



CMD 25-H2.21

Date: 2025-05-05

**Written Submission from  
Dr. Frank Greening**

**Mémoire de  
Dr. Frank Greening**

In the matter of the

À l'égard d'

**Ontario Power Generation Inc.**

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Application to renew power reactor  
operating licence for the Darlington  
Nuclear Generating Station

**Ontario Power Generation Inc.**

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Demande concernant le renouvellement  
du permis d'exploitation d'un réacteur de  
puissance pour la centrale nucléaire de  
Darlington

**Commission Public Hearing  
Part-2**

**Audience publique de la Commission  
Partie-2**

June 24-26, 2025

24-26 juin 2025

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**From:** Frank Greening  
**Sent:** Monday, May 5, 2025 2:41 PM  
**To:** Interventions / Interventions (CNSC/CCSN); Sigouin, Luc  
**Cc:** Tremblay, Pierre; 'Viktorov, Alexandre (CNSC/CCSN)'  
**Subject:** Intervention for the Darlington Relicensing Hearing

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EXTERNAL EMAIL – USE CAUTION / COURRIEL EXTERNE – FAITES PREUVE DE PRUDENCE

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To whom it may concern:

Please accept the following material as an intervention for the CSNC June Hearing on Ontario Power Generation's application to renew its power reactor operating licence for the Darlington Nuclear Generating Station. In addition, I wish to request the CNSC's approval for an online oral presentation of this material at the June Hearing.

For this intervention I would like to focus on Darlington's *Event Initial Report*, CMD 24-M35, issued in September, 2024, which documents the discovery of unexpected (unmonitored) neutron emissions emanating from pressure tube waste containers in the Darlington Waste Management Facility. OPG noted that it was not anticipated that neutron radiation would be a significant hazard in the work required to retube the reactors, nor from managing the resulting waste. OPG added that further investigation and analysis are being undertaken by OPG and Bruce Power to characterize and determine the cause of the neutron source term associated with refurbishment waste.

It appears that the current Canadian nuclear industry position on this issue is that these neutron emissions are caused by the buildup of Californium-252, Cf-252, in heavily irradiated pressure tubes. Cf-252 is a neutron activation product of U-238 trace impurities, (~ 1.5 mg/kg), in the Zr-2.5Nb alloy used to fabricate CANDU pressure tubes. Bruce Power has estimated that a fast neutron emission rate of approximately  $10^7$  neutrons per second per pressure tube is to be expected from the spontaneous fission of Cf-252 that has accumulated in pressure tubes with greater than 20 EFPY of in-reactor exposure – which is certainly the case for the Bruce B and Darlington pressure tubes removed during current refurbishments.

It may be shown that the so-called *fast neutron first collision dose rate* to exposed refurbishment workers is through elastic scattering of neutrons and is certainly greater than 1 mGy/hour. However, the *in vivo* neutron activation of elements in the human body such as nitrogen, calcium, phosphorus, potassium, sodium and chlorine, will make additional contributions to this dose rate. The energy of Cf-252 spontaneous fission neutrons peaks at about 1 MeV. The Relative Biological Effectiveness, or RBE, of these neutrons is about 10 so that the equivalent dose rate to exposed workers would be at least 10 mSv/h, which is much greater than the equivalent dose rate from the Co-60 and Nb-94 gamma rays emitted by irradiated pressure tubes.

However, it is also worth noting that there are at least *two* additional factors that could boost the rate of neutron emissions from pressure tubes and these are (i) The presence of beryllium, and (ii) The presence of alpha emitting radionuclides such as Pu-239/240, Am-241 and Cm-244, on the inside surfaces of irradiated pressure tubes. I have considerable analytical data on the concentration of these species on removed pressure tubes. Beryllium, which stems from the brazing alloy used to

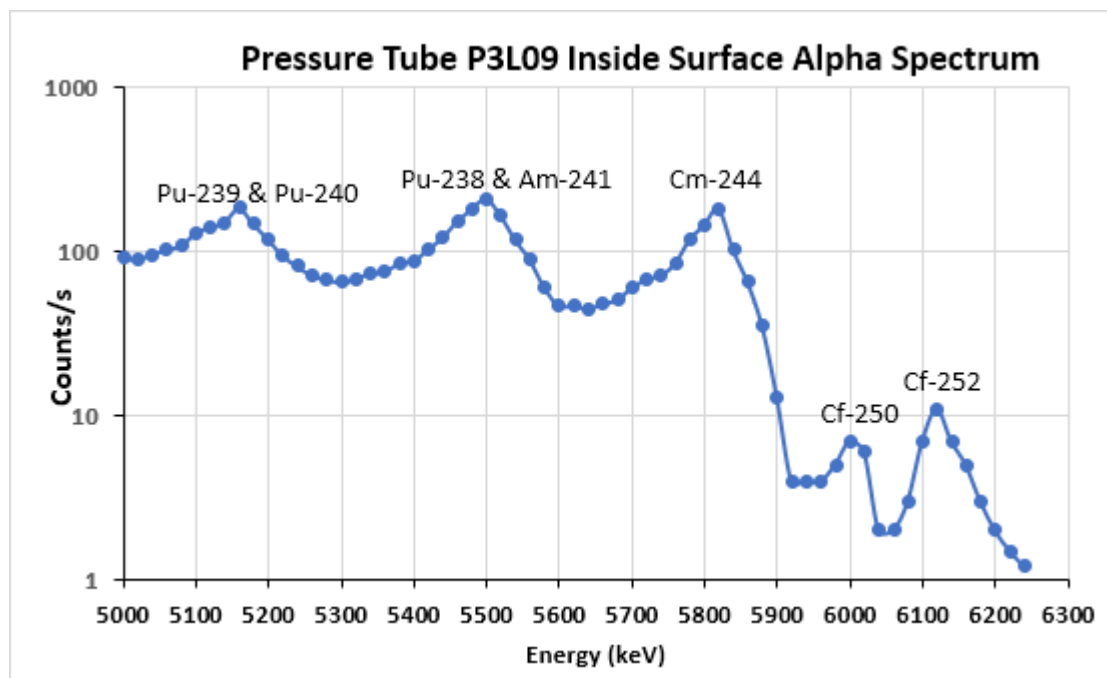
attach bearing pads to fuel bundles, is a well-known neutron emitter due to the relatively high cross sections of the Be-9 (n,2n) Be-8 and the Be-9 ( $\alpha$ ,n) C-12 reactions.

What is most disconcerting about this unmonitored radiation dose to refurbishment workers is that both OPG and Bruce Power admitted at the time of the discovery of these emissions in June 2024, that they didn't know what was causing these neutron emissions.

In 1977 AECL reported ORIGIN-code calculations of the production of transuranics by the neutron irradiation of natural uranium for periods up to 1 year. These calculations show that, after a 1-year exposure, a neutron emission rate from the spontaneous fission of Cm-244 is about  $1.3 \times 10^6$  neutrons per second per pressure tube. I have published an article on the production of Cm-244 in CANDU reactors. (See "*Cm-244 Contributions to the Alpha Source Term of CANDU Reactors*". Kerntechnik Volume 86, pages 106 – 115, (2021). In this article I show that Cm-244 builds up in irradiated pressure tubes and undergoes spontaneous fission and therefore continuously emits neutrons.

In 2004 AECL reported the results of ORIGIN code calculations on the production of transuranic isotopes in natural uranium for irradiations up to 30 years. Using this data, and assuming that a Zr-2.5Nb pressure tube contains about 80 mg of uranium impurity, it follows that a pressure tube after 30 years of in-reactor exposure would contain sufficient Cf-252 to emit  $6.75 \times 10^6$  neutrons per second per pressure tube.

Thus, it certainly looks like Cf-252 is the most likely source of neutron emissions from irradiated pressure tubes, but this needs to be experimentally verified. And, on that issue, please note I have alpha spectrometric data that confirms the presence of Cf-252 on the inside surfaces of removed pressure tubes. For example:



I find it very curious that Bruce Power and OPG have apparently not used alpha spectrometric techniques to confirm the presence of Cf-252 in pressure tube waste.

But I also have to ask: Why were health physicists at Darlington and Bruce Power unaware of this potential hazard to refurbishment workers? The answer appears to be: Because of a lack of

understanding of the radiochemical properties of neutron irradiated uranium. And this is not the first time that a similar lack of knowledge of reactor physics and chemistry led to the unmonitored exposure of refurbishment workers to significant radiation hazards, as summarized in the Table below.

Reactor Units	Date	Unmonitored Hazard
Pickering 1 & 2	1985	Carbon-14 Particulate
Point Lepreau	2008	Alpha Particulate
Bruce Unit 2	2009	Iron-55 Particulate
Bruce Unit 1	2010	Alpha Particulate
Darlington Unit 2	2018	Alpha Particulate

What is urgently needed from both Bruce Power and Darlington are *Root Cause Reports* which explain how it is possible for these reactor operators to be unaware of the hazardous properties of reactor components refurbishment workers handle every day. In addition, *Extent of Condition Reports* are needed to consider how many times unmonitored neutron emissions posed hazards during past refurbishments at Bruce, Pickering and Darlington. And, until such reports are issued and accepted by the CNSC, with proof of lessons learned by Bruce Power and OPG, these CANDU reactor operators *should be prohibited from undertaking any additional refurbishment activities on any of their reactor units.*

Sincerely,

Dr. F. R. Greening