serves to add uncertainty to environmental impact assessments.

(iii) The ACR-1000 and CANDU-6 utilize heavy water as a moderator – technologies that produce, and inevitably release, far more tritium than any comparable light water reactor design. This is of special concern to the Darlington EIS review because of the on-going debate as to an appropriate standard for tritium in Ontario's drinking water supply (as reflected in the ACES and ODWAC recommendations).

In view of these issues it is necessary to closely examine not only the conclusions reached by the requesting party – OPG in the present case – but also the claims made in the submissions to OPG by the reactor vendors.

In this regard it is perhaps a happy coincidence that the three companies that have submitted proposals to OP – namely, AECL, Westinghouse and Areva – have all recently made similar submissions to the UK's Environment Agency (UK EA) for the purpose of assessing the expected performance of new nuclear power stations to be built in England and/or Wales. Thus it is possible to compare the vendors' predictions for the environmental impact of the ACR-1000, the AP1000 and the EPR reactors with the responses of *two* requesting parties: namely, OPG and the UK EA.

Fortunately the three different reactor designs currently under scrutiny by OPG and the UK EA employ similar radioactive gaseous and liquid waste management systems. Nevertheless, to be in compliance with regulatory emission limits, it must first be proven that the proposed monitoring techniques *for each reactor design* are adequate to quantify the radioactive content of a particular discharge at the required level of detection. In addition the vendors must demonstrate that the various wastes arising from their respective reactors meet appropriate criteria for disposal in waste repositories.

It is significant that the UK EA's initial comments on the submissions it received in 2008 from the vendors of the ACR-1000, the AP1000 and the EPR, has been to state over and over again that: "*insufficient information has been supplied for us to draw any conclusions*". In the case of AECL's submission, the UK EA have requested that detailed information on the source/location, height, diameter and volume flow of gaseous and liquid discharges should be provided and add that "*designs rather than concepts should be described*".

It is rather telling, and somewhat disturbing, that no complaints about insufficient information on the three reactor designs under assessment have been forthcoming from OPG. Furthermore, as recently as November

2009, the UK's Health and Safety Executive said it could *not* recommend plans for new reactors because of wide-ranging concerns about their safety.

3.0 Radioactive Emissions: General Comments

As listed in Table 3.1 below, a large number of radionuclides are produced by the operation of water-cooled reactors. Most of these radioactive isotopes are created either through neutron activation or uranium fission (yielding "activation products" and "fission products"). In addition, a number of "transuranic isotopes" are created when non-fissile uranium atoms absorb one or more neutrons, subsequently transmuting into various isotopes of neptunium, plutonium, americium, curium, and so forth.

After an induction period, varying from a few days to several years, most of the radionuclides in question attain relatively constant (equilibrium) concentrations within the various systems in which they are produced – such as the reactor fuel bundles, coolant pipes, moderator tanks, heat exchanger tubes or cover gas plenums.

Inevitably some radioactive isotopes leak or otherwise escape from the systems in which they are produced and enter one or more liquid or gaseous waste effluent steams. It is these streams that must be assayed by continuous monitoring, or by the analysis of frequent "grab" samples, to determine the radionuclide content of the systems involved.

This type of data is essential for the control of radioactive emissions because it allows a reactor operator to follow the movement of radioactivity throughout the nuclear station under his or her control.

Furthermore, only with this level of detailed radiation monitoring may *all* radioactive releases from a nuclear facility be reliably reported to the appropriate regulatory agencies as a "source term" for each radionuclide.

Radiation dose calculations require radionuclide source terms – usually expressed as a time averaged flux – to determine the rate of release of a radioactive species and derive an associated radiation dose.

However, as we have seen, source terms for a "first-of-a-kind" reactor are problematical because they cannot be measured beforehand. Even a longstanding nuclear power station generally has insufficient data to accurately quantify *all* of its radioactive emissions and radiation doses.

Consider the problem of estimating the radiation dose at a location 1 km from an operating nuclear reactor. The expected dose could be calculated from a measurement of the mean annual concentration of radionuclides *at the location of interest* – but such data are usually not available.

The only practical way to make up for this lack of knowledge of the detailed dispersion of escaping radioactive species is to use source terms measured at the outlet of a contaminating stack or liquid effluent pipe and then determine the dose at a remote location using plume tracing models.

However, this approach still requires reliable analytical data for the rate of emission of <u>all</u> the radionuclides, including those shown in Table 3.1. This entails the measurement of the concentration of at least forty radionuclides in every effluent stream.

The analysis of a wide range of radionuclides, such as those listed in Table 3.1, is not a trivial task.

Gamma spectrometry is probably the most useful technique to quantify the gamma emitters (γ-emitters) in a sample using a single detector, but is of no use in quantifying the so-called "pure" beta-emitters (β-emitters) such as H-3 (tritium, which is radioactive hydrogen, usually given off in the form of radioactive water molecules), C-14 (carbon-14, usually given off as radioactive carbon dioxide), Cl-36 (chlorine-36), Ni-63 (nickel-63), Sr-90 (strontium-90) and I-129 (iodine-129). These pure beta-emitters require specialized, isotope-specific, analytical techniques.

The same holds true for uranium and most of the transuranic isotopes in Table 3.1 such as Pu-239 (plutonium-239), where α-spectrometry must be used on specially prepared samples.

Reactor operators, faced with the daunting task of measuring the concentrations of up to 40 radionuclides in all the gaseous and liquid effluent streams in a nuclear power station, generally resort to collecting analytical data for a much-reduced list of "high priority radionuclides", leaving the remaining radioactive species to be checked occasionally or not at all (see Section 3.4 for more details on this).

However, as we shall see, many of the most important radionuclides, such as tritium and carbon-14, *are also the most difficult to determine with good precision and accuracy* – an issue that is <u>not</u> addressed in OPG's EIS for Darlington new build.

Table 3.1 : Important Long-lived Radionuclides in Reactor Waste Streams

Radio-nuclide	Half-life	Mode of Production	Mode of Decay	Principal Gamma Energies (keV)
H-3	12.3 y	$^{2}\mathrm{H}(n,\gamma)$	β	No γ-rays
C-14	5730 y	$^{14}\mathrm{N}(n,p)$ $^{17}\mathrm{O}(n,\alpha)$	β	No γ-rays
Cl-36	3.0×10^{5} y	$^{35}\mathrm{Cl}(n,\gamma)$	β	No γ-rays
Ar-41	1.8 h	$^{40}\mathrm{Ar}(n,\gamma)$	β, γ	1293
Cr-51	28 d	$^{50}\mathrm{Cr}(n,\gamma)$	EC	320
Mn-54	313 d	$^{54}\mathrm{Fe}(n,p)$	EC	835
Fe-55	2.7 y	$^{54}\mathrm{Fe}(n,\gamma)$	EC	No γ-rays
Fe-59	45 d	$^{58}\mathrm{Fe}(n,\gamma)$	β, γ	1099, 1292
Co-60	5.27 y	$^{59}\mathrm{Co}(n,\gamma)$	β, γ	1173, 1332
Ni-63	100 y	$^{62}\mathrm{Ni}(n,\gamma)$	β	No γ-rays
Zn-65	244 d	$^{64}\mathrm{Zn}(n,\gamma)$	EC	1115
Kr-85	10.7 y	UF	β, γ	517
Sr-90	29 y	UF	β	No γ-rays
Zr-95	66 d	UF, $^{94}\mathrm{Zr}(n,\gamma)$	β, γ	724, 757
Nb-94	2.0×10^{4} y	$^{93}\mathrm{Nb}(n,\gamma)$	β, γ	703, 871
Nb-95	35 d	UF, $^{95}\mathrm{Zr}(\beta)$	β, γ	766
Tc-99	2.1×10^{5} y	UF	β	No γ-rays
Ru-103	40 d	UF	β, γ	497
Ru-106	369 d	UF	β, γ	512, 622
Ag-110	252 d	UF	β, γ	658, 884
Sb-124	60 d	UF,$^{123}\mathrm{Sb}(n,\gamma)$	β, γ	603
Sb-125	2.73 y	UF, $^{125}\mathrm{Sn}(\beta)$	β, γ	176, 428
I-129	1.6×10^{7} y	UF	β	No γ-rays
I-131	8.0 d	UF	β, γ	364
Xe-133	5.3 d	UF	β, γ	81
Cs-134	2.1 y	UF	β, γ	605, 796
Cs-137	30 y	UF	β, γ	662
Ce-141	33 d	UF	β, γ	145
Ce-144	284 d	UF	β, γ	133
Eu-152	13 y	UF	EC	122, 1408
Eu-154	8.6 y	UF	β, γ	725, 1272
U-235	7.0×10^{8} y	Natural	α	No useful γ-rays
U-238	4.5×10^{9} y	Natural	α	No useful γ-rays
Pu-238	88 y	$^{238}\mathrm{U}(n, \beta)$, etc	α	No useful γ-rays
Pu-239	2.4×10^{4} y	$^{238}\mathrm{U}(n, \beta)$, etc	α	No useful γ-rays
Pu-240	6540 y	$^{238}\mathrm{U}(n, \beta)$, etc	α	No useful γ-rays

Pu-241	15 y	^{238}U(n, β), etc	β	No useful γ-rays
Am-241	433 y	^{238}U(n, β), etc	α	59
Cm-242	163 d	^{238}U(n, β), etc	α	No useful γ-rays
Cm-244	18 y	^{238}U(n, β), etc	α	No useful γ-rays

EC = Electron capture; UF = Uranium fission; α = alpha; β = beta, γ = gamma

3.1 Tritium

In light water reactors such as AP-1000 and EPR, tritium (hydrogen-3) is produced by ternary fission within the fuel assemblies or by neutron activation of lithium (added for pH control), or boron (added for chemical "shim"), in the cooling water.

By comparison, for an advanced CANDU reactor such as the ACR-1000, or a modified CANDU-6, a far greater amount of tritium is produced by the neutron activation of non-radioactive heavy hydrogen atoms (hydrogen-2) contained in the heavy water molecules that are used as the moderator.

The relative magnitudes of the various tritium production routes in the three reactor designs under consideration by OPG shows that an ACR-1000 reactor or a modified CANDU-6 produces about 100 times more tritium than either the AP-1000 or the EPR reactors. Nevertheless, experience with the operation of OPG's fleet of heavy water reactors suggests that tritium emissions from large CANDUs can be controlled *to some degree* by the implementation of strategies to limit heavy water spills and leaks and the optimization of vapor recovery drier performance.

This probably explains why AECL's estimated HTO release to water, reported in Table D.2-1 of OPG's EIS, is only about ten times (rather than 100 times) higher than the equivalent tritium release data estimated by the vendors of the AP-1000 and the EPR reactors – but is this number realistic?

First note that *none* of the estimated tritium discharges provided by the three vendors is accompanied by documentation showing any rationale behind the reported values, nor the extent of any possible variability in the discharges. Neither is information provided on how specific events such as start-up, shutdown, maintenance, system leaks, fuel failures, etc, might impact on the reported tritium discharges.

Available tritium release data for OPG units show that high tritium emissions are associated with maintenance activities on certain systems.

Thus variable tritium emissions should be expected if an ACR-1000 or CANDU-6 is selected as the Darlington new nuclear build.

This conclusion is further supported by tritium monitoring data for CANDU units at Bruce, Pickering and Darlington over the past 20 years, which show that tritium emissions can vary by more than a factor of two for a given unit from one year to the next.
Tritium emission data for AECL's CANDU reactors at Point Lepreau and Gentilly-2 also show a very similar degree of year-to-year variability.

But let's take a closer look at the projected HTO ("tritiated water") emissions for four projected ACR-1000 reactors as reported in Tables D.1-1 and D.2-1of OPG's EIS. The projected airborne tritium release for the ACR-1000 is stated to be 0.48 Peta-Bq, while the projected waterborne release of an ACR-1000 is about three times higher at 1.4 Peta-Bq.

This is somewhat surprising because CANDU reactors traditionally release more tritium in the gas phase than in the aqueous phase.

What is more, Bruce A's four-unit airborne tritium emissions in 2008 were reported by Bruce Power to be 1.15 Peta-Bq – *more than double* the projected airborne emissions for the new CANDUs offered by AECL.

One is compelled to ask how AECL plans to maintain tritium emissions at or below the maximum projected levels of 0.48 Peta-Bq (airborne) and 1.4 Peta-Bq (waterborne). Our experience with the long-term operation of more than twenty large CANDUs here in Canada shows that current CANDUs are in some cases already above these emission levels.

Years of effort in trying to reduce tritium emissions from existing CANDU reactors have largely been unsuccessful. As a case in point, Darlington's waterborne tritium emissions more than doubled from the levels seen in the late 1990s to the levels reported in the period 2002 - 2007.

It is also noteworthy that OPG recently announced that it failed to meet its overall 2008 tritium emission targets.

Finally, as a cautionary note, there are reasons to believe that airborne tritium emissions are actually *higher* than currently measured by station monitors because, as AECL has reported, tritiated species tend to plate out on the walls of the sampling lines, thereby producing artificially low readings.

What is also not mentioned in OPG's EIS with regard to projected tritium emissions for an ACR-1000 is the fact that the tritium concentration in the moderator builds up over several years of unit operation as the function:

$$C\ (\text{tritium}) = 2.5\ [1 - \exp(-0.0563\ t)]\ \text{Tera-Bq/kg.}$$

To make matters even worse, waterborne tritium emissions also increase over time because larger leaks tend to form in aging reactor systems such as the steam generators.

Now there *is* a way to alleviate some of the expected increase in tritium emissions from a heavy water reactor, namely, *detritiation*. However we are not informed by AECL or OPG if there are plans to detritiate heavy water from new ARCs, should this reactor design be selected.

Certainly, OPG has since 1990 used cryogenic distillation to detritiate heavy water from its CANDU reactors using the Darlington Tritium Removal Facility (TRF). This facility has the capacity to detritiate up to 3000 tonnes of D_2O (heavy water) per year. It has significantly reduced the average tritium content of OPG's inventory of 10,000 tones of D_2O.

Indeed, it has been estimated that without this facility OPG would be emitting an additional 7.4 Peta-Bq of tritium per year to the environment, which is more than three times its actual tritium emission rate. It must be noted, however, that such calculations typically ignore the fact that OPG's TRF is itself a significant source of tritium emissions.

Nevertheless, if the ACR-1000 or CANDU-6 is selected for the Darlington new nuclear build, substantially higher tritium emissions from the Darlington site are to be expected, either from the buildup and escape of moderator tritium in the new reactors, or from substantially increased use of the existing TRF.

Whatever the case, the projected use of detritiation for moderator heavy water in new ACRs needs to be addressed by OPG in its EIS for Darlington new nuclear build.

3.2 Carbon-14

Radioactive carbon-14 (C-14) is produced in both light water and heavy water reactors by neutron activation of N-14 (non-radioactive nitrogen-14) and/or O-17 (non-radioactive oxygen-17). However, among the three reactor designs under consideration by OPG, the highest projected C-14 emissions of 1.1 Tera-Bq correspond to the projected airborne C-14 emissions from the ACR-1000 heavy water reactors.

Unfortunately however, as we saw for the projected tritium emissions, *none* of the estimated C-14 discharges provided by the three vendors is accompanied by documentation showing the rationale behind the reported values, and the extent of any possible variability in the discharges. Neither is information provided on how events such as start-up, shutdown, maintenance, system leaks, fuel failures, etc, might impact on the reported C-14 discharges.

What is more, as we will show below, C-14 in CANDU reactor waste (such as ion-exchange resin) is a major environmental concern because of the very long, 5730-year, half-life of C-14.

OPG's original fleet of CANDU reactors commissioned in the early 1970s at Pickering NGS, used nitrogen gas (N_2) to fill their annulus gas systems. Most regrettably, prior to 1979, no one at AECL or OHN recognized the possibility that nitrogen could produce vast quantities of C-14 particulate under neutron irradiation.

Indeed, I have seen documents from AECL Chalk River written in 1981 stating that solid C-14 was <u>*not*</u> present in the annulus gas systems of Pickering reactors, even though I had reported the presence of solid C-14 in deposit removed from Pickering Unit 4 in 1980. (See: "*Analysis of Pickering NGS "A" Unit 4* N_2 *Annulus Gas Filter Deposit*", OHRD Report No. C81-04-K, January 1981).

Unfortunately for AECL's alleged "experts" on this topic, we now know that thousand of Curies of C-14 particulate were produced in all four Pickering Units prior to the large-scale fuel channel replacement operations in the mid-1980s.

Today OPG no longer uses N_2 in its annulus gas systems, but residual N_2 from air enters moderator systems where it is readily converted to C-14 through the N-14 (n,p) C-14 thermal neutron reaction.

The fact that O-17 (oxygen-17) is enriched in heavy water relative to natural, light water, only adds to the C-14 production problems with CANDUs through the O-17 (n,alpha) C-14 reaction.

This certainly makes one wonder why OPG has no gaseous C-14 emission data for Darlington from 1993 to 1998.

While some C-14 is emitted during reactor operation, however, most of the moderator C-14 is collected on ion-exchange (IX) resin columns used for moderator water quality control.

Storage and/or long-term disposal of carbon-14-contaminated resins is already a major problem for OPG because of the potentially high collective radiation dose (63 person-Sieverts per gigawatt of electric power) from the long-lived C-14.

In light of these facts I would ask OPG to provide answers, with supporting experimental data and/or calculations, to the following questions concerning the production and fate of C-14 from four new ACR-1000 reactors at Darlington:

- What is the projected end-of-life C-14 inventory on spent IX resin from these reactors?
- Where and how will the spent resin be stored and at what repository costs?
- What is the expected condition/integrity of these IX resins to 2050 and beyond?
- What are the expected effects of self-irradiation on the retention of C-14 by the resin?
- What is the probability that microbial action could mobilize the C-14?

3.3 Noble Gases

The radioactive noble gas emissions from nuclear reactors are mostly short-lived fission product isotopes of krypton and xenon. However, Ar-41 (argon-41) from the activation of the small amount of non-radioactive argon in air (0.94 %), is invariably present in the gaseous emissions from operating reactors.

The day-to-day amounts and isotopic composition of noble gas emissions from operating reactors are variable and complex because the numerous radioactive species of interest are short-lived, ($t_{1/2} \sim$ 15 min to 12 days), with continually changing activities.

To add to this complexity, some noble gases escape containment directly and enter the environment via the "non-contaminated" stack, while other species find their way into gaseous effluent streams that use activated carbon beds to delay noble gas release.

The monitoring of noble gas emissions from CANDU reactors has been accomplished in many different ways over the years. Problems such as insufficient detector resolution and sensitivity remained unresolved until well into the 1980s. AECL also encountered similar problems at Point Lepreau and Gentilly-2, and has acknowledged that noble gas emissions reported for these reactors "were flawed", at least until 1994.

Even today, however, CANDU reactor operators do *not* provide a detailed, isotope-specific, breakdown of their noble gas emissions but simply report *gross* noble gas emission data in "energy-compensated" units of gamma – Bq·MeV.

This approach is based on the assumption that the radiation dose received by a population exposed to a radioactive noble gas mixture is proportional to the *average* gamma-ray energy per disintegration. But this is true only *if the isotopic composition of the gaseous effluent is relatively constant*. And, as we have already seen, that is simply *not* the case for CANDU reactors. Large variations in noble gas composition are caused by variable holdup times as well as by routine operational activities such as startup, refueling and shutdown.

Nevertheless, OPG and AECL continue to use such energy-compensated units when reporting noble gas emissions – even though there are internationally accepted standards, such as ISO60761, for gaseous effluent monitoring from nuclear reactors, and most jurisdictions do indeed report noble gas emissions for individual radioisotopes of argon, krypton and xenon in units of Bq.

Another important requirement of noble gas monitoring at a nuclear station is that the measuring instrument should be able to provide on-scale readings *under accident conditions* so that the station operator is able to provide meaningful release information for off-site emergency planning and actions. OPG does not address this issue in its Darlington EIS.

What we *do* find in OPG's EIS (TSD No. 27) is an analysis of *"a stylized accident radioactive release scenario"* in which a scaled source term, *assumed* to be a small portion of the reactor core inventory, is released from damaged fuel; this postulated release is subsequently used to determine a dose to the public.

However, this approach also assumes that reactor containment is not breached for 24 hours, artificially allowing the short-lived noble gases to decay. I would ask OPG to justify the assumption of a 24-hour delay.

Regrettably, OPG's accident "scenario" has little to do with anticipated reactor accidents that have actually been postulated and studied by nuclear agencies around the world; on the contrary, OPG's approach appears to be an exercise in radioactive bean-counting to satisfy emission/dose limits.

OPG's imagined accident "scenario" is not realistic because it considers a radioactive release from only <u>one</u> fuel element or assembly even though the Canadian nuclear industry and its regulators know that power pulse transients and temperature excursions could damage much more than that. Indeed, a recent CNSC risk assessment for CANDU reactors mentions the likelihood of more than one fuel element being damaged:

> *"Most accidents involve deteriorated cooling conditions, resulting in elevated fuel temperatures which in some events may reach very high values.... In* (feeder) *stagnation break or flow blockage, several bundles in a single channel are predicted to experience melting"*.

I would therefore ask OPG to explain how it arrived at "the post-accident gaseous release source term" data in Table 4.4 of its report N-REP-01200-10000 entitled: *"Use of Plant Parameters Envelope to Encompass the Reactor Designs Being Considered for the Darlington Site"* In particular I would ask OPG to explain (in relation to Table 4.4 in N-REP-01200-10000):

- How it determined, and how it would validate, the noble gas and radio-iodine emissions in Table 4.4?
- How it modeled the gas, vapor and aerosol release, transport and retention in containment for the postulated accident scenario?
- Why a more realistic accident scenario, involving the melting of several fuel bundles, was not considered?

3.4 "Missing" Radioisotopes

There are a number of radioisotopes, *known to be produced in nuclear reactors,* which are quite difficult to analyze and are therefore not monitored or reported by reactor operators. Nevertheless, these isotopes are of concern for long-term disposal of reactor wastes.

I would therefore ask OPG to provide production, emission and dose estimates for the following *unmonitored* long-lived isotopes that may be released or found in the waste generated by Darlington new build reactors:

Al-26 (7.3 x 10^5 y)	aluminum-26	730,000 years
Cl-36 (3 x 10^5 y)	chlorine-36	300,000 years
Fe-60 (10^5 y)	iron-60	100,000 years
Cs-135 (2.3 x 10^6 y)	cesium-135	2,300,000 years
I-129 (1.59 x 10^7 y)	iodine-129	15,900,000 years
Zr-93 (9.5 x 10^5 y)	zirconium-93	950,000 years
Nb-92 (3.2 x 10^7 y)	niobium-92	32,000,000 years
Ar-42 (33 y)	argon-42	33 years

3.5 Accumulation of Radioisotopes in the Near-Field Environment

An important issue that is not addressed in OPG's EIS for Darlington New Build Reactors is the potential for the accumulation of long-lived radioisotopes in the near-field environment around Darlington.

Radioisotopes of particular interest are H-3 (tritium), C-14 and Cs-137 and the near-field environment of concern would be any location within about 10 km of the Darlington NGS site. Within this region radioisotope emissions from the Darlington site accumulate in exposed vegetation, soil and groundwater as the result of natural dry and wet deposition processes.

While it is difficult to accurately measure the rate of accumulation of H-3, C-14 and Cs-137 in the near-field environment around a nuclear facility, such rates may be inferred from several years of data from suitable environmental samples and comparisons to the concentrations of these species in "background" samples. Background concentrations of H-3, C-14 and Cs-137 reveal the occurrence of these radioisotopes from natural and anthropogenic sources such as cosmic rays and nuclear weapons testing.

Nuclear weapons testing, especially in the 1950s and early 1960s, injected considerable amounts of H-3, C-14 and Cs-137 into the earth's atmosphere, much of which found its way into soil and surface waters around the world. Nevertheless, since the Test-Ban Treaty of 1963, the concentrations of these species have been slowly declining so that current environmental levels are quite low and predictable. Representative *maximum background concentrations* in environmental samples collected around Darlington are:

H-3 in water from the Great Lakes and/or inland lakes and rivers: 4.5 Bq/L
C-14 in soil: 226 Bq/kg-C
Cs-137 in soil: 7.0 Bq/kg

OPG's EIS TSD Volume 15: "*Radiation and Radioactivity Environment Existing Environmental Conditions*" provides data for these species at various sites around Darlington. The *maximum* reported values are:

H-3 in water within the study area: 29.2 Bq/L or 6.5 times background
C-14 in soil: 301 Bq/kg-C or 1.3 times background
Cs-137 in soil: 11.5 Bq/kg or 1.6 times background

These data clearly show that radioactive contamination from the existing Darlington site, which has been in operation for only about 15 years, is already spreading into the local environment.

OPG likes to claim that the radioactive emissions from its nuclear facilities are within regulatory limits and therefore pose no threat to the local environment. However, such claims ignore the *accumulation* of long-lived radioactive species in the environments around OPG's nuclear facilities due to years of exposure to controlled emissions, uncontrolled leaks and accidental spills. Radioactive species such as Cs-137 have a tendency to bio-accumulate in select species of flora and fauna such as berries, fungi and fish.

What is more, there is evidence that radioactive emissions tend to *increase* as a nuclear facility ages because more and more radioactive material such as irradiated fuel is stored on-site and radioactive circuits such as annulus gas systems tend to develop leaks and/or require more frequent purging.

Thus it is to be expected that an ever expanding and deleterious radioactive "footprint" will grow around Darlington NGS over the predicted 50-plus years of operation of new nuclear reactors at this site.

Comments on OPG's Environmental Impact Statement For New Nuclear Build at Darlington NGS

by F. R. Greening – for le Mouvement vert Mauricie's Intervention on the *Darlington New Build* Environmental Assessment Hearings in 2011

Part B – The Economics of Nuclear Power in Ontario

1.0 Introduction

The economics of nuclear power first became an issue in the early 1980s once the early promise of "electricity too cheap to meter" was seen to be an empty dream. The increasing cost of nuclear power in the 1980s came about for two main reasons:

(i) First-generation reactors commissioned in the late 1960s and early 70s were showing a disturbing trend towards declining capacity factors after less than ten years of operation due to unexpected premature aging from corrosion, metal fatigue and embrittlement and radioactivity buildup - all of which complicate the operation and maintenance of a nuclear reactor.

(ii) The growing recognition of the many hidden costs associated with nuclear power production such as radioactive decontamination and waste handling, decommissioning and insurance against third-party liability in the event of a nuclear accident.

It is significant that these initial problems with nuclear power plant economics remain issues of great concern even today, especially as we consider the pros and cons of building new nuclear reactors here in Ontario.

However, as we shall see, a *third* problem has emerged that further undermines the economic viability of new nuclear power plants: the trend towards a declining demand for electricity throughout the Western world over the past two decades.

In this report we evaluate the true life cycle economics of nuclear power by considering the construction, operation, maintenance, waste management and decommissioning costs of new nuclear reactors. We also specifically consider the *need* for new nuclear reactors at the present time in relation to the expected long-term demand for electricity and the viability of alternative sources of electrical energy in Ontario.

2.0 A Brief History of Nuclear Power in Ontario

I: The Rise and Fall of CANDU Technology 1970 - 2000

Ontario's grand experiment in the generation of electricity from uranium fission took shape in the early 1970s when eight large, 500 - 800 MWe, CANDU reactors were commissioned at Pickering and Bruce. These state-of-the-art reactors were viewed as a logical development of the smaller 200 MWe reactor at Douglas Point which was commissioned in 1967.

By the early 1980s Pickering and Bruce were being hailed as the largest and best nuclear power stations in the world. Indeed, with output capacity factors above 80 percent, Bruce units consistently appeared in the "top-ten" rankings of the world's reactors.

This early success of the large CANDU reactor design prompted the construction of four more, even larger (880 MWe), units at Darlington. However, at the same time (the early 1980s), OPG's nuclear program suffered its first setback with serious pressure tube failures in several units at Pickering and Bruce.

A CANDU reactor uses much the same principle as the cooling system of an automobile engine whereby heat energy, in this particular case from the fission of uranium, is carried out of the reactor core by rapidly flowing pressurized water.

However, the CANDU design is based on a large reactor core packed with hundreds of horizontal pressure tubes each loaded with about a dozen uranium oxide fuel bundles. Unlike the automotive design that uses only *one* inlet and *one* outlet line in its coolant circuit, a CANDU reactor typically employs 390 inlet and 390 outlet "feeder pipes" (one inlet/outlet pair for each pressure tube) to circulate the coolant water.

This creates a veritable spaghetti-junction of pipe work at the two faces of the reactor core. A short distance from each reactor face, the outlet and inlet feeder pipes merge at the so-called outlet and inlet "headers", which serve to carry water to and from the boilers ("steam generators") that produce steam for the turbines.

Many years of operating experience have shown that pressure tube, feeder pipe and boiler integrity are critical to the safe, reliable and cost-effective operation of a CANDU reactor.

The long-term performance of a pressure tube, feeder pipe or boiler tube is largely determined by two factors:

(i) The quality of the construction material used for the components in question and

(ii) The preservation of an optimum operating environment for each of these components. These factors are critical to the longevity of all reactors.

In the particular case of a CANDU reactor the pressure tubes are made from high purity zirconium alloys, the feeder pipes from carbon steel and the boiler tubes from specialized nickel alloys, each alloy being selected for its resistance to corrosion in a high temperature and pressure environment.

However, the checkered history of OPG's first generation of large CANDU reactors, namely, the four Pickering 'A' units and the four Bruce 'A' units, reveals the sad truth that AECL and OPG made a number of poor choices for some critically important alloys and provided equally poor control of system chemistry – not only during normal reactor operations but also during "outages" for decontaminations, de-scaling and similar measures unwisely selected for reactor maintenance.

For example, Bruce Units 1 and 2 were permanently shut down in the late 1990s due to excessive corrosion of critical boiler components. This unfortunate early retirement of two of OPG's prized nuclear assets was caused by the presence of undesirable impurities in the coolant – a situation that was *recognized and tolerated by the OPG operators*. Remedial measures were not implemented in the interests of achieving short-term electricity production targets.

Similarly, all Pickering 'A' units had pressure tube replacement projects after less than 15 years of operation due to the excessive, *and unexpected*, corrosion and hydrogen embrittlement of a zirconium alloy that is now deemed unsuitable for use in pressure tube construction. Unfortunately, the limitations of this alloy and other fuel channel design and construction errors were not recognized until *after* the nearly catastrophic rupture of tube G16 in Pickering Unit 2 in August 1983.

This led to the difficult and costly large-scale fuel channel replacement project whereby new Zr - 2.5 % Nb (zirconium alloyed with 2.5 percent niobium) pressure tubes were installed in Pickering Units 1 to 4 between 1984 and 1993.

A final and perhaps fatal blow to OPG's aging CANDU reactors came in the period 1997 to 2001 when it was recognized that, in addition to the need to replace pressure and boiler tubes at Bruce, the feeder pipes at Pickering would also need to be replaced. This new concern first surfaced in 1997 when feeder pipe cracking was discovered in New Brunswick Power's lone CANDU reactor at Point Lepreau.

As a result, a massive inspection program was undertaken at Pickering that soon revealed unexpected wall thinning of the outlet feeder pipes due to flow-accelerated corrosion.

The extent of the failure of OPG's nuclear power program at this time is revealed by the fact that the contribution of nuclear generation to Ontario's electricity supply fell from a peak of over 50 percent in the early 1990s to less than 30 percent by the end of 2003. Indeed, it is hard to believe that, as the world entered the 21st century, about 40 percent of Ontario's electricity supply was still coming from the 19th century technology of burning coal.

II: The Refurbishment Years 2000 – 2005

Plans to refurbish OPG's oldest nuclear reactors were first approved in 1999 and were based on an initial cost estimate of $780 million *for all four Pickering 'A' Units* and a prediction that the first Unit would be up and running by the end of 2000.

In May 2003, with the project *3 years behind schedule*, costs approaching $1 billion, and no Units yet operational, Ontario Premier Eves announced the creation of a committee, chaired by Jake Epp, to review the status of the refurbishment project. The Epp committee issued its final report in December 2003, just a few months after the first refurbished Pickering 'A' reactor, Unit 4 (or P4), was finally declared fully operational and limped back into service.

Epp's report led to the creation of another committee, chaired by John Manley, to carry out a cost benefit analysis for the return to service of the three remaining Pickering 'A' Units. In March 2004 Manley issued a report claiming to show that refurbishment of Pickering 'A' Units 1, 2 and 3 would indeed be profitable and should therefore proceed.

Significantly, Manley based his cost benefit analysis on OPG's predicted capacity factor for the refurbished Units of 85 percent. As it has turned out the actual capacity factor achieved by Units P1 and P4 since their return to service has been below 70 percent.

In addition, just over one year after Manley's report had been released, the possibility that the refurbishment of a 25 to 30 year-old CANDU reactor might *not* be justified on a commercial basis was being recognized for the first time at Pickering 'A'. Thus it was in August 2005 that then OPG President and CEO Jim Hankinson announced that the refurbishment of Pickering Units 2 and 3 would *not* be undertaken because of the discovery of severe degradation of feeder and boiler pipe-work from excessive corrosion of these Units.

Thus Hankinson and his Board of Directors at OPG concluded that to proceed with a refurbishment of Pickering Units 1 and 4 *"would have undermined OPG's core mandate to produce electricity as reliably, efficiently and cost effectively as possible."*

Nevertheless, after coming to office in October 2003, the newly elected Ontario government led by Premier Dalton McGuinty has set out to remedy the declining performance of OPG's fleet of CANDU reactors with a plan to eliminate the Province's reliance on coal-fired power stations such as Nanticoke GS while simultaneously revitalizing its ailing nuclear program.

This revitalization was to be accomplished by refurbishments of the aging reactors at Pickering 'B' and the construction of two new reactors at Darlington. This plan for a "nuclear renaissance" is discussed in detail below (See Section 3.0) – but first we need to briefly review the economics of refurbishing CANDU reactors at Pickering.

Refurbishment Economics:

If we take a close look at the true cost of refurbishment of the reactors at Pickering NGS, as in the examples of P4 and P1, one billion dollars per Unit would be a realistic figure.
We may also assume that the price of electricity in Ontario over the operational lifetime of any of the Units at Pickering will be about $48 / MWh.

Using these figures, we may calculate how many years a Pickering 'A' Unit must operate (at its full 514 MW(e) net output power) to pay back the $1 billion that was required to repair it. We proceed as follows:

Let the annual *gross* revenue from the sale of electricity from one Pickering Unit be **R** dollars, and **N** be the number of hours that the Unit is actually operated per year, then:

$$\mathbf{R} = \$48/\text{MWh} \times 514\ (\text{MW}) \times \mathbf{N}\ (\text{hr})$$

Now **N** is simply the number of hours in a year (8766 hrs) multiplied by the Unit's capacity factor. Based on historical data on capacity factors for OPG's CANDU reactors, a value of 75 percent is a realistic lifetime average capacity factor for a Pickering 'A' Unit. Hence, the annual *gross* revenue from the sale of electricity from one Pickering Unit is given by:

$$\mathbf{R} = \$48/\text{MWh} \times 514 \times 8766 \times 0.75 = \$162 \text{ million per year}$$

But not all of this revenue goes to pay back the cost of refurbishing a Pickering Unit because we must take *operating costs* into account to derive the *net* annual revenue, or *profit*.

Operating costs for OPG Units may be derived from recent *OPG Annual Reports*; these reports show that Operations, Maintenance and Administration consume about 40 % of revenues, and fuel purchasing and handling add an additional 5 %. Unspecified expenses and adjustments add yet another 3 %; therefore we may reasonably assume a Pickering Unit's operating cost to be 48 % of gross revenues or $78 million.

We note in passing that Manley actually used a somewhat higher figure of $86 million as the average annual operating cost of a Pickering 'A' Unit. Nevertheless, we shall use the OPG's $78 million estimate of operating costs – in which case the *net* annual revenue – the annual profit – from a refurbished Pickering Unit would be ($162 – $78) million = $84 million.

At this rate of earnings each Pickering Unit will take about 12 years to pay back it's refurbishment debt. Interestingly OPG also predicted a 12-year life expectancy for the refurbished P1 and P4 Units.
Thus we see that to be economically viable each refurbished Pickering 'A' Unit must operate with a minimum capacity factor of 75 % for 12 years, i.e. until 2017.

However, based on CANDU's track record in Ontario, one feels compelled to ask: is this an achievable level of performance for these old reactors? But first we might ask: why could a refurbished Pickering Unit not operate *beyond* 2017?

The answer to the second question, according to OPG, is that P1 and P4 will both require full pressure tube replacements by 2017.

This view is consistent with the long-standing Canadian nuclear industry belief that *pressure tubes are the life-limiting component of CANDU Units*. This was certainly the view back in the 1980s when pressure tubes in Units at Pickering showed signs of hydrogen embrittlement after only about a decade of operation.

By the 1990s steam generator tube corrosion became an additional concern, especially in the Units at Bruce NGS. Then, in 1997, feeder pipe cracking and wall thinning was discovered in the CANDU 6 Unit at Point Lepreau – and the fitness-for-service of feeder pipes in all CANDU reactors became an issue – yet to be resolved in *any* first generation CANDU reactor.

Feeder wall thinning is generally attributed to flow-accelerated corrosion. This is a very complex phenomenon that is poorly understood, in spite of considerable research by AECL and OPG. Some important facts to consider are:

- The initial wall thickness of feeder pipes varies between 7 mm and 3.5 mm.
- 40 percent of the original wall thickness is the maximum acceptable thinning.
- The wall thickness at a feeder pipe bend is subject to considerable variability making it difficult to determine feeder pipe thinning *rates* at any critical location without a number of repeat measurements.
- Prior to February 2005, ultrasonic measurements at the extrados of the first elbow of Pickering 'A' feeders found a minimum wall thickness greater than 3 mm. Up to this time the extrados of the first elbow was considered to be the location most susceptible to wall thinning and it was therefore concluded that the Pickering feeders were within the fitness-for-service guideline.
- In April 2005 *direct* micrometer measurements were made at the extrados *and intrados* of two removed feeders from P1. These measurements gave the unexpected result that *the elbow intrados was thinner than the associated extrados*, *and well below the fitness-for-service guideline*.

To remove and replace *one* feeder pipe from a CANDU reactor costs about $1 million. To remove and replace the full complement of inlet feeders in a Pickering 'A' Unit (390 pipes in total), costs about $300 million.

Worse yet, a full feeder pipe replacement would take at least a year to complete and allow about $30 million of interest charges to accrue on the refurbishment debt. Thus, should a full feeder pipe replacement be undertaken as part of a refurbishment of a Pickering Unit, each Unit would have to operate with a capacity factor of at least 75 percent *for the next 15 years* simply to pay for refurbishment costs. But this is an unattainable goal because these Units will also require a full pressure tube replacement after about 12 years of post-refurbishment operation.

It is these types of plant aging and degradation issues that must be considered in evaluating the economics of the refurbishment of Pickering 'B', or indeed of Darlington's existing reactors, and ultimately of any new build reactors.

3.0 Nuclear Power in Ontario 2005 to 2010: Renaissance or Retreat?

In June 2006, based on the conclusions of a review by the Ontario Power Authority (OPA) of the appropriate supply mix required to satisfy the expected electrical energy demand in Ontario to 2025, the McGuinty government announced a three-part plan expected to cost about $20 billion:

1. Close all of Ontario's coal-fired generating stations as soon as possible
2. Proceed with the refurbishment of Pickering 'B'
3. Undertake the procurement of two new nuclear reactors at an existing nuclear facility in Ontario

The economic basis of the McGuinty plan was OPA's prediction of a sustained growth of about 14 percent in electrical energy demand in Ontario over the period 2005 to 2025.

This demand growth, coupled with the loss of generation from the end-of-life closure of OPG's and Bruce Power's fleet of 20 CANDU reactors, led OPA to predict that there would be a 24,000 MW « energy gap » in Ontario by 2025 unless OPA's supply mix plan, or something similar, was implemented.

The timeline given below shows that McGuinty's energy plans, formulated between 2005 and 2007, did indeed set into motion a flurry of activity by OPG and Bruce Power to bring about a nuclear renaissance here in Ontario.

However, two major announcements in the past year, one by the federal and the other by the provincial government, have changed everything.

Thus it was in May 2009 that the Canadian Minister of Natural Resouces announced that the federal government intended to seek buyers for AECL's nuclear reactor business.

Then, in June 2009, the Ontario Energy Minister announced that plans to build new nuclear reactors at Darlington would be postponed for an indefinite period – stating that the bids from AECL, Areva and Westinghouse were too costly.

Before discussing the consequences of these announcements we need to consider the true cost of constructing, operating and decommisioning new nuclear reactors and review OPA's demand growth predictions for Ontario out to 2025 compared to its 2005 predictions.

ONTARIO'S NUCLEAR TIMELINE : 2005 to 2010

May 2005 : The Ontario Minister of Energy requests that the Ontario Power Authority (OPA) provide advice on the appropriate electrical energy supply mix to satisfy the expected demand in Ontario to 2025.

Oct 2005 : Ontario Minister of Energy announces the signing of an agreement with Bruce Power to refurbish up to four Bruce 'A' units by 2010.

Dec 2005 : The OPA reports that the province will need an installed capacity of 36,000 MW by 2025 and will need to spend $83 billion over the next 20 years to meet this projected electical energy requirement.

Jun 2006 : Ontario Minister of Energy announces plans to refurbish units at Pickering 'B' and construct two new reactors at an existing nuclear facility for a total cost of $20 billion.

Aug 2006 : CNSC receives an application from Bruce Power for the construction of up to four new nuclear reactors to be located at the existing Bruce Nuclear site.

Sep 2006 : CNSC receives an application from OPG for the construction of up new nuclear reactors to be located at the existing Darlington Nuclear site.

Jun 2007 : The Minister of the Environment refers the Bruce Power new nuclear reactor project to a CEAA Joint Review Panel.

Aug 2007 : OPA announces its Integrated Power System Plan (IPSP) for Ontario's electricity supply to 2025 which calls for an expenditure of $26.5 billion to maintain 14,000 MW of nuclear capacity either through refurbishment of existing nuclear reactors or new nuclear build.

Jan 2008 : The Minister of the Environment refers the OPG new nuclear reactor project to a CEAA Joint Review Panel.

Mar 2008 : The Ontario government issues a request for proposals for the addition of up to 3500 MW of new nuclear capacity at the Darlington site.

Oct 2008 : Bruce Power announces its plan to conduct an EA for a new nuclear generating station at the Nanticoke GS site in Southern Ontario.

Jan 2009 : CEAA formally establish a joint review panel for an EA of the prposed new nuclear construction at Darlington.

Feb 2009 : AECL, Areva and Westinghouse submit proposals to supply new reactors for Darlington.

May 2009 : Canadian Minister of Natural Resouces announces plans to seek buyers for AECL's nuclear reactor business.

Jun 2009 : Ontario Energy Minister announces that plans to build new nuclear reactors at Darlington are postponed for an indefinite period stating that the bids from AECL, Areva and Westinghouse were too costly and citing concerns regarding the future of AECL..

Jul 2009 : Bruce Power withdraws its application for new nuclear reactors at the Nanticoke and Bruce sites giving the reason for its decision as declining electricity demand.

Sept 2009 : OPG's EIS for new nuclear reactors at Darlington is submitted to CEAA for public comment.

Feb 2010 : OPG announces that it will *not* be refurbishing Pickering B but instead seeking CNSC approval for life extension of the facility for up to six years.

4.0 The Cost of Nuclear Power

The cost of nuclear power, or indeed *any* electricity generating plant, is determined by three main factors :

(i) Construction and commissioning costs
(ii) Fuel costs
(iii) Operating and maintenance costs

The first of these factors involves the cost of bringing together the required materials and equipment and paying the wages of the construction workers and system engineers until the plant is declared operational. This generally requires long-term financing, much like a mortgage on a house; consequently this cost strongly depends on interest or discount rates and whether or not public or private funding is used.

Historically, in most western countries, public funding has underwritten the cost of nuclear power projects.

The second cost of nuclear power listed above involves the mining and extraction of the raw fuel and the expenses involved in refining, isotopic enrichment (if applicable), and fabrication of the fuel elements used in the power plant.

On the specific issue of fuel costs per kWh of electricity generated, nuclear power does have a competitive edge over other means of producing energy; however, this must be weighed against the high, and somewhat uncertain, costs of storing and disposing of spent nuclear fuel and decommissioning of the radioactive structures.

The third and final cost of nuclear power noted above is the day-to-day expense of operating and maintaining equipment such as pumps, pressure vessels, valves, filters, electronics, etc, that together make up a modern nuclear power plant.

It turns out that the costs required for the safe and reliable production of electricity, and the additional costs of administering the power plant – usually referred to as the OM&A cost – is one of the greatest costs of nuclear power. First, however, we shall briefly look at the escalating construction costs of new nuclear plants.

The U.S. Center for Energy and Environmental Policy Research (CEEPR) recently completed a review of the cost of new nuclear reactors in the U.S. The authors of the study concluded that the construction costs of a 1000 MW nuclear plant are in the range of $5 billion to $7 billion in 2007 U.S. dollars.

After the global financial crisis of 2008/09, new nuclear plants have tended to be much more expensive than the highest vendor prices quoted just a few years ago.

As clear evidence of the recent escalation in the cost of new nuclear power plants, the Ontario Provincial Government announced in June 2009 that it could not accept any of the bids – rumored to be in excess of $20 billion – that it had received from Areva, Westinghouse or AECL for the construction of two new nuclear reactors at the Darlington NGS site.

In making this announcement Energy Minister George Smitherman explained that Ontario would be shelving plans to procure new nuclear reactors for the Province because the quoted prices were « *substantially too high*.»

What is most remarkable about this decision by the Provincial Government is the fact that OPG did not immediately put its environmental assessment of new nuclear reactors on hold, but simply forged ahead with its nuclear development plans as if nothing had happened.

Thus, in September 2009, OPG issued its environmental impact statement for the construction of two 1000 MW reactors at Darlington based on the designs currently offered by Areva, Westinghouse and AECL – the self-same reactors our Government has indicated that it cannot afford!

Now while there can be no doubt that modern nuclear power plants have become very costly to build, such initial costs *might* be justifiable if they could be recovered by low operating costs. Unfortunately, this is *not* the case because nuclear reactors are notoriously expensive to operate, especially compared to alternative non-nuclear based electrical power generating technologies.

For example, data from OPG’s 2008 and 2009 annual reports show that OM&A costs averaged 14 percent, 40 percent and 75 percent of the respective revenues from hydro, coal and nuclear power production in this two-year period. Significantly, the Ontario Energy Board, (OEB) recently rejected OPG’s request for a 14.8 % increase in the price of electricity and urged OPG to recover its predicted $200 million revenue shortfall for 2009 *by bringing down its nuclear OM&A costs*.

The position taken by the OEB with regards to the need for better cost control of OPG’s nuclear operations is supported by the fact that OPG’s base OM&A nuclear costs have increased by 32 % since 2005 even though the nuclear electricity generated by OPG over the past 5 years has remained relatively constant at 46 ± 2 TWh per year. The deplorable state of OPG’s nuclear finances is further documented in OEB’s 2008 *Decision with Reasons* (Report No. EB-2007-0905), where we read :

> « *The most common measure of productivity in the nuclear generation industry is the production unit energy cost or PUEC. The PUECs of the two Pickering stations are far above industry averages; in fact, the operating cost performance of Pickering ‘A’ may be the worst of any nuclear station in North America. In 2006, Pickering ‘A’ had a PUEC three times the U.S. average ($75.60 per MWh compared to $24.00 for theU.S, median) and twice the Bruce unit cost of $38.00 per MWh; in 2007 Pickering ‘A’ had increased to $130.00 per MWh compared to $23.00 for the U.S. median and $42.00 at Bruce.* »

5.0 Conclusions

In this report we have considered economic indicators of a nuclear power station’s performance – especially factors that measure its OM&A. Many of these indicators show that for the Province of Ontario in the year 2010, ***new nuclear power plants are not only too expensive to buy, but are also likely to be too expensive to operate***.

Thus we are left with one final question :

Does OPG really need 2000 MW of new nuclear capacity at this time?

To begin to answer this question we need to go back to December 2005 when the Ontario Power Authority, (OPA), released its *Supply Mix Advice* report.

This report estimated that Ontario's demand for electricity would begin to exceed the available supply by 2014 and that by 2025 the energy « gap » would be about 10,000 MW. OPA arrived at this conclusion based on the assumption that the electricity load growth in Ontario would be sustained at 0.9 percent per year to at least 2025, amounting to an overall increase of more than 14 percent load growth.

The actual Ontario load growth from 1998 to 2010 is presented in Table 1, below. It shows that the predicted load growth never happened.

Table 1 : Ontario's Total Annual Electricity Demand 1998 – 2009

Year	Total Demand (TWh)	Increase over previous Year (percentage)
1998	140	+1.4
1999	144	+2.9
2000	147	+2.1
2001	147	0.0
2002	157	+4.1
2003	152	–0.7
2004	153	+1.1
2005	157	+2.3
2006	151	–3.8
2007	152	+0.7
2008	148	–2.3
2009	139	–6.1

Meanwhile, OPG continues to spend $50 million per year planning for the construction of new nuclear reactors at Darlington and funding environmental assessments for the City of Oshawa. Thus OPG continues to ignore the economic realities it is now facing.

Simply put : If we cannot afford to *buy* new nuclear raectors, and we cannot afford to *run* new nuclear reactors, and we do not *need* new nuclear reactors, why not call a halt to this madness? These new reactors should not be approved.

Comments on OPG's Environmental Impact Statement For New Nuclear Build at Darlington NGS

by F. R. Greening – for le Mouvement vert Mauricie's Intervention on the *Darlington New Build* Environmental Assessment Hearings in 2011

Part C Nuclear Safety

1.0 Introduction

The term "Nuclear Safety" embraces many issues that may be subdivided into three broad categories: plant aging, accident analysis, and structural integrity.

Plant aging refers to issues such as corrosion or component failure arising from normal wear and tear on pipe work, pumps, valves, seals, etc.

Accident analysis considers a reactor design in terms of its capability to control the reactor's power output to prevent, or rapidly deal with, overheating from coolant loss, and/or damage to the reactor fuel.

Structural integrity refers to the strength and viability of reactor structures, especially the main containment building, under abnormal conditions arising from natural events such as earthquakes and floods, or man-made events such as aircraft impacts, terrorist attacks and acts of sabotage.

In the context of OPG's environmental impact statement (EIS) for Darlington new nuclear build we are dealing with new and unproven reactor designs: the ACR-1000; the AP1000 and the EPR. Thus the issue of nuclear safety becomes one of predicting each design's performance under normal and abnormal operating conditions.

The nature and validity of such predictions will be discussed below, but first it is of value to consider OPG's track record as the principal nuclear reactor operator here in Ontario. A review of OPG's past performance at the helm of a fleet of up to 20 large CANDU reactors is especially pertinent to the present discussion because two of the proposed *(and favored!)* designs for the Darlington new build are

CANDU reactors – albeit of a "modified" (CANDU-6) or "advanced" (ACR-1000) design.

Thus we begin our discussion of nuclear safety for new reactors with a survey of the past performance of OPG's existing reactors.

2.0 The Safety and Reliability of OPG's Current Fleet of CANDUs

OPG and its predecessor, Ontario Hydro, began operating large CANDU reactors in the early 1970s with four 500 MW units at Pickering NGS. Four 750 MW units were added in the period 1978-1980 at Bruce NGS, and four 880 MW units were added at Darlington NGS from 1990 to 1993.

Regrettably, the performance of these nuclear stations gradually and inexorably declined as each CANDU unit aged. In fact, by the year 2000, the state of Ontario's nuclear reactors was so poor it prompted Ron Osborne, then President and CEO of OPG, to declare in a speech made in Toronto on May 9th 2000:

> *"If you think about nuclear operations as we sit here today, it's an open book that Ontario Hydro became sloppy in the way it ran nuclear plants. The evidence is crystal clear, whether it's there in AECB reports, (our regulator in Ottawa), or whether it's there in WANO, (The World Association of Nuclear Operators), peer review reports, etc. The evidence is crystal clear: we may have been the leader of the pack on the nuclear front back in the 70s but by the end of the 80s we had clearly lost that position. And as we sit here today we are holding up the back of the pack in terms of nuclear excellence…."*

While it is arguable that many of OPG's problems with its fleet of CANDU reactors may be traced to poor management, it is undeniable that most of the performance failures in the period 1980 to 2000 are attributable to questionable design and/or poor construction of many important reactor systems. Some of these are discussed below.

2.1. The Annulus Gas System

OPG's original CANDU reactors used nitrogen gas (N_2) to fill their annulus gas systems. (The nitrogen gas served as a buffer between the pressure tubes, in contact with superheated heavy water coolant, and the calandria tubes, in contact with the unpressurized heavy water moderator).

Unfortunately no one at AECL recognized the fact that the non-radioactive nitrogen would undergo neutron activation to produce vast quantities of radioactive carbon-14 (C-14) particulate.

As late as 1981 researchers at AECL's Chalk River Research Establishment insisted that solid C-14 was *not* present in the annulus gas systems of the Pickering reactors. Unfortunately for AECL's experts on this topic, *we now know that thousand of Curies of carbon-14 particulate were produced in all Pickering Units!*

By the late 1980s OPG started to use CO_2 (carbon dioxide) to fill its annulus gas systems (AGS) to limit the production of carbon-14. However it was soon discovered that CO_2 was not without its own operational problems.

Thus it was frequently observed that a viscous yellow deposit collected in flow rotameters used to adjust the annulus gas flow, causing flow blockages. The yellow deposit was shown to be a complex mixture of carboxylic acids derived from CO (carbon monoxide) which was produced in turn by CO_2 radiolysis (i.e. radiation-induced ion formation).

OPG's CANDU reactor operators rely on the measurement of water vapor in their annulus gas systems (AGS) for the timely detection of small pressure tube leaks. These measurements were inhibited by blockages created by the yellow deposits. So, in order to prevent deposit formation, batch additions of oxygen gas (O_2) were made to the AGS of OPG's reactors starting in 1990.

Then in 1991, as part of the post-LSFCR (Large Scale Fuel Channel Replacement) re-commissioning of Pickering 'A', it was deemed necessary to test the capability of the equipment to detect pressure tube leaks in a selected Unit.

The idea was to verify the accuracy of the moisture measurements in the AGS following a controlled injection of moisture. A series of such leak detection tests was accordingly carried out on Pickering 'A' Unit 3 (P3) while that Unit was operating at 1 percent nominal power.

A typical test involved the injection of D_2O into the external AGS circuit, to simulate a pressure tube leak in the range of 20 grams per hour.

Previous tests of this type had been successfully carried out on other Units at Pickering and Darlington in the late 1980's. It therefore came as a complete surprise when the P3 AGS response to moisture injection fell well below expectations. For example, after 5 hours of continuous D_2O injection, a dew-point meter response equivalent to only 25 percent of the expected water vapor concentration was measured.

Additional tests of the P3 AGS response to helium injections indicated that the injected water vapor was probably being held up within the AGS pipe-work by some type of adsorption phenomenon.

Confirmation of this hypothesis was provided by subsequent tests of the purge dry-down response of the P3 AGS. Sluggish system response to the dry-down was observed and was attributed to the slow *desorption* of water from sites that had previously adsorbed water vapor from a moisture laden gas stream.

It is ironic that a report to the 12th Annual CNS Conference in 1991 on the status of the P3 AGS, *presented just prior to the tests discussed above*, confidently asserted that moisture injection test for P3 were *not* required because *"previous tests for Pickering unit 1 AGS in 1987 and Darlington Unit 2 AGS in 1989 have already validated (OPG's) dew point code."*

It is now known that the main reason for the sluggish response of the P3 AGS during the July 1991 moisture injection tests was the build-up of a large amount of corrosion product that had become scattered throughout the pipe work of this system since the early 1970's.

The source of a good portion of that P3 AGS corrosion product is now believed to be the carbon steel shielding sleeves and bearing journals located between the stainless steel lattice tubes and end-fittings in each fuel channel.

In fact, it is well documented that in the period 1973 to 1975 the P3 AGS was subject to significant D_2O in-leakage. Station records show that the D_2O in-leakage problem in P3 was so severe that the entire AGS was flooded a number of times and the carbon steel components in many lattice tubes were subjected to significant periods of severe corrosive attack.
These unanticipated bouts of corrosion generated substantial quantities of poorly adherent hydrated iron oxide (rust) in the affected fuel channels.

Because of the inaccessibility of much of the pipe work, the full extent of the cumulative corrosion damage to the P3 AGS remains uncertain even now. However, it is probable that, by the time of the start of the P3 LSFCR (Large Scale Fuel Channel Replacement) in the fall of 1989, kilogram quantities of non-adherent rust particulate had accumulated in the P3 AGS.

This estimate is based on observations of the quantities of loose particulate material in individual components, such as the pigtails and metal-bellows seals, which were opened and inspected during the P3 LSFCR.

Furthermore, as was reported in the CNS Conference paper noted above: *"vacuuming the material was not very successful"*. Thus, even *after* the P3 reactor was returned to service in the fall of 1991, the majority of the pre-LSFCR corrosion debris remained in the AGS.

2.2 The Pressure Tubes

Pressure tube problems have plagued CANDU reactors since the early days of Pickering NGS in the mid 1970s.

OPG, NBP (New Brunswick Power), AECL and other members of COG (the CANDU Owners Group) have collectively spent over $100 million on pressure tube research and development in the past 20 years but achieved only marginal improvements in pressure tube performance.

There have been problems with leakage at the pressure tube rolled joints, neutron induced creep of in-core pressure tube sections (leading to sagging), pressure tube embrittlement and hydride blister formation caused by excessive hydrogen pickup, and localized fretting corrosion.

Starting in 1974 many individual pressure tubes were replaced in Pickering and Bruce Units, typically involving outages of several months and a dose commitment of about 10 man-rem per tube.

In August 1983 pressure tube G16 in Pickering Unit 2 suffered a catastrophic rupture and the decision was made to replace the full complement of 390 pressure tubes in all four Pickering "A" Units. One would expect that after OPG and AECL fixed all these early problems, CANDU pressure tubes would provide many years of trouble-free service. Indeed, the CNSC stipulates that nuclear pressure boundary materials meet stringent inspection codes as a licensing requirement.

Unfortunately, the complexity and inconsistent results of pressure tube inspections over the past 25 years leave the question of future CANDU pressure tube performance still very much in doubt.

In the CNSC's 2004 *Reason for Decision* on Bruce 'A' there is a section, albeit a very short one, that discusses the issue of pressure tube integrity. However, the perfunctory discussion offered by the CNSC fails to deal with, or even mention, some very important observations concerning Bruce 'A' pressure tubes. A small sampling of these observations is given below:

- Anomalous eddy current (EC) scans for a number of Unit 4 pressure tubes during SLAR inspections carried out in 1993.
- Some EC scans near the center of channel B4O13 that were so noisy it was impossible to reliably locate the spacers. The noisy EC signal was attributed to *either* very thick oxides *or* magnetite deposits.

- SLAR UT blister detection inspections, also carried out in 1994, produced highly variable signals that were shown to be caused by interferences from lubricant and/or adhesive contaminants.
- Metallographic sectioning of removed tubes carried out in 1993 - '94 showed *some* very thick patches of oxide on ID surfaces close to mid-bundle positions. Other sections that were predicted to have thick patchy oxides on the basis of EC inspections, were found to have thin uniform oxides.
- Data on deuterium uptake by Bruce pressure tubes are largely derived from scrape samples taken from "scrape campaigns" first undertaken on Unit 3 in October 1988. By 1993 it was realized that all previous scrape data were essentially worthless because of oxide contamination of the samples.
- Scrapes taken from pressure tube outlet regions of Unit 3 in 1994 were higher than predicted by the current AECL/OPG deuterium uptake model. The model was therefore revised to accommodate the new data.
- Re-scraping of Bruce 3 tubes in 1996 showed a *decline* in deuterium levels. AECL/OPG declared that the 1994 data were obviously in error and should not be included in deuterium uptake prediction calculations.

These observations raise serious concerns about the reliability of the inspection procedures used for pressure tubes in Bruce Units and undermine any belief in the long-term integrity of the pressure tubes in all CANDU reactors.

Certainly, as a veteran of many years of research into pressure tube corrosion and hydrogen pickup, I can attest to the poor level of mechanistic understanding of pressure tube behavior inside a CANDU fuel channel in spite of efforts by literally hundreds of scientists and engineers worldwide.

I have also been witness to the reporting of falsified data for some of OPG's pressure tubes from Pickering NGS – a situation I reported to OPG management in 1995 (and to the CNSC subsequently) but that has yet to be rectified.

The CANDU research community is unable to account for another unexpected problem observed in a number of Bruce "A' fuel channels: namely, thick oxide patches in high flux regions of the core.

The true extent of this problem is largely unknown – and our ignorance is compounded by the phenomenon of oxide spalling, which is known to have occurred in Bruce 'A' Units. Measurements on heat transport system particulate from Bruce Unit 3 indicate that several *kilograms* of pressure tube oxide have been released to the coolant over 15 years of operation.

An additional observation that should give added cause for concern to the operators and regulators of CANDU reactors is the detection of lithium-6 *enrichment* and beryllium deposition within the oxide patches formed in high-flux areas of some tubes removed from Bruce reactors.

2.3. The Feeder Pipes

Feeder pipe cracking and wall thinning was first discovered in CANDU reactors in the 600 MW(e) Unit at Point Lepreau in 1997. Subsequent studies have shown that wall thinning is widespread in CANDU outlet feeders and this problem has become a very serious issue for OPG's aging fleet of reactors.

The wall thinning observed in CANDU reactors is generally attributed to flow accelerated corrosion (FAC). Studies have shown that FAC is most likely to occur at tight bends in carbon steel piping carrying high temperature water at high flow velocities – a condition present at the first elbow of every outlet feeder pipe in CANDU reactors.

FAC in Pickering "A" Units has been particularly severe for two reasons:

(i) The use of carbon steel containing less than optimum chromium.

(ii) The use of aggressive decontamination reagents in the mid 1980's

CANDU reactors built before 2000 use feeder pipes that were fabricated from relatively low grade SA-106 *Grade B* carbon steel that is very prone to flow-accelerated corrosion (FAC) and/or stress corrosion cracking (SCC).

SA-106 steel is about 98 percent iron with small specified additions of C (carbon), Si (silicon), S (sulphur), P (phosphorus) and Mn (manganese) - a steel that is not particularly corrosion resistant. Thus chromium, a metal that is known to passivate steels, is *not* specified for SA-106 Grade B pipes and is only present in trace amounts - typically less than 0.1 percent.

The thinning of the feeder pipe bends in CANDU reactors is exacerbated by the tendency of the pipes to become somewhat crimped during the pipe fabrication process. However, the precise degree of this initial thinning is variable and largely unpredictable.

Consequently every CANDU feeder pipe “elbow” begins its in-service operation with an unknown initial wall thickness at a critical, life limiting location. This means that wall thickness measurements undertaken since 1997, do not allow a meaningful thinning *rate* to be determined - a quantity that must be measured with reasonable precision and accuracy for the fitness-for-service timeline of a feeder to be determined.

Nevertheless, wall thickness data that were available for Pickering ‘A’ Units by 2005 showed a significant number of outlet feeder pipes were already close to the acceptable minimum thickness limit for SA 106-B carbon steel. The pipes so identified have to be immediately replaced – a task involving considerable cost, and with a major radiation dose commitment to the personnel involved.

However, as we have seen, the root cause of the most serious problems with CANDU feeder pipes is the basic design and construction of first-generation CANDU reactors such as those at Pickering (8 Units), Bruce (8 Units) and Darlington (4 Units). This design requires a feeder pipe to be connected to every inlet and outlet of a large array of pressure tubes.

Thus, for example, the 4 Units at Pickering “B” each employ 380 inlet and 380 outlet feeder pipes that are crammed together in rows at the reactor faces, adding over 50 tonnes of intricate pipe-work that requires constant monitoring and maintenance.

There *are* techniques that could possibly mitigate against the potentially disastrous effects of severe FAC in low-chromium feeder pipes. These include the maintenance of high pH and low dissolved O_2 in the primary heat transport D_2O or the use of corrosion inhibitors such as TiO_2, but these techniques remain largely unproven.

Thus OPG is faced with the unfortunate reality that, short of a large-scale feeder pipe replacement project, the only option for the continued safe operation of Pickering reactors is a program of regular and intensive feeder pipe fitness-for-service inspections with feeder pipe replacement where necessary.

Now OPG has *always* been obligated to carry out regular feeder pipe inspections as a requirement of the nuclear inspection standard CSA N285.4. But let's consider what standard CSA N285.4 has to say about feeder pipe inspections.

However, to do this properly for the past 20-years of operation of PNGS "B" Units we need to look at the version of CSA N285.4 written in 1994, 3 years *before* wall thinning in carbon steel piping was recognized as a problem in CANDU reactors. In addition, when we look at this document, we need to remember it was this version of CSA N285.4 that was being used by the Canadian nuclear industry from 1994 to as late as 2005.

It turns out that the pre-June 2005 CSA N285.4 standard was almost exclusively focused on *pressure tube* inspection requirements and had no more than *two pages (out of forty-five)* dealing specifically with *feeder pipe* inspections. Hence, for many years, CSA N285.4 was hopelessly inadequate for the purpose of detecting excessive feeder pipe thinning in CANDU reactors.

To understand just how poor CSA N285.4 was as a feeder pipe inspection regulation one only has to look at some of its key requirements:

Section 7.4.7.2: Specifies that feeder pipe inspections should be carried out: *"at locations considered to have the highest erosion/corrosion rates."*

This specification is inadequate because the Canadian nuclear industry has long assumed *without proof* that the highest erosion/corrosion rates in CANDU feeders are to be found at the <u>extrados</u> (outer curve) of the first elbow. Unfortunately, the first direct wall thickness measurements on feeders removed from a Pickering Unit early in 2005 found the highest erosion/corrosion rates at the <u>intrados</u> (inner curve) of the pipe elbow, a location that has never needed to be inspected under CSA N285.4.

Section 7.6: Specifies that *"Repeat inspections shall be made within a 5-year period."*

This specification is inadequate because thinning rates up to 200 µm/year are now known to be possible in CANDU outlet feeders and this would take many Pickering "A" feeders beyond the fitness-for-service guideline of 40% wall thinning *well before 2010*.

Sections 13.2 and 13.3: Specify that *"a minimum of 10 locations (per Unit) shall be chosen from those which are accessible and these locations shall be subjected to periodic inspection."*

Thus, in the 1994 version of N285.4, the CSA assumed that 10 feeders would constitute a representative sample even though this accounts for less than 3 % of the total number of outlet feeders in a large CANDU reactor.

All of this is in sharp contrast to what OPG now has to say about the statistics of feeder pipe inspections. In OPG's *Feeder Piping Aging Management Strategy and Plan* report issued in late 2005, we read:

> *"During the spring 2004 Pickering Unit 8 outage, a thin area slightly below the current required thickness of 3.3 mm on a 2.0-inch feeder (N21W) was found. A similar thickness was also found in the Fall 2004 outage on Unit 7 feeder B09E. These results suggest that isolated feeders may deviate significantly from the rest of the population.*

> *The only means of detecting such 'outliers', since they are not predictable, is to perform a 100 % inspection."*

But we need to ask: has OPG *ever* managed to inspect 100 percent of the PNGS "B" feeders? The answer to this question is simply no – not even close!

And the reason for this failure to achieve the requisite 100 percent inspection of feeder pipes is not due to cost/time restraints. No indeed! 100 percent inspection of feeders is a target that OPG is unable to meet *because of two factors that are inherent in the CANDU reactor design*: the inaccessibility of many feeder pipe bends (due to overcrowding of the pipes) and the high radiation fields associated with locations close to the face of a recently shut down reactor.

The build up of high radiation fields at the face of a large CANDU reactor has been a significant problem with all Pickering "A" & "B" Units since the early 1980s. Thus, for example, the radiation field one meter from the face of Pickering Unit 3 prior to decontamination efforts in 1989 was over 2.0 Rem/hr.

And it is important to note that a full feeder pipe inspection campaign requires a lot more than wall thickness measurements. The clearance between adjacent feeders and other reactor face components – such as yokes and Grayloc hubs – needs to be checked.

In addition, feeders require close inspection for the presence of cracks, especially at bends and welds. In many instances, however, OPG has admitted that feeder pipe welds that *should* have been inspected were not, simply due to the presence of high radiation fields.

For example, in the 2005 feeder inspection campaign at Pickering Unit 5, although 42 welds were scoped for crack inspection, 14 were not examined because the contact fields were too high (greater than 1.1 Rem/hr).

And this raises the troublesome issue of the high radiation dose to the crews that carry out feeder pipe inspections. A feeder inspection campaign takes well over a month to complete and typically results in significant radiation exposures (0.2 to 0.5 Rem) to more than 50 personnel.

The 2005 inspection of the feeders in just two PNGS "A" Units resulted in a collective occupational whole body dose of 153 Rem. Furthermore, OPG records show that feeder pipe inspection crews *are mostly non-OPG contract workers*.

It is ironic that while OPG claims that Pickering is implementing a comprehensive ALARA (As Low As Reasonably Achievable) strategy to minimize radiation dose, *OPG applies this approach at the expense of non-OPG contractors*.

Most nuclear reactor operators strive to avoid such discriminatory practices. For example it was stated by J. Weston, at the 1995 BNES Conference on Radiation Dose Management in the Nuclear Industry, "that it has always been the policy of (the British) Nuclear Electric to treat contract staff the same way as its own employees".

Weston backs up his claim by noting that the maximum radiation dose received at Hinkley Point in1994 was 0.584 Rem for an employee, and 0.476 Rem for a contractor. By comparison, the maximum dose from the OPG P5 feeder pipe inspection campaign of 2005 was 0.284 Rem for an OPG employee and 0.516 Rem for a contractor.

It is also important to note that when OPG inspection campaigns discover feeder pipes that fail to meet the wall thickness requirements specified in CSA N285.4, the thinned sections must be removed and replaced – an operation known as "cut and weld". This task is discussed in OPG's 2005 *Feeder Piping Aging Management Strategy and Plan* report as follows:

> *"The feeder replacement techniques that have been used in the past are totally inadequate for replacing feeders on anything but a very small scale. Present feeder replacement can only be carried out in a regular outage, by freezing the feeder at the appropriate locations, cutting out the section of pipe and replacing it. This may require other feeders to be removed in order to gain access to the section of feeder pipe to be replaced. If more than a few feeders have to be replaced, this quickly becomes an extremely difficult task in terms of time and dose expenditure."*

To add to the litany of woes with feeder pipe replacements in OPG's CANDU reactors it has been reported that preferential corrosion occurs at feeder pipe welds and that stress corrosion cracking at such welds is a concern because the fracture would be circumferential and could lead to a guillotine type of failure.

Furthermore, OPG has not validated its FEA model predictions for stress intensities or "leak-before-break" behavior in feeders with pipe-to-pipe welds – something that could be accomplished, for example, by using strain gauges to monitor *in situ* stresses and deformations of field welds.

This is important for PNGS "B" feeder bends because the bends were fabricated by cold bending without any subsequent stress relief.

2.4 CANDU Operations in Canada, 1970 to 2010: Summary & Conclusions

The 40-year track record of OPG's original fleet of 20 CANDU reactors shows that corrosion and other degradation processes have plagued all of the important pressure boundaries – especially the feeder pipes and pressure tubes – in the primary reactor circuits.

And, as many well-documented examples show, the day-to-day operation of the reactors at Pickering, Bruce and Darlington has been fraught with many problems and difficulties that amply illustrate the inability of the designer (AECL), the operator (OPG) and the regulator (CNSC) to predict the long-term performance of these Units.

Indeed, we observe the same story being repeated over and over again – a story which goes like this: AECL designs the original reactor systems and components and selects *what it believes* to be the most appropriate alloys and fabrication technologies.

Multi-Unit stations are then built under AECL's supervision and operated by OPG. Sometimes the new Units perform well – but inevitably, after several years, problems start to develop. In many cases, the severity of these problems is found to be far greater than predicted, or the problems were not anticipated at all. At this point the CNSC becomes involved in deciding how to proceed and a strategy to deal with the problem(s) is developed and implemented.

This "fix-it-on-the fly" approach to reactor operations and maintenance makes a mockery of claims that CANDU reactors embody a safe, mature, technology.

On the contrary, the seriousness of some of the problems with OPG's reactors has taken many years to be recognized and additional years of research to understand and remedy. In many cases, such as the on-going problems with annulus gas systems, pressure tubes, and feeder pipes, no definitive consensus on the cause of flow blockages, cracking or material degradation has been reached. As a consequence, potential solutions to such problems are usually tentative and experimental.

Furthermore, in some cases, internal damage has proved to be so severe and expensive to repair – as in the case of Pickering Units 2 and 3 – OPG has simply abandoned the reactors altogether, even though the Units in question were well short of their predicted life expectancy.

Given the fact that the some or all of the same players (AECL, OPG, and the CNSC) will be involved in the design, construction, operation and regulation of the proposed new nuclear reactors at Darlington, I see no reason to expect any changes to Canada's "fix-it-on-the-fly" approach to nuclear safety.

3.0 Potential Accident Scenarios: Darlington New Build Reactors

As stated by A. V. Nero in his "*Guidebook to Nuclear Reactors*":

> "*The fundamental design goal* [of a nuclear reactor] *is to prevent any transient, including a loss of coolant accident (LOCA), from leading to damage to the fuel, particularly breaching of the fuel cladding or melting of the fuel. Two capabilities are fundamental to preventing such damage: the ability to shut down the chain reaction rapidly and dependably when required, and cooling systems with*

> *enough redundancy and capacity to carry away the heat generated in the reactor core.*"

The first of these requirements, namely the need for rapid reactor shutdown, is particularly pertinent to CANDU reactors because the physical separation of coolant and moderator–- inherent to the CANDU design – creates a positive coolant void reactivity feedback.

[In plain English, this means that if the cooling water suddenly escapes – or boils – to form "voids" (empty spaces or steam bubbles), then the nuclear chain reaction speeds up.]

This feature of the CANDU, as admitted by the CNSC, "*leads to challenges in anticipated operational occurrences and design basis accidents where core void increases as a result of the initiating event*."

The ability to safely control a reactor is measured by the reactor period T, which is the time required for the neutron flux to increase by a factor of 2.72. The longer a reactor's period is, the easier it is to control. Conversely, a short reactor period, say less than one second, makes the possibility of a runaway power surge – capable of destroying the core of the reactor, thereby releasing large quantities of radionuclides – a serious concern.

Technically speaking, the ability to control the reactivity of any large nuclear reactor depends on the delayed production (by up to 20 seconds) of some of the U-235 fission-produced neutrons. These are the so-called "delayed neutrons".

"Prompt neutrons", on the other hand, are produced almost instantaneously – much too fast for any mechanical apparatus to intervene in time to stop them. In order to keep a reactor under control, the number of "prompt neutrons" must remain below a certain level; if the prompt neutrons increase beyond that level, the reactor is said to go "prompt critical" and will inevitably self-destruct.

Loss of coolant by a CANDU reactor (due to a pipe break for example) causes an immediate increase in the reactivity of the system measured to be several milli-k. This is mainly because of an increase in the number of prompt neutrons compared with the number of delayed neutrons.

Under normal operating conditions, with full coolant flow, a CANDU reactor's fission power is controlled by limiting the number of delayed neutrons. But in the event of a LOCA, the prompt neutron contribution to the reactivity multiplies rapidly and boosts the overall reactivity at rates of one milli-k per second or more – too fast for the normal control mechanisms to respond.

Under such circumstances the reactor may rapidly become "prompt-critical". It is therefore essential to be able to safely shut down or "scram" such a potentially runaway reactor in the time available.

This may be done, for example, by tripping the power to the electromagnetic clutches holding the primary shutdown system (SDS1) of 20 or more spring-loaded shut-off rods. When these rods are plunged into the core of the reactor they will absorb most of the surplus neutrons and shut the reactor down quickly.

It has been reported (2005) that a large LOCA at a Bruce reactor involving full-core voiding could add up to 6 milli-k of reactivity within two seconds. This would produce a power pulse in the reactor core peaking at about 5 times normal power in a time interval of about 2 seconds.

It is claimed in AECL and OPG reactor safety studies that significant negative reactivity insertion may be accomplished in a typical CANDU reactor within 0.6 seconds of trip. This is accomplished using spring-loaded gravity driven absorber rods triggered by fast-response flux detectors.

However, it should be noted that core heating caused by a LOCA also changes the effective neutron absorption and fission characteristics of the natural uranium fuel. With all these variables at play it is quite possible that fuel melting could begin within 2 seconds of a LOCA.

This remark is consistent with the CNSC Regulatory Guide on this issue given in "Trip Parameter Acceptance Criteria for the Safety Analysis of CANDU Nuclear Power Plants" (See CNSC document

G-144, May, 2006)). Here we read that the shutdown system rod insertion rate must be 1.5 seconds or less to prevent fuel melting.

The CNSC was for many years quite consistent in its public declarations on the positive void reactivity coefficient problem with CANDU reactors. Thus in 2007 in its *Annual Report on the Safety Performance of the Canadian Nuclear Power Industry*, we read:

> *"A loss of regulation (LOR), a loss of flow and a loss of coolant accident (LOCA) are made more severe by positive feedback. Among these accident scenarios, a large LOCA is the most difficult accident to analyze for a CANDU reactor, because many aspects of the reactor behavior under accident conditions, and its computer modeling, are subject to considerable uncertainties."*

The CNSC discussed the issue of positive void reactivity uncertainty again in 2008 in its *Integrated Safety Assessment for Canadian Nuclear Power Plants* under the heading "Generic Action Item 95G04":

> *"Accuracy of void reactivity calculations is a significant safety issue in the analysis of design basis accidents involving channel voiding, especially for large LOCAs. Uncertainties and safety margin adequacy are the main questions."*

The CNSC also noted that closure to this issue depends on the final recommendations by a joint industry/CNSC team. However, the CSNC was unable to provide an anticipated closure date, suggesting that it is the industry half of the "industry/CNSC team" that is setting the pace on this issue.

Remarkably however, by July 2009, the CNSC expressed a complete reversal of its position on this issue in its E-DOCS # 3399585, *Technical Note: Positive Coolant Void Reactivity Feedback Phenomenon in Currently Operating CANDU Reactors*:

> *"The existence of the positive coolant void reactivity feedback effect in CANDU reactors has been known to both the designers and the CNSC since the first CANDU commercial reactors.* ***The phenomenon is well understood*** *– Over the years, this phenomenon has been the object of close scrutiny by CNSC staff*

> *and the nuclear industry, and has been the object of numerous research and development activities. By now this phenomenon is well understood"*

Nevertheless, just one month later, in August 2009, the CNSC revealed its *true* position on the void reactivity coefficient issue in the internal document E-DOC # 3413831, *Application of the CNSC Risk-informed Decision Making Process to Category 3 CANDU Safety Issues*:

> *"It is important that safety analyses account for the positive void coefficient of reactivity in a conservative manner, which requires the assessment of the accuracy in determination of this coefficient. However, the current validation of the theoretical models and computer codes used by the CANDU industry are such that errors associated with void reactivity calculations are not well defined due to lack of specific experimental data at in-reactor operating conditions and fuel burn-up.*
>
> *Inadequate knowledge of the uncertainties in models and data used to predict the key phenomena increases the risk that consequences of a limiting large break LOCA could be greater than those currently estimated in plant Safety Reports. Large Break LOCA is of interest because it is the design basis event for shutdown systems and emergency core-cooling systems. However, the increased magnitude of void reactivity is potentially of concern for predicted consequences of other relatively high frequency events such as LOR, etc…."*

In the CNSC's E-DOC # 3413831 we find a discussion of other safety concerns related to large LOCA events where it is acknowledged that there is insufficient information on fuel behavior under channel voiding conditions to predict safety margins *and the radiological risk to the public* – in other words: <u>*The environmental impact of a large LOCA remains indeterminate*</u>.

4.0 OPG's EIS documentation on nuclear accidents is unacceptable

One of the most serious problems with OPG's Darlington new build EIS may be found in its position (described in TSD-27) on the radiological effects of potential nuclear accidents at one of the new reactors.

OPG states that the CNSC's RD-337 safety goals were used to make a preliminary assessment of the environmental impact of the new reactors, and add:

> *"The selected reactor technology will undergo a thorough review of its design and safety analyses by the CNSC during licensing. It will be demonstrated during that time that CNSC Regulatory require-ements, particularly those relating to nuclear safety, are met**."***

There are at least two problems with this statement:

(i) When we look at how OPG obtains compliance with RD-337 we find an exercise in reverse engineering in which "*a stylized accident radioactive release scenario*" is analyzed. The analysis uses *assumed* portions of the reactor core inventory that correspond to the I-131 (iodine-131) and Cs-137 (cesium-137) releases stipulated in RD-337. These portions turn out to be very small fractions – about 0.02 percent for I-131 and 0.01 percent for Cs-137 – of the core inventories. In addition, OPG *assumes* that reactor containment is not breached for 24 hours after an initiating event, artificially allowing short-lived isotopes such as Te-132 (tellurium-132), I-132 (iodine-132), Xe-133 (xenon-133) and Xe-135 (xenon-135) to decay. I therefore ask OPG or the CNSC to justify the use of this 24-hour delay and also to justify the fractions of the core inventories *assumed* to be released for each radioisotope.

(ii) OPG is presumptive in assuming that a more detailed accident analysis by the CNSC "*will demonstrate that all RD-337 regulatory requirements are met*." Here we see OPG deviating from the quantitative estimation process required for a true environmental assessment of the radiological footprint of new nuclear build at Darlington, and entering instead into the realm of opinion and speculation.

But there are other problems with the nuclear accident analysis presented in OPG's TSD-27. The document fails to address many important issues. In addition, parts of the document lack supporting evidence for some of the claims it makes. Some examples of the problems with TSD-27 are:

(i) On page 2-2 of TSD-27, OPG takes the position that relying on the performance of Ontario's existing CANDUs is <u>not</u> a valid approach to accident analysis - the argument being that once a nuclear accident happens, or is *predicted* to happen, the necessary steps are taken to prevent it from (re)-occurring. Nevertheless, OPG states on the same page that: "o*perating experience and other relevant information from existing OPG nuclear stations <u>was used</u> to support the development of accident scenarios for EA purposes*." (Emphasis added)

(ii) On page 4-6 of TSD-27 OPG claims that *the fundamental causes of nuclear accidents are well understood and an extensive body of knowledge and expertise exists in Canada.* In fact there is a dearth of knowledge and information on possible initiating events and the probable progression of a large LOCA. Once a fuel channel has lost water, dried out and heated up, (which may take place in a matter of seconds), the timing of operator actions that could potentially propagate or terminate the sequence of core damage states is highly uncertain. This is especially important for the ACR-1000, which incorporates a moderator that is physically separated from the coolant. During a large LOCA in an ACR it is possible that the emergency core cooling will be ineffectual or simply unavailable so that the moderator will boil dry and allow the fuel to attain extremely high temperatures of more than 1000 C. Under these conditions a large fraction of the fuel cladding will fail due to internal pressurization, rapid oxidation and/or embrittlement. The subsequent behavior of the molten mixture of fuel, zirconium cladding and pressure tube material, referred to as *corium*, is largely speculative but may involve a spontaneous in-vessel or ex-vessel explosion. The CNSC has in fact expressed its concern, (Section 7.9 of E-Doc # 3413831 issued Aug 2009), over the uncertainties in molten-fuel/moderator interactions during a large LOCA.

(iii) OPG admit that in order to satisfy the CNSC's RD-337 safety goals, "*a somewhat conceptual*" and "*stylized accident scenario was created*". However, even though an environmental release of an assumed magnitude is postulated, the initiating event is never explained or described in detail. In addition the role of operator actions on the outcome of an at-power initiating event is known to be a major contributor to subsequent core damage. Indeed, Westinghouse has estimated that the core damage frequency of an AP1000 increases by a factor of about 50 if a LOCA takes place with inappropriate or no operator intervention. I would therefore ask OPG to provide details of the postulated accident, such as a break location, type and size, that was used to specify the initiating event and sequence of failures in its accident analysis. I would also ask OPG to provide details of the plant operating mode prior to and immediately after the initiating event; the assumed availability and performance of backup systems and equipment and operator actions or inactions which could affect the results of the analysis. Finally, I would ask OPG to provide the rationale used to select the initiating event and accident progression, and to clarify if the LOCA analysis selected a break location using probabilistic arguments or on the basis of a break location that would maximize accident consequences.

(iv) OPG use the computer code MACCS2 to evaluate the off-site consequences of a reactor accident that releases a radioactive plume to the atmosphere. The resulting radiological doses are then used to evaluate the need for temporary evacuation and/or permanent relocation of the population around the Darlington site. Nevertheless, minimal information is provided in TSD-27 on the assumptions and data inputs used in the application of the MACCS2 code. For example, OPG assumes, without providing any rationale, that the accident airborne release will be a continuous plume lasting 72 hours and calculates that the 7-day dose at a location 10 km from the Darlington site will be 1 mSv. This calculated dose is highly questionable when we look at other independent estimates of the radiological consequences of some postulated accident scenarios for large nuclear power facilities. For example, the Romanian Authority for Nuclear Activities (RAAN) has used the MACCS2 code to evaluate doses from a predicted LOCA in a CANDU 6 - a reactor that is quite representative of so-called "third generation" CANDU technology. The RAAN study published in 2003 predicts a dose of about 100 mSv at a location 10 km from the postulated accident site – *a dose that is <u>100 times higher</u> than OPG's TSD-27 estimate*.

(v) AECL uses a version of the MAAP code (Modular Accident Analysis Program) for its accident analysis. This code was developed and accepted by the US NRC for use with LWRs, but has *<u>not</u>* been validated for use with heavy water moderated reactors such as the ARC-1000. Also it appears that AECL and OPG have not considered tritium emissions from an ACR-1000 in the event of a LOCA. I would therefore ask OPG to address this issue and provide data on projected tritium emissions from an ACR-1000 following a LOCA.

(vi) In the regulatory document RD-337 the CNSC specifies quantitative safety goals for new plants based on estimates of core damage frequencies (CDFs). The RD-337 document also stipulates that a safety analysis should consider "*all credible events involving component and system failures or malfunctions*". The U.S. NRC utilizes a set of risk models that are <u>standardized</u> based on U.S. industry-average performance of components and initiating events at nuclear power plants in the U.S. (See for example: NUREG/CR-6928, published Feb, 2007). With *three* vendors bidding on the Darlington new nuclear build, involving three countries subject to different regulatory agencies, I would ask OPG to explain how it arrived at a unified set of meaningful CDFs for the three reactors under consideration.

(vii) The CNSC requires through its regulation RD-337 that, in the absence of protective measures, the effective dose at the Darlington site exclusion area boundary (EAB) should not exceed 20 mSv. Nevertheless, safety evaluations for the AP-

1000 and EPR reactors predict that in the event of a design basis LOCA the total effective dose equivalents will be 190 mSv (AP-1000) and 122 mSv (ERP) for an EAB at 805 meters – a dose that would approximately *double* OPG's proposed EAB of 500 meters. Similarly, the Romanian government agency ICIM has estimated (in a 2007 Environmental Impact Assessment Report) the radiological effects of a number of design basis accidents for a CANDU 6. The resulting effective doses extrapolated to a 500-meter exclusion boundary area are approximately 240 mSv for a large LOCA with containment isolation unavailable and 330 mSv for an end fitting failure with containment isolation unavailable. It is therefore quite clear that *none* of the new reactors proposed for Darlington would meet the requirements of RD-337 for an EAB of 500 meters. I would therefore ask OPG to comment on this issue.

5.0 Additional Issues:

A truly meaningful Environmental Impact Statement (EIS) for new nuclear reactors at Darlington should include an assessment of the radioactive emissions from the proposed facilities under normal and abnormal operating conditions.

While the *normal* behavior of a nuclear reactor is generally quite predictable, *abnormal* behavior by a reactor is, by definition, difficult to predict. Evidently, this uncertainty is even more pronounced with first-of-a-kind reactors such as those proposed for Darlington, and this is where OPG's EIS for Darlington is most deficient.

OPG's analysis of Darlington's proposed nuclear reactors under severe accident conditions is doubly flawed because it is based on a *specified* outcome – the release of 100 TBq of Cs-137 – to an *unspecified* and entirely hypothetical accident.

However, the details of a nuclear accident, such as the involvement of steam or hydrogen explosions, determine the chemical and physical forms of the radioactive releases and the subsequent dispersion and deposition of radioactive contamination. Hence it follows that OPG's severe accident analysis is highly questionable because it lacks sufficient detail to make meaningful radiological predictions.

Perhaps this is why a severe accident at Darlington is analyzed so superficially by OPG; evidently the intent is <u>not</u> to model credible accident scenarios but to satisfy an arbitrary safety requirement imposed by the CNSC in its document RD-337: *Design of New Nuclear Power Plants*.

But by limiting its EIS to the requirements of RD-337, it is clear that OPG has not in fact completed an environmental assessment at all; it has only completed a partial safety assessment of the proposed reactors. And I say *"partial assessment"* because so many details of the new reactor's performance under severe accident conditions remain unknown.

That compliance with RD-337 is <u>not</u> sufficient to satisfy an environmental assessment of Darlington's new reactors is confirmed by the wording of RD-337 which reveals that this document has next to nothing to say about the environmental impact of new nuclear facilities. In fact, out of the 58 pages of the RD-337 report, <u>less than one page</u> is devoted to the topic of environmental protection, and all that is said about the environmental impact of new reactors in Canada is the cryptic imperative: *"The design makes adequate provision to protect the environment …"*.

Let's consider the extent to which new nuclear reactors at Darlington could possibly "protect the environment". And in assessing how well Darlington NGS might achieve this environmental objective, we must bear in mind that nuclear reactors do not operate in isolation but as part of a larger fuel cycle that starts with uranium mining and ore processing and ends with radioactive waste disposal.

Thus the operation of new nuclear reactors at Darlington will involve unavoidable off-site activities, such as uranium mining, processing and isotope enrichment, that are known to be detrimental to the environment. For example the uranium destined to be "burned" at Darlington will be extracted from open-pit mines in northern Saskatchewan and processed at facilities in Blind River and Port Hope, Ontario. It follows that the environmental impact of new nuclear reactors at Darlington is not limited to a local area such as

Durham Region but includes locations hundreds or thousands of miles from Darlington.

According to data published by the NWMO, new reactors at Darlington will, over the course of their operating life, use approximately 12,480 tonnes of enriched uranium fuel. The initial, natural, uranium required for this fuel is extracted from Saskatchewan ore that typically contains about 2 percent uranium – leaving 98 percent of the mined material as a fine sandy waste known as "mill tailings".

Uranium mill tailings contain about 85 percent of the radioactivity in the original ore body in the form of long-lived radioisotopes such as Ra-226 (radium-226, half-life 1600 years) and Th-230 (thorium-230, half-life 76,000 years), as well as high concentrations of toxic elements such as arsenic, selenium and molybdenum. The safe disposal of uranium mine tailings is a matter of great concern; nevertheless, no proven technology yet exists for the long-term management of this noxious waste.

All of the nuclear reactors proposed for Darlington will be fuelled with uranium enriched to at least 2.5 percent U-235. This specialized nuclear material will likely be produced at the UF_6 gaseous diffusion plant in Paducah, Kentucky – one of three U.S. plants originally constructed for nuclear weapons production. The other two were at Oak Ridge, Tennessee and Piketon, Ohio.

These uranium enrichment plants are notorious for their toxic emissions and wastes. For example, the Oak Ridge plant was the subject of U.S. Senate Hearings in March 2000 over its chronic environmental emissions of HF and oxy-fluoride gases.

In addition, the UF_6 gaseous diffusion process uses thousands of tonnes of CFC-114 as an evaporative coolant that tends to escape from the diffusion cascades to the tune of 100 tonnes per enrichment plant per year. CFCs are responsible for the destruction of the ozone layer and are potent greenhouse gases as well.

Uranium enrichment also produces thousands of tonnes of *depleted* uranium hexaflouride, DUF_6, as a highly corrosive and toxic waste material. DUF_6 is stored in steel cylinders in open-air yards close to the enrichment plants – areas that have to be regularly inspected and monitored for signs of leakage.

Yet another example of how new reactors at Darlington will inevitably create chemical and radiological "footprints" at locations well beyond the 500-meter exclusion boundary area of Darlington NGS, is the shipment of large quantities of nuclear station waste to the Bruce Nuclear Power Development (BNPD) site.

What is of great concern in this regard is that much of the low and intermediate level radioactive waste, especially waste derived from OPG's nuclear operations going back to the early 1970s, is very poorly characterized with regard to its radiochemical composition.

In fact most of OPG's non-processable waste, currently stored at BNPD in warehouses, trenches, quadricells and in-ground containers, has *never* been subjected to quantitative analysis of alpha and beta activities.

This poorly characterized waste includes a wide variety of miscellaneous items containing metals, paper, plastic, oil, wood, rubber, glass, etc, as well as reactor components such as feeder pipes, pressure tubes, end-fittings, yokes, studs, irradiated fuel storage baskets, ion exchange resins and filter assemblies.

Thus we conclude that, far from "protecting the environment", new nuclear reactors at Darlington will be a major contributor to hot spots of noxious waste all over North America: from the uranium tailing ponds of Saskatchewan, to the depleted uranium dumps of Kentucky; from the uranium escaping into the fresh air and water around the Blind River UO_3 processing facility on the shores of Lake Huron, to the UF_6 hydrolysis products emitted from the Port Hope manufacturing plant on the shores of Lake Ontario; from the radioactive waste trenches and bore-holes on the rocky crags of the Bruce Peninsula, to the tritium-contaminated wells and streams in the green fields of Southern Ontario.

Is this the legacy we wish to leave our sons and daughters, and their descendents? I think not! For it's *our* nuclear waste that, sooner or later, *they* will have to deal with . . . .

Comments on OPG’s Environmental Impact Statement
For New Nuclear Build at Darlington NGS

by Michel Duguay – for le Mouvement vert Mauricie’s Intervention on the *Darlington New Build* Environmental Assessment Hearings in 2011

Reduced safety margins in CANDU nuclear reactors

1: OPG’s decision on Pickering B.

Technical safety issues have played a central role in OPG’s decision in February 2010 not to refurbish the four reactors at the Pickering B nuclear power plant.

OPG had previously encountered serious difficulties in having the CNSC approve the early part of its Integrated Safety Review (ISR). A refurbished nuclear reactor cannot be put back in operation unless its full ISR has been approved by the CNSC.

On 7 April 2008, in a letter addressed by CSNC’s T.E. Schaubel to OPG’s senior vice president Patrick McNeil (CNSC document E-Docs #3232348), CNSC staff had rejected and strongly criticised a safety analysis report that was to be part of OPG’s ISR for renewing its Pickering B operating licence and for possibly refurbishing its four CANDUs. This rejection by the CNSC made OPG realize that the CNSC was beginning to implement the new safety regulations that were formally adopted on 10 June 2008 and that have raised the Canadian nuclear safety requirements to international standards.

Another group in Ontario, the Association of Major Power Consumers in Ontario (AMPCO), has also expressed strong reservations about CANDU technology. On 21 July 2008, in written testimony presented to the Ontario Energy Board (OEB), after praising OPG for the management of its hydroelectric generation, AMPCO had declared:

> ‘’OPG’s nuclear generation facilities constitute the second, sad part of the story. The nuclear tale is a tragedy featuring a long, sorry litany of technological and operational failures characterized by prolonged inferior performance at exorbitant and rapidly escalating costs – all of which fall upon Ontario

> ratepayers. This dismal situation has led AMPCO to conclude that OPG's nuclear business is a story that is more akin to an exercise in palliative care of uneconomic and unsustainable CANDU technology as opposed to reflecting a business unit characterized and driven by economic sustainability and renewal.''

This citation is taken from paragraph 3 in the document identified by the OEB file number EB-2007-0905, dated 21 July 2008, corrected 25 July 2008.

2: 16 safety issues in August 2009 CNSC report

In August 2009 the CNSC completed a 268-page document (identified at the CNSC by E-Doc # 3413831) in which it described 16 safety issues that still had not been fully resolved in spite of extensive R&D work over many years. In a reply letter to Michel Duguay dated 5 May 2010, CNSC's president Dr. Michael Binder did not answer the question as to whether OPG had judged the refurbishment work to be too technically and economically demanding in the context of the 16 outstanding safety issues described in the August 2009 report. If OPG, with its considerable refurbishment experience, has found that effort unacceptable from an economic and most likely from a technical point of view, why invest in Darlington in an ''enhanced CANDU-6'' or an ''advanced CANDU'' when fundamental safety issues have not been resolved?

The fact that 16 serious safety issues with CANDUs had not been resolved as of August 2009 makes it extremely unlikely that they would be resolved in time for the Darlington new build proposal. Nuclear technology problems are never resolved overnight. On the contrary it usually takes long periods of time, measured in years and sometimes in decades, to fully resolve nuclear technical issues.

An example of a long period is the time it took to develop sufficiently capable computer software to properly model CANDU reactor physics. From its start in the early sixties it was not until year 2000 that computer simulation software and physical models were judged by the CNSC to adequately describe the neutron physics and the power dynamics of CANDU reactors. Moreover, in its 268-page August 2009 report, the CNSC is still urging the Canadian nuclear industry to further develop the new simulation software and to carry out experiments to validate it. Large uncertainties are still prevalent when the existing software is used to predict CANDU behaviour under accident conditions.

Request. The Panel should exercise critical judgment in considering the purchase of new and risky nuclear technology. The precautionary principle calls for not engaging in a new activity when there is insufficient knowledge at hand. That this is the case is very well documented in the August 2009 CNSC report.

3: Safety margins ''eroded to an unacceptable degree''

The extensive CNSC documentation on CANDU reactors expresses a range of opinions among nuclear experts from industry and from regulatory bodies in several countries. On some issues consensus is not always reached. A worrisome opinion was expressed in a recent document obtained from the CNSC by investigative journalist Gilles Provost thanks to the law of free access to information. This document, dated December 2009, is identified as COG-JP-4290-V02 and is entitled ''CNSC-Industry Working Group on Positive Reactivity Feedback and Large Break LOCA Safety Margins''. The following startling statement appears at the bottom of page 3 in Volume 1. To understand the citation one needs to know that LOE stands for *Limit of Operating Envelope*, that LBLOCA means *Large Break Loss Of Coolant Accident*, that the word ''discovery'' is used at the CNSC to denote a new finding, most often on the negative side of things, and that ''margins'' refers to *safety margins* in the operation of a reactor under normal as well as under accident conditions.

> **Citation:** ''The small margins predicted on the basis of the LOE methodology makes it susceptible to discovery issues. In particular, the analysis of LBLOCAs in Canada has been affected by periodic discoveries that have increased the predicted consequences of the event to the extent that the margins available have been eroded to an unacceptable degree.”

The expression ''eroded to an unacceptable degree'' is very strong and is repeated again in Volume 2, p. 8, of the December 2009 document.

Later on in the report the authors argue that the development and the implementation of a so-called BEAU (Best-Estimate and Uncertainty) methodology moves the calculated safety margins into a more tolerable or acceptable category. The essential difference between LOE and BEAU methodologies is that LOE assumes worst-case values for a spectrum of reactor parameters, whereas BEAU assigns random values centered on the best estimates.

One should note that one set of BEAU parameter values will fall by chance on the LOE worst-case values so that a BEAU result is only ''acceptable'' with a certain probability. The ''U'' in BEAU will remind a prudent investor of the *Uncertainty* pertaining to the calculations of safety margins with estimated reactor parameter values. Direct and precise measurements of reactor parameters are often difficult, and sometimes impossible, as is the case under accident conditions.

The margins referred to above are the safety margins against major nuclear accidents. Following a large loss of coolant accident (LOCA), for example due to a large pipe break in the high pressure system, voids would appear in the cooling water and would cause the neutron-induced nuclear fission reactions to be accelerated. This dangerous phenomenon is accounted for by what is called the CANDU's ''positive coolant void reactivity (CVR) coefficient''.

With less cooling water and accelerated nuclear reactions, a large overpower pulse is predicted to grow within about one second after the start of a large LOCA. About halfway into this one second the computer-controlled shutdown system #1 must initiate dropping neutron-absorbing rods into the reactor core in order to prevent the power pulse from melting down the reactor core. The short time scale involved and several uncertainties associated with accident conditions indicate that the calculated safety margins against a core melt accident are small, *unacceptably small* according to the statement quoted above.

The December 2009 report's authors present the counter-argument that for many types of large break loss of coolant accidents (LBLOCAs) the break does not occur instantly so that the reactor shutdown systems would have enough time (about two seconds) to terminate the power pulse before it gets too large and starts melting the uranium oxide fuel and the zirconium-niobium high-pressure tubes.

There are nevertheless types of pressure tube breaks that could be sudden, so that the expression quoted above for the LBLOCA safety margins, namely *''....eroded to an unacceptable degree''* would apply. The voluminous CNSC documentation on LBLOCAs will inform a prudent investor that CANDU nuclear reactors present a substantial risk. The full magnitude of this risk has yet to be revealed to the public and its associated probability of occurrence is estimated on the basis of calculations that are plagued with many uncertainties.

When the CNSC rejected OPG's ISR-related safety analysis report on 7 April 2008, it urged OPG to:

> ''Acknowledge the positive power coefficient and, especially, positive void reactivity feedback which is a significant shortcoming in terms of inherent safety features.''

A prudent investor will take notice of the expression ''*a significant shortcoming in terms of inherent safety features*''.

Another CNSC document is the one identified as E-DOCS # 3336957, dated August 2009 and entitled ''Information and Recommendations from Canadian Nuclear safety Commission Staff regarding Bruce Power, Approval to Reload Fuel for Bruce A Units 1 and 2, in preparation for its one-day public hearing to be held on October 1st 2009.'' In the citation below the word ''derated'' refers to a reactor power level reduced to 93% of its nominal power by order of the CNSC.

> **Citation:** ''Since the mid 1990's, Bruce A and B reactors have been derated because of issues related to the large Loss of Coolant design basis accident (LLOCA). Current predictions of energy depositions (power pulse) in the fuel during the first two seconds of this postulated event are far greater than the predictions of the early 1990s. Furthermore rates of power increases typical of prompt critical regimes are now being predicted. While the regulatory requirements continue to be met for this event, this situation has led to a reduction in large LOCA safety margins and thus to a vulnerability of the predicted consequences to discovery issues, and to concerns regarding validation of physics codes in the prompt critical regime.''

The sentence *''Furthermore rates of power increases typical of prompt critical regimes are now being predicted''* could mean the following, as an example: following a sudden large break LOCA, a large power pulse would rise in one second and in the following second the reactor core could start melting. As the CNSC 268-page August 2009 report explains, uncertainties in modeling neutron physics in the CANDU reactor core are such that the ultimate consequences of such melting are not well known. One thing is sure, however: a multibillion dollar investment would be wiped out in seconds, arguably an unacceptable outcome.

The possibility of a nuclear core meltdown has been explicitly recognized by the largest nuclear reactor manufacturer in the world, the French firm Areva. In their reactor under construction in Olkiluoto in Finland, Areva is building an EPR reactor and has installed underneath the nuclear core a so-called ''core-melt catcher'', a large metal plate that will capture and cool down a run-away core melting its way down. This will prevent the core melt from reaching the water table.

Request: If the Panel recommends a new build at Darlington then it should include a core melt catcher.

4: Positive CVR coefficient, an inherent design weakness

The fact that the CANDU's positive CVR could lead to a large power pulse capable of melting the nuclear reactor core has been worrying the Canadian nuclear community over the last ten to fifteen years, and since 2005 it has also come to the attention of the international nuclear community.

This concern has been explained in another important document obtained from the CNSC by former Radio-Canada reporter Gilles Provost through the law of access to information. This document is identified as COG-07-9012, dated August 2007, and is entitled ''Large LOCA Margins and Void Reactivity in CANDU Reactors''. Its authors were Ajit Muzumdar and Daniel Meneley.

At the time when Linda Keen was president of the CNSC this work had been initiated in response to questioning by nuclear experts who had met at the International Convention on Nuclear Safety in Vienna in 2005. On page 15 of this 139-page document the authors wrote this:

> ‘’The issue is closely linked to an inherent reactivity characteristic of CANDU reactors (viz., positive void reactivity coefficient) which leads to a power increase following a Large LOCA. This characteristic of CANDUs has been discussed at the Convention review meetings and in other international forums by other regulators, and hence is also visible to the international community. The perception of the international community that a positive void reactivity coefficient is an inherent weakness has no doubt contributed to the subject of CANDU Large LOCA safety margins being raised during periodic Convention review meetings.’’

Note the expression *inherent weakness* characterising the CANDU design.

On page 21 of this report the authors wrote the following paragraph:

> ‘’While this latter driver stemmed partly from the growing international safety analysis trend in this regard, this approach was considered particularly important to CANDU, since the safety analysis margins available under the LOE approach were (and are) exceedingly small, driven primarily by void reactivity considerations.’’

Note the reference to *exceedingly small* margins in the safety analysis.

The extensive CNSC documentation of the last few years has clearly underlined the fact that the accepted value of the positive CVR coefficient is about 50% larger than had been believed by the Canadian nuclear community prior to year 2000. A larger CVR coefficient results in a faster and larger power pulse following a LBLOCA.

On page 43 of the August 2007 report the authors Muzumdar and Meneley add the following about the CVR coefficient:

> ‘’This coefficient is extremely difficult to quantify because it is the net result of separate effects of opposite sign. It also varies considerably with fuel burn-up, and virtually no experiments are available for irradiated fuel’’.

On page 93 Muzumdar and Meneley wrote the following:

> ‘’The focus of CANDU Large LOCA analysis and code validation efforts over the past 10-15 years has been based on

> the prediction of the coolant void reactivity and the associated uncertainty of this prediction. As the predicted value of the coolant void reactivity steadily increased, the estimated safety margins gradually decreased, thus necessitating compensatory operational/design changes to retain adequate margins.''

The authors then list several changes including a reduced power level for some reactors and tighter control of ''neutron flux tilt'' (i.e. assuring a more uniform density of neutrons in the reactor core).

Finally, Muzumdar and Meneley add this:

> ''These changes have resulted in extremely narrow margins in all CANDU reactors .....In some instances, the estimated safety margins (and resulting operating margins) have decreased to the extent that safety investments are currently being considered to increase these margins for both refurbished and new build reactors.''

Note the expression ''extremely narrow margins in all CANDU reactors''

These important statements support what journalist Martin Mittelstaedt had written on the 29th of June 2009 in the Globe and Mail journal following an interview with CNSC's Dr. Greg Rzentkowski, who is Director General, Directorate of Power Reactor Regulation. Referring to the positive CVR coefficient problem and quoting an internal CNSC document Mittelstaedt had written:

> "The commission and the three utilities that operate reactors – Ontario Power Generation, NB Power, and Hydro-Québec – will likely have to spend 'considerable resources' dealing with safety issues related to the problem and still may not be able to resolve it fully", it said.
>
> "In the end, despite the best efforts on all sides, the possibility of further erosion of the available safety margins as well as imposition of additional operational and procedural limits cannot be precluded … for current Candu reactors."

In view of these reports by Canadian nuclear experts, a prudent investor in Ontario will want to ask tough questions before investing in new CANDU technology.

Request. That before recommending new nuclear investments in Darlington, the Panel take into serious consideration the prudent comments made by the nuclear CNSC experts quoted above.

5: The discarding of the low void reactivity fuel (LVRF) solution

Over the last decade the Canadian nuclear community has been exploring the idea of using a modified uranium fuel in the CANDU reactors that would exhibit a very low coolant void reactivity coefficient. This modified enriched uranium fuel is referred to as LVRF. At the beginning of its 2002 annual report, the AECL advisory panel had discussed modifications for the proposed third generation Advanced CANDU Reactor ACR-700, the 700 referring to the nominal electric power of 700 megawatts then contemplated. The advisory panel had written the following about the proposed LVRF solution :

> ‘’2.2.3.1 Modification of design parameters from the preliminary conceptual design.
>
> In the final conceptual design of the ACR-700, the fuel bundle enrichment has been increased to 2.00% from 1.65% in the preliminary design and dysprosium, a burnable poison (note 2), has been added to the centre element at a concentration of 4.6%. In addition, the gas gap between the pressure tube and the calandria tube in the ACR has been increased to 20 mm, compared to 10 mm in a conventional CANDU and the lattice-pitch has been reduced to 220 mm, compared to 286 mm in a conventional CANDU.
>
> The reason for these changes is to ensure that the coolant void reactivity (CVR) coefficient for the ACR is slightly negative under all operating conditions. This will ensure that there is no power surge in a loss-of-coolant accident, as occurs in a conventional CANDU reactor with its positive CVR coefficient, but actually a power decrease. While the power surge in a conventional CANDU is limited by the two independent shutdown systems, thus preventing fuel damage, the regulatory authorities in the USA and in the UK demand a negative CVR coefficient. The overall effect of the foregoing changes results

> in the ACR being undermoderated, like an LWR, rather than overmoderated like in a conventional CANDU, and being inherently stable under all operating conditions.’’
>
> *“Note 2. As the fuel is irradiated, the dysprosium absorbs neutrons and gradually disappears as neutron-absorbing fission products build up. This behaviour limits parasitic neutron absorption in the fuel while ensuring a negative CVR.’’*

The promise of this LVRF solution to the positive CVR was such that Bruce Power in Kincardine, Ontario, had decided to try it out in a few fuel channels of one of its 8 reactors. In 2007 and 2008 the results had been reported by Bruce Power as promising. But then, unexpectedly, in the Spring of 2009 Bruce Power told the CNSC that they were giving up on the LVRF as a potential solution to the large positive CVR plaguing the CANDU. The December 2009 report explains that the LVRF solution was deemed to be too expensive. It was also feared that other problems could pop up with future ‘’discoveries’’.

The 268-page CNSC August 2009 report offers to CANDU owners two distinct options for mitigating or resolving the positive CVR issue. The first option is the so-called ‘’Composite Analytical approach’’ which is designated RCM-1, for Risk Control Measure 1. This option would comprise calculations, experiments, design changes and operational conditions that would seek to convince the CNSC that the safety margins are adequate.

The second option, designated RCM-2, is the change to LVRF. On the fifth page of the executive summary the CNSC report states the following:

> ‘’LVRF involves the implementation of fuel design changes to reduce the positive coolant void reactivity, and as such alleviates the root cause of the problem and therefore enhances the robustness of the LOCA safety case.”

Note the CNSC’s recognition that a positive CVR is ‘’the root cause of the problem’’. In this connection it’s important to note that the latest proposed design for the Advanced CANDU Reactor ACR-1000 (power of 1000 megawatts or more) will, it is hoped, display a *negative* coolant void reactivity coefficient.

The CNSC's offer of two options in the August 2009 report exposes very clearly the disagreement among Canadian nuclear experts concerning the wished-for restoration of safety margins in CANDU reactors. It is remarkable that Muzumdar and Meneley favour the RCM-1 ''composite analytical approach'' in their August 2007 report, but yet write the following on page 99:

> ''For example, with respect to the substitution of natural uranium fuel with LVRF to increase Large LOCA safety margins (which is actively being pursued or investigated at this time as an option by some licensees) the value side of the equation includes factors such as increased reactor power limits, increased energy production, improved flexibility and increased reliability, improvements in consequences of other Design Basis Accidents, greater regulatory certainty and protection against further discovery issues, improvement in public risk estimates, greater public acceptance, and so on.''

Atomic Energy Canada Limited (AECL) will likely offer the LVRF option for the Darlington new build. Whether AECL will achieve a negative CVR, as they have promised, remains to be seen. It is also an open question as to whether the LVRF solution offers inherent safety. Why did Bruce Power first go for it in 2007-2008, and then backed down in Spring 2009?

Request. In view of much Canadian expert opinion that finds present calculated CANDU safety margins to be either *unacceptably small* or *exceedingly small* , and in view of the USA and UK regulatory authorities demanding a negative void reactivity coefficient, the Panel will need to question CNSC experts on the sign of the CVR offered by AECL for the Darlington new build.

6: The ultimate consequences of an LBLOCA

In several CNSC documents the authors report that, following a LBLOCA, the melting of the zirconium tubes holding the uranium fuel channels could alter the core geometry and impair the operation of the two shutdown systems. One cannot therefore know for sure what the very large overpower pulse will do. The CNSC reports only state that the radiobiological dose imposed on the population is *expected* to be within regulatory limits.

The CNSC requires CANDU owners to have emergency evacuation plans in case of a large release of radioactivity into the atmosphere, such as could happen during a severe core-melt nuclear accident, or in the case of a terrorist attack causing a breach of containment.

As to the probability of core melt accidents one finds the following historical record summarized here below. Nuclear reactor core meltdowns have occurred approximately once every 20 years. Here is their history (see http://www.atomicarchive.com/Reports/Japan/Accidents.shtml):

- **December 1952 in Chalk River, Ontario :** partial core melt and release of radioactivity within the building.
- **October 1957 at Windscale, England :** a fire destroyed part of the reactor core, large quantities of radioactive elements were released into the environment.
- **October 1966, near Detroit** , **Illinois** : meltdown of the core of the Enrico Fermi reactor; reactor confinement was not breached;
- **March 1979, Three-Mile Island**, near Harrisburg, Pennsylvania : the core melted down and was completely destroyed. Large quantities of radioactive gases were released into the atmosphere.
- **April 1986, Chernobyl, Ukraine :** meltdown and explosion of a nuclear reactor; massive release of several radioactive elements into the northern hemisphere. Locally, 10 000 square kilometres were evacuated for an unspecified time (probably for a century or two).

The CNSC documentation reveals uncertainties in the predictable consequences of a core meltdown. On 1 November 1982 the Washington Post published an article in which a team from the Sandia National Labs gave their estimates for the numbers of deaths and the level of property damage following a worst-case nuclear reactor accident. For some US cities the Sandia CRAC-2 report had the number of deaths ranging in the tens of thousands and property damage up to 200 G$.

These frightening estimates from Sandia have been gradually confirmed as the consequences of the 1986 Chernobyl accident have been unfolding. In

‘’The Other Report on Chernobyl (TORCH)’’ the authors Ian Fairlie and David Sumner give data for the estimated numbers of fatal cancers resulting from exposure to Chernobyl fall-out reaching in the tens of thousands (see http://cricket.biol.sc.edu/chernobyl/papers/TORCH.pdf). The fact that ten thousand square kilometres have been evacuated for a century or more in Ukraine and Belarus gives the scale of the economic losses.

Request: the Panel could question the new-build proposers regarding the ultimate consequences of a worst-case accident.

7: Moody’s June 2009 warning about nuclear investments.

The weight of the evidence presented against CANDU economics and physics creates an additional danger with respect to credit ratings on the part of agencies such as Moody’s in New York City. In June 2009 Moody’s had issued a report warning electric utilities that investing in new nuclear reactors could bring about a downgrading of their credit standing and therefore result in increased interest rates (see http://www.scribd.com/doc/18057014/Moodys-New-Nuclear-Generation-June-2009). In a paragraph entitled ‘’Historical rating trends are not good’’ Moody’s had written the following (the word ‘’issuer’’ means the utility that issues bonds to finance a project): ‘’Historical rating actions have been unfavorable for issuers seeking to build new nuclear generation. Of 48 issuers that we evaluated during the last nuclear building cycle (roughly 1965-1995), two received rating upgrades, six went unchanged, and 40 had downgrades. Moreover, the average downgraded issuer fell four notches. All of these ratings were evaluated on the senior secured or first mortgage bond ratings.’’

It should be noted that Moody’s warning concerning new reactors could become sterner once they have a close look at the 16 technical problems detailed in the August 2009 CNSC report. In February 2010 OPG chose the easy way out by foregoing refurbishment at the problem-plagued Pickering B nuclear station. OPG said that they were concentrating their forces on the later refurbishment of the four second-generation CANDU reactors at the Darlington nuclear generating station.

We are historically in a period of time where many governments, including the Canadian federal government, are urging other governments to reduce budget deficits and debt levels. An uneconomic investment in Darlington new build goes against prudence and against present federal financial policy recommendations as they were expressed in June 2010 at the G8/G20 summit meeting in Toronto and elsewhere.

In this connection it is noteworthy that on-going troubles with Point Lepreau refurbishment had contributed to Moody's downgrading New Brunswick's credit rating in August 2009 (see http://www.ibew37.com/newsItem.php?NewsID=121).

Request: that the Panel consider the economics of nuclear new build with great prudence.

8: Two key decisions by the Federal Government

First decision. On 17 December 2009 the Harper government announced that it was putting for sale the CANDU division of AECL. It is well known that AECL does not have orders for new CANDU reactors and that it has been running deficits for a great many years. Being a crown corporation, AECL has relied on federal government subsidies in order to keep running. Total subsidies have been more than 20 G$ over AECL's history. On 12 July 2010 the senate passed the C-9 bill that had previously passed the House of Commons. One provision of this omnibus budget bill was for the CANDU division of AECL to be privatized.

On 15 October 2009 the Society of Professional Engineers and Associates (SPEA), which represents 900 employees of AECL, had warned the Harper government that selling AECL's CANDU division would probably mean the end of the CANDU technology in Canada. A prudent investor will consider the possibility that AECL's SPEA is right. If that is the case what will be the repercussions on Darlington new build and on its maintenance in the 25 years of subsequent operation that might lie ahead?

Would OPG encounter repeatedly the large cost overruns that have characterized the nuclear industry over the last 40 years? In the USA construction cost overruns have averaged a factor of 3 for 75 reactors for which data are available. For the construction of Gentilly-2 the cost overruns have been by a factor of 4, and for the construction of the 4-

reactor Darlington nuclear power plant near Toronto, the cost overruns have been by a factor of 3.

The CNSC documentation has explained with painful clarity 16 technical problems that were still plaguing the CANDUs as of August 2009. Three groups of high-level decision makers in Ontario have decided to exercise restraint in investing public funds into CANDU nuclear reactors. The three groups are with the Federal and Ontario governments and with OPG.

Second decision. On the 31st of March 2010 the Harper government announced in the context of medical isotope fabrication that it would invest in accelerators, notably in cyclotrons, to meet Canadian demand and for exports. The Harper government declared that it would not invest one billion dollars or more in the construction of a new nuclear reactor in Chalk River for isotope production.

What is remarkable about the Harper government's isotope decision is that it made the following declaration in the section of the voluminous announcement that discusses the cyclotron option:

> ''An important consideration from cost-savings and environmental perspectives is that this option would largely avoid nuclear waste issues.''

This declaration reflects the lower cost anticipated for the cyclotron-based production of medical isotopes, and importantly it underlines the economic and environmental benefits of not producing radioactive waste, as a new nuclear reactor at Chalk River would have produced.

Ontario has reasonable sources of hydro-electricity and an extremely large wind and solar energy potential. Public opinion polls have shown that a good part of Ontario's society is favorable to ecological issues and to solar and wind energy development

Request: that the Panel weigh the arguments in favor of renewables versus nuclear new build.

9: Alan Kupcis's legacy.

In the May/June 2005 issue of the Canadian National Geographic Magazine the renowned Canadian author Elaine Dewar wrote an article entitled ''Nuclear Reaction or Nuclear Resurrection'' in which she reviewed the history of nuclear power in Ontario. She interviewed many of the managers in the nuclear enterprise, including notably Dr. Allan Kupcis, at one time president of Ontario Hydro, the company that later on gave rise to Ontario Power Generation (OPG). Elaine Dewar described the many troubles that Ontario Hydro has had with its fleet of 16 nuclear reactors and how these troubles sometimes kept Allan Kupcis awake at night. In 1994 Kupcis hired a team of American nuclear engineers headed by Carl Andognini and asked them to diagnose the trouble with the nuclear business in Ontario. Elaine Dewar wrote about Kupcis's worries and about the Andognini team's report completed in 1997, quoting :

> ''His nightmare had been that the safety margins had all but disappeared. But the team found all Ontario's reactors to be minimally acceptable – the lowest rating before mandatory shutdown.''

As a result of Andognini's recommendations Ontario Hydro shut down 7 nuclear reactors in 1998, four at the Pickering A power plant, and three at the Bruce A power plant near the city of Kincardine on the shore of Lake Huron. One of the Bruce A reactors had already been shut down in 1995.

A significant quote from Allan Kupcis is in the following paragraph that Elaine Dewar wrote (I have put Kupcis's words in italics):

> ''*"Before anyone becomes a chief nuclear engineer,"* says Kupcis, *"they should go to Prypiat, to see the meaning of their responsibilities."* Prypiat is the town of 40,000 that was permanently abandoned after Chernobyl vented radioactive gases into the atmosphere in 1986.''

Another scientist who worries about Chernobyl-type accidents is Robert Alavarez in the USA. Robert Alvarez and colleagues have published in the journal Science and Global Security, 11: 1-51, 2003 (the article is available at the web address:

www.princeton.edu~globesec/publications/pdf/11_1Alvarez.pdf).

Supported by the US National Academy of Sciences Alvarez and colleagues have argued that the water pools hosting radioactive waste next to nuclear reactors are potential targets for terrorist attacks because:

-1. they typically contain 10 times more radioactive waste
than the reactor itself, and

-2. they have roofs that would not resist an airplane crash
or explosive-laden missiles.

Following a terrorist attack, tens of thousands of square kilometres would be covered by very high levels of radioactive waste and would have to be evacuated.

In response to Michel Duguay here is what Dr. Michael Binder commented on Alvarez and collaborators in his May 5th 2010 letter posted on the CNSC web site:

> ‘’ In response to your reference to Robert Alvarez’s 2003 misleading article on the possibility of terrorist attacks on radioactive waste, please note the CNSC has aggressively ensured that such an event remains very improbable. The nuclear power plants in Canada are subject to the CNSC order issued on October 19, 2001. Following the order, rigorous security measures were put in place, including specialized detection systems and armed forces with the capacity to intervene efficiently. The CNSC verifies the efficiency of these measures on an on-going basis.’’

A prudent investor might not be fully reassured by this statement, especially when he/she realizes that a nuclear catastrophe, be it accidental or malicious, can be triggered in seconds. Intervention by armed forces takes more than a few seconds to be set in motion.

Request: that the Panel consider the findings of Robert Alavarez and collaborators regarding the danger posed by minimally protected nuclear waste wet and dry storage areas near nuclear reactors.

10: Tricky operation of a CANDU reactor.

Dr. Michael Binder wrote the following in his 5 may 2010 letter to Duguay:

> ‘’Finally, although the positive void reactivity coefficient is sometimes referred to as a “design weakness”, it enables the shutdown systems to be especially sensitive to slight local temperature or power perturbations, thus ensuring the triggering of two fast shutdown systems for a spectrum of postulated initiating events. This allows CANDUs to have a robust safety response for postulated accidents, not just for large LOCA.’’

This statement by Dr. Binder is itself well supported by the citation quoted above from the report by Muzumdar and Meneley, which is:

> ‘’These changes have resulted in extremely narrow margins in all CANDU reactors .....In some instances, the estimated safety margins (and resulting operating margins) have decreased to the extent that safety investments are currently being considered to increase these margins for both refurbished and new build reactors.’’

In promoting its Advanced CANDU Reactor (ACR) AECL has numerous times asserted that the ACR would be easier to operate. The above-quoted statements clearly show that the CANDU reactor is very difficult to operate safely and can never be relied upon at all times to deliver electric power. Not only a sudden pressure tube burst, but a whole ‘’spectrum of postulated initiating events’’ can trigger its immediate shutdown. Once shut down, a nuclear reactor may require months, sometimes years, to come back on line.

Another example of the CANDU’s drawbacks took place in August 2003. During the August 14th 2003 large-scale power outage in the US North-East and Ontario as 50 million customers were deprived of electric power for several days. It took up to one week for some of the nuclear reactors in Ontario to come back on line.

One is very far from an electric generator suitable for a modern smart grid.

Request: that the Panel critically examine the operational weaknesses of CANDU technology.

11: Conclusion

One can assert the following:

-1. CANDU nuclear reactors suffer from a major design weakness, namely the positive coolant void reactivity coefficient that can lead to a core melt-down under certain types of accidents.

-2. The economics of refurbishing four CANDU reactors at the Pickering B power plant near Toronto have been deemed to be unfavourable by Ontario Power Generation.

-3. Many uncertainties are associated with the modeling of neutron physics in the reactor core not only under accident conditions but also during normal reactor operation. Uncertainties are also associated with various corrosion phenomena leading to accelerated aging of reactor components and reduced safety.

-4. The very short time scale, namely a few seconds, associated with potential nuclear accidents imposes computer control at all times, so that human judgment may not have time to ‘’save the day’’ for many types of accidents.

-5. The very short time scale of potential terrorist attacks will not allow an effective intervention of the part of armed forces, even if deployed locally.

-6. The generation of radioactive waste and the routine emissions of radioactive tritium at a CANDU power plant have a negative impact on the economy and on the health of people in neighbouring regions. In a major nuclear accident Chernobyl-like consequences on the economy and on health are possible.

The uncertainties are associated with the numerous unresolved problems of the CANDU technology which will surely exert a downward pressure on the credit rating of Ontario as evaluated by Moody’s and other credit rating firms. These uncertainties will not help attract potential investors in the Ontario economy. The most ominous uncertainty is connected with the consequences of a Chernobyl-like accident.

12: Alternatives to Nuclear: Renewable Energy and Smart Grids

What could be done in Ontario to escape this dire nuclear nightmare? One fundamental law of economics states that a region will be wise to exploit assets that offer a natural advantage. Ontario is surrounded by the Great Lakes and James Bay. For Ontario with its one million square kilometers, as well as for the rest of Canada with its 10 million square kilometers, an obvious natural advantage is an immense territory, which means that vast wind and solar energy resources are potentially available.

A simple calculation shows that by devoting just one or two percent of Ontario's land and water surface to wind power, Ontario could double its electric production. The same applies to the deployment of solar photovoltaic (PV) panels. An additional advantage of the latter is that PV systems can be deployed near the point of use, on roofs, building façades, parking lots, and underused land. In addition, such PV systems would constitute a back-up electric power system when the Hydro-Québec network fails because of weather conditions or accidents. This is clearly the way to a smart reliable power grid.

Electric energy storage can be located in homes and commercial buildings in the form of thermal mass storage for heating applications, and in the form of high-capacity batteries being developed for plug-in electric automobiles. So-called ''smart grid'' concepts are being developed by electric network engineers to enable electric power providers to accommodate fluctuating sources of electric power. Depending on the circumstances, a smart grid will store available excess power in homes and in commercial buildings, or it will tap the electric energy stored by the clients during times of peak demand on the network.

The potential of renewable energy development in Ontario is enormous. Assuming a good fraction of it is developed in the future, what will Ontario do with all this electricity? There are many vital applications of reliable and green electric generation, such as powering hospitals, the fabrication of medical isotopes by means of accelerators, powering many types of uninterruptible manufacturing, powering web servers and computers, greenhouse culture of vegetables and flowers, powering electric vehicles and public transportation systems, and other applications yet to be invented.

With an 8-billion dollar investment Ontario expects to create 30 000 jobs in future-oriented renewable energy technology. Germany already has created some 200 000 jobs in the field of renewable technology. Germany as of March 2010 had about 25 GW of installed peak wind power and 6.5 GW of installed photovoltaic peak solar power.

Note 1: Nuclear reactors are not a good fit to a smart electrical grid

The following considerations apply to Ontario as well as to Québec because, on the positive side, Québec will benefit from Ontario's experience in developing a modern smart grid based in part on renewable energy. On the negative side, Québec will become less attractive to persons and to industry if relatively risky new and untried nuclear reactors are built in Ontario; a major accident in Darlington could dump radioactive fallout in the Saint-Lawrence Valley because of prevailing westerly winds, thereby causing large economic losses and very serious negative conditions for the environment and health. One thing is sure: the *perception* of a large fraction of Canadians is that nuclear generation, together with its attendant generation of radioactive waste, presents a physical danger and an economic risk.

Note 2: A smart grid requires predictable resources.

The concept of a ''smart grid'' has been given more and more importance in the last decade as a result of the rapid expansion of both wind and photovoltaic solar power, the latter two being intermittent but fairly predictable sources of electricity. The basic idea is that a smart grid predicts the availability of wind and solar power and compensates for their reduced levels at times by increasing the contribution of adjustable sources of electricity, such as turbines fed by natural gas and hydroelectric turbines coupled to large reservoirs. A smart grid may also manage the electrical power demand to a certain extent (e.g. heating hot water at night on customer premises).

There is a considerable historical record of solar and wind power availability. It is generally accepted that wind and solar power can be fairly well predicted at least one hour ahead of time, which is sufficient time to bring on line natural gas and hydroelectric resources. On the contrary, a nuclear reactor has a temporal availability profile that is basically unpredictable: for safety reasons a nuclear reactor must at times be suddenly shut down and may remain shut down for days or weeks, and even for months. The historical performance record of CANDU reactors shows that almost every year the average CANDU reactor will have both planned and unplanned week-long or month-long outage periods. On the web site of the Canadian Nuclear Association one can see that for the 27 CANDU reactors in operation in the world, the average lifetime performance has been 81.5% as of December 2009. This figure indicates that on average the reactors are not online about 18% of the time. Four CANDU reactors in Canada have been out more than 30% of the time, these being Pickering A-1 and A-4 near Toronto, and Bruce A-3 and A-4 on the shore of Lake Huron.

Not only is the outage time of a a nuclear reactor mostly unpredictable, but when the reactor is operational one cannot adjust its power level according to the demand. For maximum safety of operation one must run a CANDU reactor at a constant power level.

New ‘’discoveries’’ regarding the operation of CANDU nuclear reactors have considerably reduced the range of physical conditions under which the operation of the reactor is considered to be sufficiently safe in the context of the highest international standards. Such a situation had been anticipated by Atomic Energy Canada Limited (AECL) in the 2002 annual report from its advisory board. As a result of these past and potential future ‘’discoveries’’, one cannot predict with certainty whether the temporal availability profile of CANDU nuclear reactors will improve or worsen with time.

Request. The Panel should encourage the development of a smart grid in Ontario with increased reliance on renewable energy and a reduced reliance on CANDU nuclear technology.