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Written submission from Bruce Power

Mémoire écrit de Bruce Power

Update from OPG on the Potential neutron exposure of workers

Mise à jour par OPG sur l'exposition potentielle des travailleurs aux neutrons

Commission Meeting

Réunion de la Commission

February 25 and 26, 2025

25 and 26 février 2025

Canada

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January 31, 2025

BP-CORR-00531-05900

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Dr. Alexandre Viktorov
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Canadian Nuclear Safety Commission
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Dear Ms. Salmon and Dr. Viktorov:

Bruce A and B: Update to Request Pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers

The purpose of this letter is to provide an update on the following items, as committed in Reference 1 and required pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*, and to request closure of Action Item 2024-07-32522 (Reference 2):

1. Methods, models and modeling assumptions used to ascertain worker neutron doses,
2. A characterization of the unanticipated neutron dose rates, including a description of, and the values of, the general and working field dose rates,
3. Update to the estimate of unaccounted dose, with a corresponding update to conclusions regarding regulatory dose limits,
4. A characterization of the neutron source term, and
5. Confirmation that affected parties have been informed.

Attachment A provides a detailed update on the above items. As such, Bruce Power requests closure of Action Item 2024-07-32522.

If you require further information or have any questions regarding this submission, please contact Mr. Maury Burton, Senior Director, Regulatory Affairs, at (519) 361-2673 extension 15291, or maury.burton@brucepower.com.

Yours truly,

Digitally signed by Maury Burton
Date: 2025.01.31 11:11:44 -05'00'

Maury Burton
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Attach.

References:

1. Letter, M. Burton to A. Viktorov, “Bruce A and B: Update to Request Pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*: Potential Neutron Exposure of Workers”, July 15, 2024, e-Doc 7322127, BP-CORR-00531-05625.
2. Letter, A. Bulkan to M. Burton, “Bruce A and B: Response to Request Pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations* – Potential Neutron Exposure of Workers – New Action Item 2024-07-32522”, November 4, 2024, BP-CORR-00531-05973.

Attachment A

Update on Subsection 12(2) of the *General Nuclear Safety and Control Regulations* – Potential Neutron Exposure of Workers

Attachment A:
Update on Subsection 12(2) of the *General Nuclear Safety and Control Regulations* – Potential Neutron Exposure of Workers

As committed in Reference A1, Bruce Power is providing an update on the following, pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*:

Methods, models and modeling assumptions used to ascertain worker neutron doses

Bruce Power performed an investigation into neutron dose exposures as a result of the discovery of a neutron hazard present on the Retube Waste Containers (RWCs) containing volume reduced Pressure Tubes (PTs) and Calandria Tubes (CTs) during the Major Component Replacement (MCR) campaigns in Units 3 and 6. Extent of condition characterization surveys limit the likely exposure resulting in a recordable dose greater than 0.1 mSv (10 mrem) to individuals directly involved in the handling of these RWCs. An initial investigation report has been submitted to CNSC staff for review (Reference A2) of the dose assignments identified, with a final report being submitted in accordance with REGDOC-2.7.2, Volume 1.

Event task dose reconstruction was the method used to model the missed neutron dose. The exposure assessment consisted of the following:

1. Hazard Characterization – Neutron dose rate surveys of RWCs
2. Exposure Model – Time and motion study of RWC handling tasks via video review of Unit 3 MCR (MCR3) work evolutions
3. Personnel Identification – Determining which individuals were involved in which tasks based on recorded datasets
4. Method Validation – Comparison to NP-2 'Snoopy' neutron meter doses for similar work
5. Evaluation of Significance – Comparison of calendar year doses against limits

The model created was then applied to each individual RWC and scaled as required for Unit 6 MCR (MCR6) to account for radioactive decay. Where the recorded dataset could not justify excluding an individual from having participated in the execution of a given task, the individual was conservatively included and assigned neutron dose for that task.

Assumptions used in the development of this model were:

- The upper quartile dose rates of the respective RWCs provides good representation of potential exposure to workers.
- The source of neutrons is through the activation of Uranium-238 (U-238) to Californium-252 (Cf-252) resulting in an effective half-life of 2.647 years.
- Dose rates in MCR6 are conservatively represented by decay corrected calculations.
- Occupational factors determined through MCR3 modeling are reflective of the MCR6 execution
- Only workers directly involved in the processing of RWCs would have received a potential neutron dose exposure requiring dose assignment.

The model for MCR3 was reviewed by external industry experts through a COG project and found to be reasonable and would be expected to yield valid results.

The risk of neutron exposure during the Bruce A Units 1 and 2 Restart project was also assessed. Through Origen-S modeling and Monte Carlo simulation, contact neutron dose rates were determined to be a maximum of 7.41×10^{-2} μSv/h (7.41 μrem/h) and therefore did not pose a hazard to workers during the execution of Restart 1 and 2.

Beyond the risk of handling RWCs, it is expected that a low neutron dose rate could exist during the execution of the single fuel channel replacement (SFCR), but that the need for neutron dose assignment is unlikely. The upcoming Bruce B Unit 5 outage will be used to assess whether the observed neutron dose rates warrant further neutron dose evaluations associated with historical SFCR work.

A characterization of the unanticipated neutron dose rates, including a description of, and the values of, the general and working field dose rates.

Neutron dose rate measurements were performed on 15 RWCs, covering all four combinations of PT and CT from MCR3 and MCR6. All RWCs in the custody of Bruce Power after the hazard discovery date of June 5, 2024 were surveyed using NP-2 "Snoopy" survey meters. Additionally, with the cooperation of Ontario Power Generation (OPG), arrangements were made to take neutron dose rate measurements of one PT and two CT RWCs from MCR6. In all cases, measurements were taken at multiple distances from each of the four sides (Left, Front, Right, and Back). The data is presented in Table 1 below.

Table 1: Measured upper quartile neutron dose rates, without decay correction, of PT and CT RWCs from MCR3 and MCR6.

Distance (cm)	MCR3-PT μSv/h(mrem/h)	MCR3-CT μSv/h(mrem/h)	MCR6-PT μSv/h(mrem/h)	MCR6-CT μSv/h(mrem/h)
30	115 (11.5)	39 (3.9)	98 (9.8)	42 (4.2)
100	50 (5.0)	25 (2.5)	53 (5.3)	21 (2.1)
200	25 (2.5)	10 (1.0)	25 (2.5)*	11 (1.1)*
300	13 (1.3)*	4 (0.4)*	11 (1.1)*	5 (0.5)*

***Extrapolated data**

Additionally, distances to 25 μSv/h (2.5 mrem/h) and 10 μSv/h (1 mrem/h) were noted.

To characterize the MCR6 2021 neutron hazard, the MCR6 measured surveys were decay corrected assuming the 2.647 year half life of Cf-252, resulting in the following calculated dose rates (Table 2).

Table 2: Calculated decay corrected neutron dose rates for MCR6 PT and CT RWCs

Distance (cm)	MCR6-PT μSv/h(mrem/h)	MCR6-CT μSv/h(mrem/h)
30	223 (22.3)	96 (9.6)
100	121 (12.1)	48 (4.8)
200	57 (5.7)	24 (2.4)
300	26 (2.6)	11 (1.1)

Update to the estimate of unaccounted dose, with a corresponding update to conclusions regarding regulatory dose limits

For MCR3, the assessed missed neutron collective dose was calculated to be 12.17 mSv (1.217 rem), with the maximum missed individual dose being 0.7 mSv (70 mrem).

For MCR6, the assessed missed neutron collective dose was calculated to be 87.45 mSv (8.745 rem), with the maximum missed individual dose being 2.01 mSv (201 mrem).

When the unaccounted for missed neutron dose was added to the individuals' measured doses in the associated year, no exposure control, administrative or regulatory limits were exceeded.

The individual maximum dose is in line with original projections, while the collective missed neutron is higher than forecasted for MCR6. The higher than forecasted collective dose is a result of being unable to exclude workers from potentially supporting these evolutions in 2021 based on the records available.

A characterization of the neutron source term

Following the event, a neutron spectroscopy campaign was initiated with two main goals:

1. To ensure the neutron fields outside the containers fell within the detection range of our neutron survey instruments.
2. To measure the neutron spectrum outside the containers and analyze it for features that could reveal the neutron production mechanism inside.

To date, almost 30 neutron spectroscopy measurements have been performed on five containers from Unit 3 and four containers from Unit 6. Half of these containers held irradiated PT components, while the other half contained irradiated CT components. Three possible mechanisms for neutron emission were considered: photoneutrons, spontaneous fission neutrons, and (α, n) produced neutrons. The approach used to identify the dominant mechanism involved excluding possibilities using gamma-ray and neutron spectroscopy measurements, supported by Monte Carlo simulations.

Findings indicated that the neutron production mechanism was consistent across both PTs and CTs. However, containers with higher neutron dose rates suggested the mechanism depended on the mass of the material inside. Variation in dose rates based on the components' location within the reactor core was also observed. Containers with components from the core center had higher dose rates than those from the periphery, suggesting that neutron activation of impurities played a role. Exposure to a greater neutron flux resulted in a greater neutron dose rate.

Gamma spectroscopy of smaller, unshielded PT and CT samples showed no significant gamma rays above 2.2 MeV, ruling out photoneutrons as the primary mechanism. Monte Carlo simulations also showed that the deuterium content would need to exceed 100,000 ppm for significant photoneutron production, but historical data showed deuterium levels in the tubes were only in the tens of ppm.

Previous waste characterization reports suggested fission products like Cf-252, which has a high neutron yield, could be present. Neutron spectroscopy results showed evidence of high-energy neutrons after accounting for the shielding and moderation from the container. Gamma spectroscopy of the bulk containers also detected high-energy gamma rays in the 6-9 MeV range, consistent with ongoing fission.

High-fidelity Monte Carlo simulations of the containers and the source were completed, which matched the measured neutron spectra. These simulations allowed Bruce Power to estimate a neutron emission rate of approximately 10^7 neutrons per second. This emission rate was consistent with spontaneous fission from Cf-252, which likely originated from U-238 impurities in the base metal (around 1.3 ppm) that had been exposed to continuous neutron flux in the CANDU reactor for 20-30 years.

To validate Cf-252 as the source, a longitudinal neutron spectral survey was performed on certain containers previously surveyed, and the half-life is consistent with Cf-252. One final survey will be performed in the June 2025 timeframe to complete the longitudinal study, validating for certain, with measured data, Cf-252 as the neutron source.

Confirmation that affected parties have been informed

Bruce Power prioritizes the protection of workers. Since becoming aware of this issue in June 2024, Bruce Power has increased communications through in-person briefings, podcasts, and written communication updates. Every effort has been made to contact workers for whom a dose assignment was required, through direct or registered mail.

References:

A1. Letter, M. Burton to A. Viktorov, “Bruce A and B: Response to Request Pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*: Potential Neutron Exposure of Workers”, June 24, 2024, e-Doc 7306524, BP-CORR-00531-05578.

A2. Email, J. Thompson to A. Bulkan, “Major Component Replacement Retube Waste Container Retroactive Neutron Exposure Assessment”, January 23, 2025, BP-CORR-00531-06206.