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Exposé oral

Written submission from Darek Kulczyński

Mémoire de Darek Kulczyński

In the Matter of the

À l'égard de

Darlington New Nuclear Project

Projet de nouvelle centrale nucléaire de Darlington

Application to renew the nuclear power reactor site preparation licence for the Darlington New Nuclear Project

Demande de renouvellement du permis de préparation de l'emplacement d'une centrale nucléaire pour le projet de nouvelle centrale nucléaire de Darlington

Commission Public Hearing

Audience publique de la Commission

June 10, 2021

10 juin 2021

Dariusz (Darek) Witold Kulczyński

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Subject: Submission to Public Hearings on DNNP 2021

My name is Darek Kulczyński. Having worked at Ontario Hydro/OPG nuclear generating stations for 33 years I retired from OPG in February, 2015. I remain a member of the Society of United Professionals retiree chapter.

Back in 2011, I was a part of the Society of Energy Professionals' team at DNNP Public Hearings.

I herein file my 2021 submission supporting the Darlington New Nuclear Project in general.

However, I strongly believe that an SMR is not the way to go for Darlington B. SMR's are still in development stage (NuScale seems most advanced in development process).

The DNNP website contains the following statement and related Q & A's:[quote] *On Nov 13 OPG announced resumption of planning activities for Darlington New Nuclear with the goal of hosting a Small Modular Reactor(SMR) as early as 2028* [unquote]

OPG is not a research company. Its mandate is to ensure adequate power supply to the province of Ontario at reasonable cost. Even if the first SMR works, a 300 MW unit will not be helpful in closing the nuclear generation gap once Pickering NGS shuts down.

The site to build and test operate the first SMR is Chalk River, not Darlington. SMR's may be helpful in remote, Northern areas. Densely populated areas of central and southern Ontario would not benefit from SMR's. In the recent update of PPEJ (Polish nuclear power programme) in October 2020, Small Modular Reactors were not included for the same reason.

SMR's may be an interesting solution for Canada's North. Hence, it should be built with the support of Federal funds with the risks borne by Ottawa, not Queen's Park and Ontario Ratepayers. Even if the manufacturer financed everything related to their SMR construction, OPG should not waste Darlington site for a unit that would not be important in Ontario energy supply due to its small size and unproven capacity factor.

The following is an updated excerpt from my submission to the Ministry of Energy, EBR registry number:011-9490; Comment ID: 159974 originally filed in 2013. This part of my report pertains to Darlington B. As such, it can be used to support the Darlington New Nuclear Project as such. A short analysis what should be built at the Darlington site and why has been provided below.

Nuclear power provides over half of Ontario's generation. […] How should we proceed with nuclear new build? [i.e. question#3 [(MC-ROLTEP page 13)]

By 2025 Pickering NGS A & B will have been permanently shut down and one or two Darlington units will be off line for overhaul. This generation gap should not be closed using base load generators burning natural gas. For decades, natural gas has been the largest source of Carbon Dioxide in Canada while nuclear power plants produce negligible amounts of CO_2, mainly from backup power generators normally run during reliability tests only. For the above reasons, it is essential that new nuclear units be added to Ontario's Grid and the existing nuclear units be refurbished.

While the construction costs of nuclear generating stations are higher than for those burning natural gas, the nuclear operating costs are likely to be lower in the long run. The demand for natural gas increases more rapidly than the demand for Uranium. Nuclear Power Stations can produce ecologically friendly Hydrogen for automotive use by powering electrolysers (especially at times of low demand).

1. It takes a minimum of 6 years to build and commission a nuclear unit. Ontario should swiftly proceed with the Darlington New Build, paying attention to the following considerations:
    a. Minimize nuclear generation gap - Nuclear capacity already removed or to be removed in 4 years' time from Pickering NGS A&B amounts to **4,124 MW(e)** net [4,328 MW(e) gross].
    b. Two new units (Darlington B) would inevitably add less power than is now available from Pickering. With Darlington C (the following two units) **4,124 MW(e**) could be compensated for but not necessarily with CANDU reactors. OPG applied to build up to 4 new nuclear units at their Darlington NGS site. There are two designs that could be considered for the first two units:
        i. AP-1000, an American Pressurized Water Reactor (PWR) by Westinghouse with a projected **net power rating of 1,117 megawatt electric (MWe).** 4 x 1,117 = 4, 468 that is: Pickering A & B (originally installed) + 8 % or Pickering A & B (2 + 4 units that remain in operation) + 44%.
        ii. EC 6 (Enhanced CANDU 6) – Pressurized Heavy Water Cooled and Moderated Reactor (PHWR)- by CANDU Energy (previously AECL) with the projected **net power rating of 700 megawatt electric (MWe)** approx. (between 730 and 745 MWe gross output depending on the condenser cooling water temperature and other site parameters). 4 x 700 = 2,800 that is: 68% of Pickering A & B (originally installed) or 90% of Pickering A & B (2 + 4 units that remain in operation). Building more than 4 EC 6 units (4 at Darlington and additional 2 at, say, OPG's Weseleyville site), would replace fully the power available from Pickering A and Pickering B (all 8 reactors).

        Note: There is another CANDU design possible to be developed by the time unit 7 and 8 at Darlington are required. A CANDU 9 was a stand-alone reactor based on Darlington A "four pack". There were differences in that Darlington A reactors have two cooling loops and CANDU 9 was designed to have one. CANDU 9 would have a net power rating of 900 MWe approx.

However, CANDU 9 has never been built while EC 6 is an evolutionary design of the successful CANDU 6; CANDU 6 units have operated well in many countries, including Canada. EC 6 has been designed with deep load following capability (i.e. it could lower the power output down to 60% if required by the grid). Normally, nuclear units run at full power or close to full power (base load). The aforementioned EC 6 feature provides flexibility that the grid may need as demand fluctuates.

2. AP 1000 or EC 6?

a. AP1000 appears to be a good design but the Westinghouse's construction record in the USA leaves a lot to be desired. It looks much better in China. With larger power output it may be cheaper than EC 6 for the unit of energy produced. Four AP1000 reactors at Darlington would more than compensate for the removal of Pickering A and Pickering B from the Ontario grid.

b. However… The actual operating experience with AP1000 is limited at the present time. AP1000 would require expensive, enriched Uranium fuel not the cheap and easy to make natural Uranium fuel used by CANDU reactors. Personnel employed in Canadian utilities and at the CNSC have limited expertise in PWR's while they are very familiar with designing, licensing and operating CANDU reactors. Building new CANDU's in Ontario would most likely generate more well-paid jobs in Canada than selecting the American PWR. Please note that the recent, successful, D2 refurbishment has proven that functional CANDU infrastructure still exists in Canada and the EC6 is poised for success if given a chance.

Attached is my report on Enhanced CANDU-6 (EC6) prepared in February 2011 which is still relevant.

This report was originally filed as an addendum to the DNNP submission by the Society of Energy Professionals.

Yours truly,

Dariusz (Darek) Witold Kulczyński, P. Eng.

Enhanced CANDU-6 (EC6™); Rev 6

By Darek Kulczynski, P. Eng.*, Feb 18th, 2011 – updated March 31, 2021*

Enhanced CANDU-6 (EC6™)

Executive Summary

It is recommended that classic CANDU reactors, similar to those currently in operation in Ontario be considered for Darlington New Build.

1. **CANDU (Canada-Deuterium-Uranium)** is a heavy water cooled and moderated pressurized reactor (**PHWR**) that uses Natural Uranium fuel. CANDU fuel bundles are easy to manufacture. In fact, they are manufactured right here in Ontario. GE Hitachi manufactures Fuel Bundles for OPG in three locations: Arnprior (tubing-fuel sheaths), Toronto (fuel pellets) and Peterborough (fuel bundle assembly). More details have been provided in the **Fuel** section of this document.
   CANDU technology is characterized by cheap fuel and expensive moderator and coolant which is Heavy Water (D_2O). However, the cost of coolant and moderator is considered part of capital cost for the project. During operation, heavy water leaks are collected and upgraded right at the sites and then returned to the system. The aforementioned process is referred to as Heavy Water management. Losses of Moderator and Coolant inventory are thus minimized. Darlington site also operates a Tritium Removal Facility that serves all CANDU stations in Canada and ensures very low Tritium emissions. For Tritium, as well as for other radioactive substances, OPG releases less than 1% DRL, where DRL or Derived Release Limit is a regulatory limit set for each radioactive substance by the CNSC. Thus, the environmental impact of a CANDU generating station is minimal (e.g. ISO 14001 Green Dove Award received by Darlington Site). The new generation of CANDU nuclear power plants will be designed for an even smaller environmental footprint [9 – section 3.5].

2. **EC6™** stands for an **"Enhanced CANDU-6**". These will be 740 MW(e) gross output reactors designed in a twin unit arrangement. **EC6™** will have a reduced station load. That is, less power will be required to operate pumps, fans and fuelling machines. More energy efficient motors and drives will be used. EC-6 will operate for 50+ years with one mid-life retubing based on a 90%+ lifetime capacity factor. EC-6 design offers a target life of 60 years with one mid-life refurbishment [9].The actual time before retubing an **EC6™** reactor will depend on its capacity factor
   Modern CANDU stations such as units at Darlington A and CANDU-6 units in South Korea, China and Romania can operate at capacity factors of between 95 and 100% [2]. At such high capacity factors, neutron irradiation of pressure tubes is higher which promotes their elongation up to the point that retubing is required. However, an **EC6™** reactor will be designed for longer operation before retubing than CANDU models currently in service. This will be achieved by the application of thicker feeder pipes and pressure tubes designed to make use of the most recent state-of-an art metallurgical achievements [3, 9].
   EC6™ will offe**r** increased plant margins, both in terms of operational and safety, enhanced environmental protection, improved severe accident response, an improved

fire protection system, improved plant security, modern computers and control systems, improved plant operability and maintainability, optimized plant maintenance outages, advanced MACSTOR design for spent fuel storage, potential to perform deep load-following (60%-100% Full Power). Load following means adding extra power to the grid in peak hours and removing it in demand valleys. Currently, nuclear units are run to satisfy base load demand only and load following is afforded largely by thermal units. However, with the removal of coal-fired generators now in progress, the aforementioned load following ability of **EC6™** units will be very important for Ontario power supply security. [3, 4, 5, 7, 9-section 10.5]

3. **Safety improvements in EC6™** include additional heat sinks and a redesigned cooling system to further enhance control of containment temperature and pressure. Like on all single unit CANDU stations, a Dousing System, rather than Vacuum Building will provide containment pressure control with significant improvements compared to previous designs. The number of containment penetrations (wiring and piping, entrances and exits) is also reduced, and the containment structure strengthened to meet a higher design pressure and afford protection against external events (e.g. a large, commercial airliner impact).
   The current CANDU 6 design is a proven and highly successful technology, with 11 units licensed and operating in five countries. The vendor (AECL) built on these aspects in the **EC6™**, while enhancing safety and ease of licensing to meet the latest Canadian and international expectations for a new plant. For the purpose of offering their products internationally, AECL has internally performed a comprehensive review to confirm that their designs comply with safety requirements in the CNSC RD-377 and IAEA NS-R-1 documents governing European regulatory expectations such as WENRA (Western European Nuclear Regulators Association) [9 – section 3.1].
   The safety goals for the EC6 design are based on those defined in the CNSC regulatory document RD-337 for Nuclear Plants in Canada. Core damage frequency (CDF), the sum of frequencies of all event sequences that can lead to significant core degradation is less than 10^{-5} per reactor year [9 – section 3.5]. CANDU reactors currently in service have a calculated Core Damage frequency of 10^{-4} per reactor year

4. **Enhanced CANDU 6** (**EC6™)** is classified as a **Generation III** nuclear reactor. A generation III reactor incorporates evolutionary improvements in design developed during the lifetime of the generation II reactor designs. These include improved fuel technology and superior thermal efficiency. For example, net power plant efficiency for **EC6™** will be **35.5%** [9] while overall net efficiency for generation II Darlington A units is **31.7%** [15].
   In Generation III reactors there is some presence of passive safety systems and standardized design for reduced maintenance and capital costs. A generation III reactor will have a longer operational life (designed for 60 years - compared with generation II designed for 40 years - and extendable for even longer service). The calculated Generation III reactor core damage frequencies are significantly lower than those calculated for Generation II reactors. Core damage frequency calculations must be

performed as part of safety analysis. A future Operator of a nuclear power plant, such as OPG, is required to submit a complete Safety Report to the CNSC to obtain construction and operating licenses for a specific project, such as Darlington B.[3, 6, 7, 9 – section 3.5, 10, 11]

5. Licensing

In 2009, **the CNSC** complete**d Phase 1 of a Pre-Project Design Review of EC6™**. The CNSC concluded that at an overall level, the design intent was compliant with the CNSC regulatory requirements and met the expectations for new nuclear power plant designs in Canada. The CNSC will require a much more detailed review of the design and safety case for a specific application and a specific site [9 – section 3.1].
Phase 2 of the Pre-Project Design Review is expected to be completed by early 2012. While not binding for the CNSC, a successful pre-project review facilitates future application by an Operator, such as OPG, for licenses relating to a specific project e.g. Darlington B.
A copy of the Phase 1 Executive Summary is available for download from the CSNC web site [8].

6. Construction:

For international projects, the vendor (AECL) expects to be able to deliver an EC-6 within six years of signing the contract (which includes design, construction, training of personnel and commissioning). The EC6 construction project schedule is planned for 55 months from first-concrete to in-service, utilizing advanced project management and construction techniques that were perfected in previous projects such as the twin CANDU-6 installation at Qinshan III, China.[3, 9 - section 10.3,]. Enhanced CANDU-6 design is based on Qinshan III. This was a very successful project; Qinshan III unit 1 was put in service 6 weeks ahead of schedule, and unit 2 was commissioned 4 months early (both under budget). Early commercial operations at Qinshan resulted in project savings of US$312 million and additional US$187 million in extra revenues.
Qinshan III units 1 and 2 were built and commissioned with the use of modularization and pre-fabrication technology (15 modules per unit were used in Qinshan). Enhanced CANDU-6 will use redesigned pre-fabricated modules that will further reduce its construction cycle. The objective is to modularize where doing so can reduce construction cost, shorten the critical path, reduce risk and/or improve quality. Currently 23 prefabricated modules per unit are planned to be used for EC6. [18].
CANDU supply chain ‘localization’ provides for high use of local markets for manufacture and construction. To put it in a perspective, Wolsong unit 4 in South Korea achieved over 70% of local content. All CANDU-6 units in Korea and in Romania were built and commissioned on budget and on schedule [3, 16].

7. EC6™ Fuel

Enhanced CANDU-6, like its predecessors, will use natural Uranium as fuel. CANADA has one of the largest deposits of Uranium ore in the world. In addition, EC-6 is capable of executing advanced fuel cycles for example using such materials as Thorium which is three times as abundant in nature as Uranium. This might become a significant advantage of **EC6™** if a rise in the price of Uranium were to affect power generation economics in future decades.

In the existing Darlington A nuclear generating station, new fuel is loaded in reactors by computer controlled Fuelling Machines. Irradiated fuel is transferred to Spent Fuel Bays for cooling under a multi-metre layer of water. After 10 years in the bays, spent fuel can be transferred to a dry storage facility presently operated at Darlington site. From there it will eventually be moved to a deep geological repository that will be built in the Canadian Shield. Fuel storage is conducted by personnel and in special facilities licensed by the CNSC and therefore presents no environmental or security hazard. [3].

Used fuel storage is also monitored by IAEA as part of its Safeguards program for non-proliferation.

8. **Training:** OPG has superb training programs for all families of personnel required to operate CANDU nuclear generating stations. Authorization training for Nuclear Shift Supervisors and Authorized Nuclear Operators that are licensed by the CNSC makes extensive use of a computerized simulator and mock-up of a unit control centre. An **EC6™**based station will also be equipped with a full scale, computerized simulator and mock-up. OPG, assisted by AECL, has the capacity of establishing an **EC6™** specific training program for future nuclear power plant operators. A time frame of up to 6 years is a standard time taken by Canadian Nuclear Shift Supervisors and Authorized Nuclear Operators to obtain their Canadian Nuclear Safety Commission licenses.
   OPG's Nuclear Training and Conduct of Operations is based on a Nuclear Safety Culture that permeates the organization and guided by the OPG Nuclear Safety Policy N-POL-0001[13].

9. Discussions about CANDU reactor safety – reality check

The two most common accusations relating to CANDU (PHWR) that one can hear are: **positive temperature coefficient** (reactivity would increase with coolant or moderator temperature) and **positive void coefficient** (reactivity would increase during voiding of fuel channels – loss of coolant).

Although positive, the combined moderator-coolant temperature coefficient is small and adequately handled by control and cooling systems. The fuel temperature coefficient of CANDU is close to zero (or small negative depending on the state of fuel). In PWR's, there is an increase in reactivity when the reactor is shutdown that requires compensation. In CANDU there is no such reactivity increase.

While a CANDU has a positive void coefficient, this physical feature is adequately mitigated in all CANDU reactors operating in Canada and in many other countries. Each CANDU reactor, including the **EC6™** design, **has two independent, automatic and fast acting Shutdown Systems,** each capable of fully shutting down a reactor within two seconds. Two CANDU Shutdown Systems (Shut-Off Rods and Liquid Poison Injection) are fully independent of the Reactor Power Control system and of each other. **Shutdown System I involves Shut-Off Rods that penetrate the Moderator area which is not pressurized** (essentially at atmospheric pressure). **Thus, there is no risk of Shut-Off Rod ejection.**
On the other hand, a Control Rod Ejection is a standard design basis accident analyzed for PWR's where Control Rods penetrate the pressure boundary. In PWR's Control Rods are used for both reactor power control and for SCRAMs (reactor trips).
The Positive Void Coefficient of CANDU is further mitigated by operating procedures (power holds during start-up).

For a number of years PHWR (CANDU) safety has been questioned in potential new markets. A classic example of such criticism is Russia where the media like to compare a CANDU design with that of the infamous RBMK, such as the one that exploded in Chernobyl. These attacks intensify whenever Ukraine considers CANDU to make use of its natural Uranium deposits rather than relying on enriched fuel from Russia that considers Ukraine as its "natural market" for Russian built VVER-1000's.
It is true that both RBMK and CANDU are pressure tube reactors and both have positive void coefficients (RBMK's positive void coefficient is particularly large). However, the Chernobyl disaster was due to the way the reactor was run on April 26, 1986 and due to the design of RBMK's shutdown system. RBMK's positive void coefficient would have had no effect on unit safety had the operator not violated fundamental Chernobyl NPP operating and safety procedures. The 'last straw' was the design and operation of RBMK's control/shut-off rods.
Comparing RBMK with CANDU is not reasonable for several reasons. RBMK has vertical, not horizontal fuel channels and a direct steam cycle. A CANDU has horizontal fuel channels and an indirect steam cycle (steam separators versus steam generators). Heat transfer in each reactor follows a different pattern due to dissimilar design. For example, CANDU has an emergency heat removal system through steam generators. RBMK uses light water and graphite as coolant and moderator, while a CANDU uses heavy water in both systems, with its heavy water moderator providing an additional heat sink.
In the Chernobyl reactor there was no upper containment while a CANDU has a concrete containment building surrounding high pressure piping and employs dousing sprays to reduce pressure.
One of the main causes of the Chernobyl disaster was that RBMK used Control Rods of very unusual design for SCRAMs (reactor trips). These rods employed graphite elements

called displacers at the bottom which, in the Chernobyl scenario, added reactivity to the core after the shutdown button had been pushed (note that graphite is RBMK's moderator). CANDU reactors employ shut-off rods fully made from neutron absorbing materials.

In addition, RBMK's Control Rods required at least 10 seconds to become effective depending on the state of the plant. [14].

A CANDU reactor has dual, independent and fast acting Shutdown Systems that are capable of fully stopping the chain reaction within the extremely short time (less than 2 seconds) prescribed by rigorous requirements of the Power Reactor Operating License. [17]. Operating Policies and Principles would not allow the unit to be operated if these limits were not met. CANDU reactor shutdown systems are some of the most advanced engineered systems in the world. Nuclear Shift Supervisors and Authorized Nuclear Operators can only start up a CANDU reactor when both Shutdown Systems are fully operational.

Lastly, the RBMK accident was largely due to operator error. The operator deliberately disabled a number of automatic trip parameters and violated the fundamental policy of having at least 30% of Control Rods inserted in the core. He operated the reactor in an unstable zone, outside of Chernobyl NPP's limits of Design Basis and outside of Licensing Limits. His behaviour was the result of a culture that allowed economic pressure to complete a test to take precedence over safety. The CANDU Operating Policies & Principles and Operating Procedures are designed to prevent the type of operator action that led to the Chernobyl disaster. Normal operation of OPG reactors is well within the Safe Operating Envelope (SOE). This means that there are adequate margins between operating parameters and values allowed by operating procedures. The latter are within Design Basis limits which constitute a boundary of the SOE. The SOE itself is still contained within the Licensing Limits. Adequate margins from the licensing limit boundary must be maintained or else a CANDU reactor is safely shutdown [12, 13, 14].

References:

[1] E-mail on Tritium Emissions vs. DRL's, Feb 3, 2011

[2] Load Tables; Nuclear Engineering International (various years, e.g. Nuclear Engineering International, vol. 54, nr 664, s. 30-35, November 2009).

[3] Jerry Hopwood, Stefan Doerffer, Ron Denom, Ala Alizadeh, Roger Belanger et al: Seminar on CANDU Technology, Warsaw, Poland January 23, 2007 (AECL, SNC-Lavalin, Canada's Trade Commission).

[4] Enhanced CANDU 6 (AECL) http://www.aecl.ca/Reactors/EC6.htm

[5] CANDU reactor http://en.wikipedia.org/wiki/CANDU_reactor

[6] EC-6 Pre Project Review http://www.aecl.ca/NewsRoom/News/Press-2010/100408.htm

[7] CANDU FAQ by J. Whitlock, PhD, http://www.nuclearfaq.ca/cnf_sectionA.htm#ec6

[8] CNSC EC-6 Pre-project Review Phase 1: http://www.nuclearsafety.gc.ca/eng/pdfs/Pre-Project_Design_Review/AECL-EC6_Phase1_Executive_Summary_March2010_E.pdf

[9] AECL: Status Report for Advanced Nuclear Reactor Designs - Report 68

[10] Core Damage Frequencies, Wikipedia http://en.wikipedia.org/wiki/Core_damage_frequency

[11] Generation III reactor, Wikipedia http://en.wikipedia.org/wiki/Generation_III_reactor

[12] Protecting the Design Basis; Spring 2005 Conduct of Engineering Continuing Training Workshop.

[13] Nuclear Safety Culture [N-POL-0001]; Spring 2009 Conduct of Engineering Continuing Training Workshop

[14] [Ref. Report **Chernobyl –A Canadian Perspective** by Dr. V.G. Snell and J.Q. Howieson]

[15] Darlington Generating Station Data Units 1-4 [G&E/1102/Feb 1984]

[16] CANDU Design and Equipment Overview, AECL, Ian Love http://www.enterprisesaskatchewan.ca/AECL-dalton

[17] Nuclear Operating Policies & Principles

[18] E-mails on Modularization J.T. and D. S. to DK; Feb 7th, 2011