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Written submission from Ontario Power Generation Inc.

Mémoire écrit de Ontario Power Generation Inc.

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

OPG Proprietary

January 31, 2025

CD# N-CORR-00531-24262

Ms. CANDACE SALMON
Commission Registrar

Dr. ALEXANDRE VIKTOROV
Director General
Directorate of Power Reactor Regulations
Canadian Nuclear Safety Commission
P.O. Box 1046
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Ottawa, Ontario, K1P 5S9

Dear Ms. Salmon and Dr. Viktorov:

OPG – Response to CNSC 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 OPG's response to CNSC staff request (Reference 1) to Potential Neutron Exposure of Workers as committed in Reference 2 as well as the methods, models and modelling assumptions to assign worker dose and the outcome of our investigation on the cause of the neutron source as committed in Reference 3 and Reference 4.

This response is prepared pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*, and in accordance with Darlington NGS PROL 13.04/2025, Pickering NGS PROL 48.01/2028, Darlington, Pickering and Western Waste Management Facility's Operating Licenses, WFOL-W4-355.00/2033, WFOL-W4-350.00/2028 and WFOL-W4-314.00/2027 respectively.

Attachment 1 provides OPG's response to CNSC staff request in accordance with Subsection 12(2) of the *General Nuclear Safety and Control Regulations.*

This submission completes Action Request (AR) 28267994, OPG requests the closure of Action Item 2024-OPG-33816.

Should you have any questions, please contact Lauren CORKUM, Director Radiation Safety, at 905-718-1327or via email at lauren.corkum@opg.com.

Sincerely,

Allan Grace
Senior Vice President
Darlington Nuclear

Paul Seguin
Senior Vice President
Pickering Nuclear

Kapil Aggarwal
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A. El-Merhi – CNSC (Ottawa)
P. MacDonald – CNSC (Ottawa)

Attach.

Reference:

1. CNSC Letter, A. Viktorov to A. Grace, R. Geofroy, K. Aggarwal, “Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers” June 13, 2024, e-Doc# 7299458, CD# N-CORR-00531-24101.

2. OPG Letter, A. Grace, P. Seguin, K. Aggarwal to C. Salmon, A. Viktorov, “OPG – Response to CNSC Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers” June 24, 2024, CD# N-CORR-00531-24074.

3. OPG Letter, A. Grace, P. Seguin, K. Aggarwal to C. Salmon, A. Viktorov, “OPG – Response to CNSC Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers”, July 15, 2024, CD# N-CORR-00531-24106.

4. OPG Letter, A. Grace, P. Seguin, K. Aggarwal to A. Mathai, R. Richardson, N. Greencorn, "OPG – Response to CNSC Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers", December 13, 2024, CD# N-CORR-00531-24274.

OPG letter, A. Grace, P. Seguin, K. Aggarwal to C. Salmon and Dr. A Viktorov, “OPG – Response to CNSC Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers”, CD# N-CORR-00531-24262

Attachment 1

OPG Response to CNSC Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers

Prepared by: E. Schwartz

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Total 7 Pages

Attachment 1

1. **A summary of the work activities with the most potential for unaccounted dose and an associated conservative estimate of the magnitude of that dose.**

OPG Response:

Ontario Power Generation (OPG) has assessed the work activities associated with neutron hazards at its facilities, including the refurbishment irradiated components waste stream, as well as for Darlington and Pickering operating units.

OPG has assessed and assigned previously unaccounted neutron dose, see Table 1. The threshold for making a change for a worker's neutron dose record is 0.1 mSv (10 mrem) within a quarter.

OPG Operating Site	Number of Workers with Assigned Neutron Dose	Assigned Maximum Individual Neutron Effective Dose mSv (mrem)	Assigned Collective Neutron Effective Dose mSv (mrem)
Darlington Refurbishment Unit (DNRU) 1	3	0.17 (17)	0.41 (41)
DNRU 2	49	0.26 (26)	6.82 (682)[1]
DNRU 3	1	0.13 (13)	0.13 (13)
DNRU 4	- [2]		
Western Waste Management Facility (WWMF) Campaign Major Component Replacement (MCR) Unit 6 – Second Quarter (Q2) 2021	8	0.35 (35)	1.56 (156)
WWMF Campaign MCR Unit 3 - Q2 2024	4	0.17 (17)	0.49 (49)
Darlington Waste Management Facility (DWMF)	0	0	0
Pickering Waste Management Facility (PWMF)	0	0	0
Darlington NGS	0	0	0
Pickering NGS	0	0	0

Table 1: Neutron dose previously unaccounted and unassigned

[1] DNRU 2 was the first Darlington NGS Unit to be refurbished. The Pressure Tubes (PT) were removed from the reactor core and moved separately from the Calandria Tubes (CT). For DNRU 3, 1 and 4, the CT and PT were removed from the core, placed into a flask and moved as a set.

[2] Neutron in the Refurbishment waste stream was identified prior to the DNRU4 CT and PT removal series. All worker doses were assessed, assigned and recorded in the OPG Radiation Dose System.

2. Assessment of whether the unaccounted dose has caused any worker to exceed the effective dose limit for the current one-year dosimetry period, as well as the current and previous five-year dosimetry periods.

OPG Response:

As per Table 1 above, there has been no worker exceedance of the regulatory effective dose limit at OPG for:

- the current one-year dosimetry period,
- the current five-year dosimetry period (01 January 2021 – 31 December 2025),
- The prior five-year dosimetry period (01 January 2016 – 31 December 2020).

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

OPG Response:
A consistent approach for method, model and modelling assumptions has been applied for all OPG facilities to ascertain potential worker neutron doses and is in accordance with the Dosimetry Service Licence requirements.

OPG's neutron dosimetry program is applicable to all its facilities and enables use of indirect neutron dosimetry in low dose rate fields through application of:

- Characterized neutron dose rates as measured with an approved instrument and time spent in the field; or
- Application of operating experience using ratios of gamma to neutron dose
  - The gamma dose as recorded by the electronic personal dosimeter (EPD): the measured neutron dose rate and time spent in field (neutron dose).

Darlington Nuclear Refurbishment (DNR):
With the presence of a neutron hazard identified prior to PTs and CTs being extracted from Darlington Nuclear Refurbishment Unit (DNRU) 4, extensive dose rate surveys were conducted throughout the series. The initial set of surveys focused on understanding the neutron dose rate distribution along the length of a full PT/CT flask. Two of the four flasks were from channels close to the centre of the core, N-13 and N-15, while the other two were closer to the periphery, O-20 and S-05. Results of the flask neutron profile surveys are shown in Table 2 and illustrated in Figure 1. The gamma dose rate profile along the loaded PT/CT flask, which had been extensively examined on previous units, was validated for DNRU4 and illustrated in Figure 2.

Channel	Neutron Dose Rate μSv/ h (mrem/h)		
	Inboard End	Centreline	Outboard End
O-20	0.6 (0.06)	15 (1.5)	0.6 (0.06)
N-13	0.6 (0.09)	9 (0.9)	0.8 (0.08)
N-15	0.9 (0.09)	13 (1.3)	0.9 (0.09)
S-05	0.5 (0.05)	10 (1)	0.8 (0.08)
Average	0.7 (0.07)	12 (1.2)	0.8 (0.08)

Table 2: PT/CT Flask Neutron Dose Rate Profile Surveys

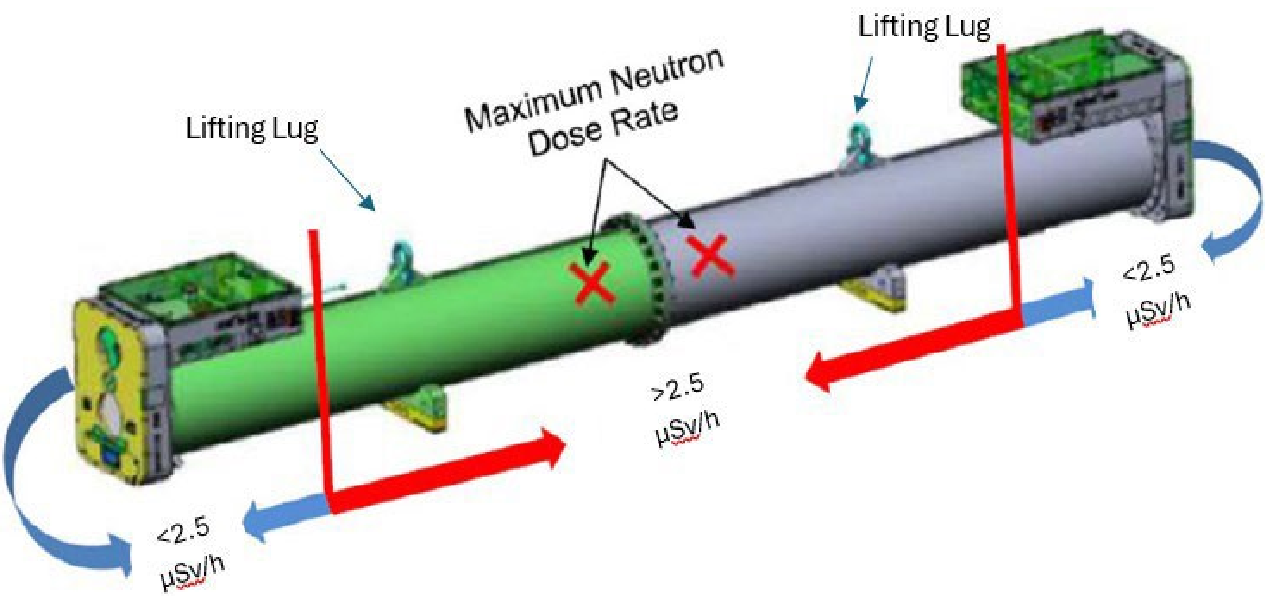

Figure 1: Neutron dose rate profile of PT/CT Flask

Given that neutron surveys of the flasks from previous refurbished units were unavailable, a review of the gamma dose rates at the maximum neutron dose rate location was performed, this data was available for both DNRU2 (PT Removal only) and DNRU3. These surveys were not performed for CT removal during DNRU2 nor for the DNRU1 campaign.

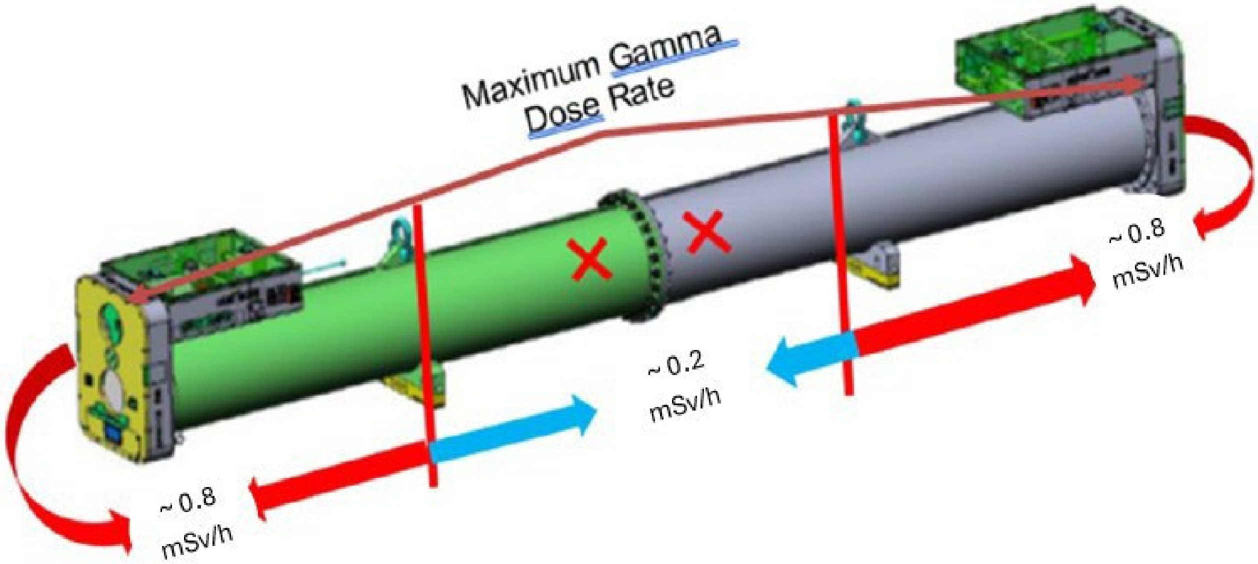

Figure 2: Gamma dose rate profile of PT/CT Flask

To estimate the neutron dose to workers for DNRU 2, 3, and 1, measured neutron dose rate and exposure time from DNRU 4 was applied. The measured neutron dose rate was compared to the gamma dose as recorded by the electronic personal dosimeter (EPD).

For the purposes of subsequent retrospective neutron dose assignment using the indirect method, Responsible Health Physicists for DNR selected the mode value of the ratio distribution as the factor by which neutron dose would be assigned based on worker EPD results. The 10:1 ratio was selected based on the following:

- The gamma and neutron dose rate measurements used to compute the ratio were performed at a point on the flask that would result in the most conservative neutron dose assignments. That is, where gamma dose rates were at their lowest and neutron dose rates were at their peak.
- During the PT/CT removal process, workers are only required to be in close proximity to the flask during flask door decontamination, manual closing, and flask handling operations. During these steps the work is predominantly performed at either end of the flask where gamma dose rates peak, and neutron dose rates are at their minimum.
- The only occasion when workers are required to approach the centre of the flask was to attach the rigging to the lifting lugs. This results in an additional factor of conservatism being applied as the gamma to neutron ratio would be significantly higher (resulting in lower neutron dose) at the ends of the flask.
- Ratio distribution showed that more than 85% of the gamma to neutron ratios are at or above the mode value of 10.

Western Waste Management Facility (WWMF):
Refurbishment waste arising from Bruce Power Unit 3 and Bruce Power Unit 6 Major Component Replacement (MCR) waste are stored in Retube Waste Containers (RWC). These robustly designed waste containers are constructed of steel only (no high-density concrete) and therefore the neutron dose rates are higher than that encountered from Darlington NGS Darlington Storage Overpacks (DSOs) containing similar refurbishment material.

Radiological surveys consisting of gamma and neutron measurements were performed around recently delivered Bruce Unit 3 RWCs in 2024 as well as inside the WWMF Retube Component Storage Building (RCSB). These measurements allowed for an accurate and conservative neutron to gamma ratio to be determined for work during 2021 Bruce U6 RWC receipts (including decay correction for Cf-252) as well as that performed in 2024 during Bruce U3 RWC receipts. Similarly, time and motion observations showed that each RWC receipt and storage was quite repetitive and routine in nature.

Once neutron to gamma ratios were determined, they were applied to EPD results from each campaign that were tracked with unique Radiation Exposure Permits consistent with the indirect method permitted in OPGs Neutron dosimetry framework.

For the purposes of retrospective neutron dose assignment using the indirect method, WWMF Health Physicists selected a conservatively developed neutron to gamma ratio for each campaign to reflect the exposure situation for each scenario.

Different ratios were used for the two campaigns based on the following:

- Noted differences in gamma and neutron dose rates between Bruce U3 and Bruce U6 RWCs
- Different neutron to gamma ratios based on field measurements
- Neutron to gamma ratios at the 1-3 m exposure distance were used in both campaigns

As it relates to worker exposure, it was shown that generally only the forklift driver and spotter would have had unaccounted neutron exposure during Bruce U3 and Bruce U6 RWC receipts (gamma and neutron) due to their extended occupancy in the RCSB itself.

Final gamma to neutron ratios for each campaign were 1:1.4 for Bruce Unit 3 RWC and 1: 2.2 for Bruce Unit 6 RWC.

4. A characterization of the neutron source term.

OPG Response:
OPG completed a formal investigation to fully understand the neutron source. 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.

Following the event discovery and in collaboration with industry partners and vendors, 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.

Neutron spectroscopy measurements have been performed on five(5) containers from Bruce Power Unit 3 and four(4) containers from Bruce Power Unit 6 as well as PT and CT removed from Pickering Nuclear Generation Station.

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. The higher the neutron flux the components were exposed to, the higher the neutron dose rates.

Gamma spectroscopy of smaller, unshielded PT and CTs samples showed no significant gamma rays above 2.2 MeV, eliminating photoneutrons as the primary mechanism. Monte Carlo simulations also showed that the deuterium content would need to be implausibly high for significant neutron generation to occur.

Previous waste characterization reports suggested fission products like Californium-252 (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.

Monte Carlo simulations of the containers and the source were completed, which matched the measured neutron spectra. These simulations allowed us 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 Uranium-238 (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 repeat neutron spectral survey was performed after a period of several months on a container previously surveyed, and the half-life is consistent with Cf-252.

A CANDU Owners Group (COG) Joint Panel of experts reviewed OPG's RCI to characterize the neutron source term and the phenomenon that generated the unanticipated neutron hazard and found OPGs investigative approach, measurements and modelling were appropriate. The COG Joint Panel agreed with OPGs conclusion that the neutron radiation fields were due to prolonged (greater than 20 years) irradiation of reactor components that have trace impurities of natural Uranium. The production and ingrowth of Californium-252, and the spontaneous fission of ^{252}Cf produced the majority of the neutron signal.

5. Confirmation whether Ontario Power Generation Inc. included a neutron source term in their original source term characterization of reactor component waste.

OPG Response:
Addressed in OPGs previous correspondence (Reference A-1). OPG can provide more information to the CNSC upon request.

6. Additional work controls implemented to mitigate future exposures.

OPG Response:
As previously communicated to the CNSC in Reference A-1, once the presence of neutrons was identified, OPG Health Physicists directly oversaw the initial surveys and field controls to mitigate and assess the magnitude of the neutron hazard.

- Extent of condition surveys were completed across all of OPG's Nuclear facilities.
- Radiation exposure permits and hazard boards were updated and communicated to staff to reflect in-field conditions.
- Operational controls, barriers and signage were deployed.
- Expanded the scope of neutron surveys across OPG facilities.
- Meetings to facilitate direct discussions with field staff were conducted in affected departments and trade groups. Health Physicists were present to promptly address any worker comments and concerns.
- OPG Radiation Protection Governance procedures for dosimetry and radioactive work planning have been updated.
- Radiation Protection Training Material has been updated to incorporate Operating Experience (OPEX) from this event.
- Industry wide OPEX sharing is taking place and the incorporation of assessments of neutron hazards are being factored into future MCR and Pickering NGS Refurbishment plans.

7. Confirmation that affected parties have been informed.

OPG Response:

Since becoming aware of this neutron event in June 2024, OPG prioritized the protection of workers and the communication of information on the work to understand the mechanism, determine the cause and to complete dose reconstruction and reassignment so that affected workers are informed of any change to their dose record.

All workers for whom a dose re-assignment was required, as per Table 1 have received or were sent by registered mail a personalized communication along with an up-to-date life occupational dose report that includes their neutron dose assignments.

Reference: A-1 OPG Letter, A. Grace, P. Seguin, K. Aggarwal to C. Salmon, A. Viktorov, "OPG – Response to CNSC Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers", July 15, 2024, CD# N-CORR-00531-24106.

Summary of Regulatory Commitments, Regulatory Obligations and Regulatory Management Actions Made/Concurrence Requested

CD# N-CORR-00531-24262

Submission Title: OPG – Response to CNSC Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Potential Neutron Exposure of Workers

Regulatory Commitments (REGC):

No.	Description	Date to be Completed
	None	

Regulatory Management Action (REGM):

No.	Description	Date to be Completed
	None	

Regulatory Obligation Action (REGO):

No.	Description	Date to be Completed
	None	

Concurrence Requested: None