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**Written submission from
Frank R. Greening**

**Mémoire de
Frank R. Greening**

**Regulatory Oversight Report for
Canadian Nuclear Power
Generating Sites: 2018**

**Rapport de surveillance
réglementaire des sites de centrales
nucléaires au Canada : 2018**

Commission Meeting

Réunion de la Commission

November 6, 2019

Le 6 novembre 2019

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From: Frank Greening
Sent: September 19, 2019 11:47 AM
To: Velshi, Rumina (CNSC/CCSN)
Cc: Interventions (CNSC/CCSN); Purvis, Caroline (CNSC/CCSN); Fabian Mendoza, Melissa (CNSC/CCSN); Jin, John (CNSC/CCSN); McDougall, Glen (CNSC/CCSN); Rinker, Mike; barrettj@cna.ca; Catherine.McKenna@parl.gc.ca; 'Locatelli,Sunni (CNSC/CCSN)'; Elder, Peter (CNSC/CCSN); Amarjeet.Sohi@parl.gc.ca; Frappier,Gerry (CNSC/CCSN); Levert, Louise (CNSC/CCSN)
Subject: Regulatory Oversight Report

To whom it may concern:

Please accept this email as an intervenor comment on the CNSC’s September 2019 draft *Regulatory Oversight Report for Canadian Nuclear Power Generating Sites: 2018*. My comments will address two issues: (i) The question of the fitness-for-service of pressure tubes in Pickering, Bruce and Darlington Units, and more specifically the validity of the data presented in the CNSC’s *Appendix G*, (pages 271 - 272), of the *Regulatory Oversight Report*, (ROR); (ii) The precision and accuracy of the effluent monitoring data presented in *Appendix H*, (pages 273 – 282) of the ROR.

(i) Fitness-for-Service and Appendix G:

The first, and most obvious problem with the information presented in the table that forms the basis of *Appendix G*, is that the H_{eq} data are reported to 0.1 ppm, that is a precision of about 0.2 %. An obvious problem with data reported to this level of implied precision is that [H]/[D] concentrations in irradiated pressure tubes can only be measured down to about 0.4 ppm, with an uncertainty of $\pm 5\%$, using High Vacuum Extraction Mass Spectrometry (HVEMS) – the primary source of measurement data for [H] and/or [D] in pressure tube material.

In addition, HVEMS measurements of [D] in pellet or scrape standards in the concentration range 5 – 25 ppm show a slight, $\sim 4\%$, low bias with a standard deviation of about $\pm 3\%$. Thus, it is entirely meaningless to report H_{eq} data to within 0.1 ppm as we have in the CNSC’s *Appendix G*. To make matters worse, *Appendix G* provides no information on the source or nature of the reported H_{eq} data. Certainly, we *know* the end-of-service life values for H_{eq} in *Appendix G* are calculated, not measured, but if the present H_{eq} values can only be measured to say ± 1 ppm, future values can only be predicted to the same or lower precision.

A second, and more serious concern with the data presented in *Appendix G* of the CNSC’s *Regulatory Oversight Report* (ROR) relates to the numerical values quoted for pressure tube H_{eq} concentrations as of January 1st, 2019, and the anticipated concentrations at the end-of-service dates of CANDU Units at Pickering, Bruce and Darlington. The reason for this concern is that the data presented in *Appendix G* of the CNSC’s *Regulatory Oversight Report* do not agree with equivalent values of H_{eq} presented by the CNSC at a Commission meeting held on January 23rd 2018 as reported in CMD 18-M4. This discrepancy is particularly apparent in the end-of-service predictions in CMD 18-M4 compared to the ROR’s *Appendix G*, as shown in Table 1, below:

Table 1: End-of-Service Max H_{eq} Projections as Reported by Two CNSC Documents

Station	End-of-Service Max H_{eq} Projections
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	CMD 18-M4 (H_{eq} , ppm)	ROR Appendix G (H_{eq} , ppm)
Pickering B	82	71
Darlington Units 1, 3, 4	127	72
Bruce A (Units 3,4)	105	< 120
Bruce B	160	120

I would ask the CNSC to tell us: Which of these end-of-service H_{eq} values should we believe?

An additional concern with the H_{eq} data presented in the ROR's *Appendix G*, (and the CNSC's CMD 18-M4), stems from the fact that some of the reported data do not satisfy the criterion set out in CSA N285.4 for the maximum acceptable rate of change in H_{eq} . This data was measured as part of mandated periodic inspections of CANDU nuclear power plant components; the portion of the CSA N285.4 Standard dealing with the rate of change of H_{eq} is shown under item 12.3.5.2 below:

N285.4-09

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12.3.4.2 Procedures

The following requirements for procedures shall apply:

- (a) A written procedure(s), complete with technical justification for any procedure use, shall be prepared for each measurement method used. This shall include the procedure for obtaining material samples to be used in measurement(s), if applicable.
- (b) The procedure(s) outlined in item (a) shall be submitted to the regulatory authority for acceptance.

12.3.4.3 Calibration specimens

Calibration specimens of known condition shall be used to calibrate measurement equipment over the full range of measurement values expected.

12.3.4.4 Personnel qualification

The licensee shall ensure that personnel are trained and qualified in the use of H_{eq} determination procedures. Training and qualification records shall be retained by the licensee.

12.3.4.5 Recording criteria

All data collected shall be recorded to permit comparison with previous and future measurements.

12.3.4.6 Reporting criteria

The H_{eq} value for each location that is measured shall be reported to the regulatory authority. Specific parametric data used in the determination (or calculation) of the H_{eq} values shall also be reported to the regulatory authority.

12.3.5 Evaluation of results and dispositioning

12.3.5.1 Evaluation of results

The licensee shall be responsible for the evaluation of H_{eq} measurements in order to determine compliance with the acceptance criteria of [Clause 12.3.5.2](#).

12.3.5.2 Acceptance criteria

The determination of H_{eq} shall be considered acceptable when

- (a) the predicted concentration value at the end of the next periodic measurement interval is below the level at which hydrides are present at sustained operating conditions; and
- (b) the measured/determined rates of change in H_{eq} are less than those defined in the following Table:

Maximum channel outlet temperature	Maximum allowable rate of change in H_{eq} concentration per 10 000 hot operating hours
< 315 °C	3 ppm H_{eq}
< 305 °C	2 ppm H_{eq}
< 295 °C	1 ppm H_{eq}

12.3.5.3 Dispositioning

When the results of a measurement do not satisfy the acceptance criteria of [Clause 12.3.5.2](#), evaluation and further action by the licensee shall include the following:

- (a) notifying the regulatory authority of the measurement results;
- (b) evaluating the measurement results to determine
 - (i) acceptability for continued operation. The procedures specified in CSA N285.8 may be used;
 - (ii) the need for additional measurements as well as changes to the type, extent, and frequency of measurements. Consideration shall be given to obtaining measurements in other units; and

The three fuel channel temperatures listed in Clause 12.3.5.2 of CSA N285.4, shown above, – namely, 315 °C, 305 °C, and 295 °C – correspond to the conditions for Darlington, Bruce and Pickering NGS fuel channel

outlets, respectively. Thus, we see that CSA N285.4 sets the maximum allowable rate of increase in H_{eq} per 10,000 hot hours, or $\Delta H_{eq}/10^4$ HH, to be 3 ppm, 2 ppm and 1 ppm, for Darlington, Bruce and Pickering respectively.

I have used Darlington, Bruce and Pickering H_{eq} data from the CNSC’s ROR *Appendix G* to estimate values for $\Delta H_{eq}/10^4$ HH in order to investigate if the reported values do in fact satisfy Clause 12.3.5. 2 of CSA N285.4. In this way it was discovered that only for Pickering A & B are the $\Delta H_{eq}/10^4$ HH values essentially constant from zero EFPH up to ~ 280,000 EFPH, while $\Delta H_{eq}/10^4$ HH increases significantly with increasing EFPHs for Darlington and Bruce.

Nevertheless, to treat all H_{eq} data in the same way I have developed a simple model in which the H/D pickup of an operating pressure tube is represented by a function of the form:

$$[H_{eq}]_t = At^2 + Bt + C$$

Where, t is the in-reactor full power exposure time of a tube, or set of tubes, in HH, (or EFPH), and A, B, and C are constants to be determined. Clearly, when t = 0,

$$[H_{eq}]_o = C$$

Where C is the concentration of hydrogen in the as-installed tube – typically ~ 5 - 15 ppm. However, we also require the *rate of change* of $[H_{eq}]_t$, which is equal to the differential function:

$$d[H_{eq}]_t / dt = 2At + B$$

And in particular, for the quantity $\Delta H_{eq}/10^4$ HH, we have:

$$\Delta H_{eq} = 10^4 \times \{2At + B\}$$

To illustrate the use of this methodology I have carried out detailed calculations for Darlington Units 1, 3 and 4, (Darlington Unit 2 was excluded from the study because it is currently shut down for a full refurbishment). The results of this study are presented in Figures 1 and 2, below.

Figures 1 and 2 show that although H_{eq} remains below 120 ppm for Darlington Units, 1, 3 and 4 out to 300,000 EFPH of reactor operation, $\Delta H_{eq}/10^4$ HH *exceeds* 3 ppm before these Units reach 150,000 EFPHs. Furthermore, at the present time, (September 2019), $\Delta H_{eq}/10^4$ HH now exceeds 4 ppm. Thus, we conclude that these Darlington Units are non-compliant with CSA N285.4 because they do not satisfy all of the acceptance criteria of Clause 12.3.5.2. of this Standard.

Similar calculations have been carried out by Pandey et al. for a Bruce B Unit and the results are compared with the average $\Delta H_{eq}/10^4$ HH values determined for Darlington Units 1, 3 and 4 in Table 2. The good level of agreement between these data, especially at high EFPHs, is apparent.

Table 2: Comparison of ΔH_{eq} Calculations for some Darlington and Bruce Units

EFPH	Rate of Change of H_{eq} : $\Delta H_{eq}/10^4$ HH (ppm/10,000 EFPH)	
	Darlington Units 1, 3 & 4 (Average)	Pandey et al: Data for a Bruce Unit
100,000	2.80	3.40
150,000	3.67	4.10
200,000	4.54	4.80
250,000	5.40	5.50
300,000	6.27	6.20

Figure 1

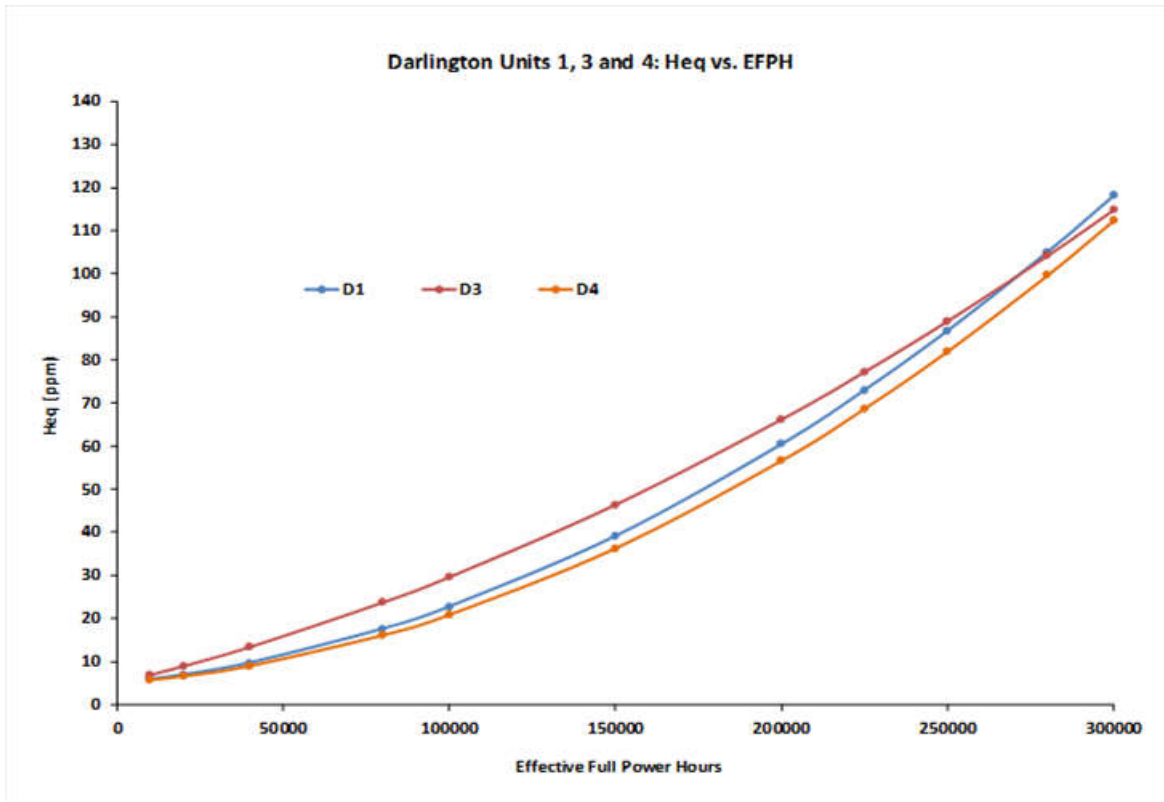
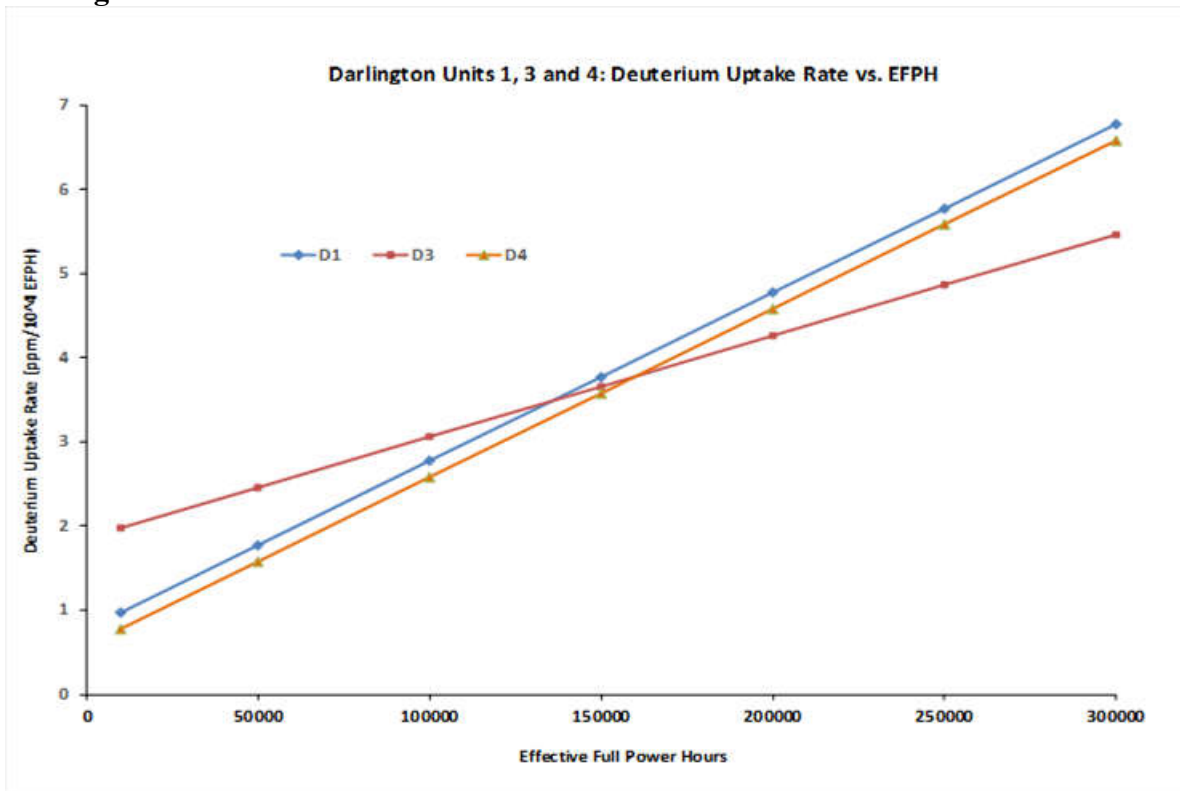


Figure 2



(ii) Effluent Monitoring Data and Appendix H:

The CNSC's *Appendix H* of its 2018 ROR begins with a very strange statement about the number of significant figures used in its radionuclide release data tables:

Releases are reported in the following tables as total becquerels (Bq) per year or in the case of noble gasses, becquerels-million electron volts (Bq-MeV). A becquerel is an SI (International System of Units) unit of radioactivity defined as the activity of a quantity of radioactive material in which one nucleus decays per second. Since the Bq is a very small unit, releases are reported here in scientific notation. In most cases, numbers are rounded to two or three significant figures.

For example:

$$\begin{aligned}100 &= 1.0 \times 10^2 \\1,260,000 &= 1.2 \times 10^6 \text{ (sic)} \\4,445,758,748 &= 4.4 \times 10^9\end{aligned}$$

The above statement completely ignores the true precision and accuracy of the measurements that were used to calculate the annual radionuclide emissions reported in *Appendix H* of the CNSC's 2018 ROR. Indeed, it suggests that the reported data were arbitrarily "rounded to two or three significant figures." However, inspection of *Appendix H* shows that, while OPG reports effluent monitoring data to two significant figures, the Bruce Power data are reported to three significant figures, implying a precision of at least 1% for these effluent monitoring data, But is this level of precision realistic? Is it scientifically justifiable? The simple answer to these questions, as I demonstrate below, is "No!"

The Standard B-ST-03480-10000: *Radionuclide Effluent Monitoring System Requirements*, is a typical CANDU station control document that contains the requirement that uncertainty estimates should be made for each radionuclide group in each performance or control monitored effluent stream. This standard further stipulates that the error bounds on effluent monitoring data should not exceed $\pm 50\%$ for a radionuclide group emitted at $\geq 0.5\%$ of the monthly DRL and $\pm 100\%$ for a radionuclide group emitted at $< 0.5\%$ of the monthly DRL. Examples of actual uncertainty estimates for a CANDU station's radiological emissions may be found in reports such as:

Measurement Uncertainty Calculations for Gaseous Radioactive Emissions, Report No: NK29-REP-67876-00003, June 2000

Measurement Uncertainty Calculations for Radioactive Emissions from the CMLF, Report No: NK37-REP-67872-00001, December 2001

Measurement Uncertainty Calculations for Radioactive Emissions from Active Liquid Waste, Report No: N-REP-79200-10000 R00, June 2002

In these reports, computer simulations of airborne and waterborne radionuclide emissions are carried out and statistical analyses such as Monte Carlo calculations are used to determine relative uncertainties in emissions data at the 95% confidence level.

The measurement of the activity of a radionuclide in an effluent stream is a two-step process involving sample collection followed by sample analysis. Each of these steps introduces uncertainties in the reported data. In the case of gaseous effluents, sampling involves passing a side stream from an exhaust stack through a collection medium such as charcoal or silica gel and analysing the collected activity. In this case uncertainties in parameters such as the stack and monitor flow rates, collection efficiencies and analytical precision determine the overall uncertainty of airborne emissions data.

By comparison, effluent monitoring of active liquid waste (ALW) uses a tank level indicator and flow transducer to estimate the total volume of effluent discharged from a holding tank while a representative sub-sample from the tank is analysed to determine its radionuclide content. In this case the overall uncertainties in the reported ALW emissions depend on the imprecision involved in the determination of the discharged volume and its associated sub-sample, and the analytical imprecision in the measurement of the radionuclide content of the sub-sample.

The specific example of airborne tritium emissions monitoring is considered below:

A typical CANDU station's Chemistry Laboratory Procedure for weekly effluent reporting (See for example NK29-CLP-01806.2-00002), provides the following formula to calculate tritium stack releases for weekly effluent reporting:

$$\text{Stack H-3 Release (in Curies)} = A_S(\mu\text{Ci}) \times 1\text{Ci}/10^6 \mu\text{Ci} \times [V_{\text{stack}} / V_{\text{sample}}]$$

Where,

A_S is the tritium activity of the sample

V_{stack} is the total stack volume released in a week

V_{sample} is the total volume sampled by the monitor in a week

This equation identifies *three* sources of uncertainty in the determination of weekly airborne tritium emissions, namely the sample activity, the stack flow and the monitor flow. Stack flows are required in the calculation because they are used to determine the volume, V_{stack} , in the above equation. In order to quantify the associated uncertainties, each parameter that contributes to the reported tritium activity must be assigned a value. These values must then be added in quadrature to arrive at an estimate of the overall relative uncertainty, U_{tot} :

$$U_{\text{tot}} = \sqrt{\sum (u_i)^2}$$

In this equation the u_i represent individual relative uncertainties as described in Annex D of the UK Environmental Agency Report: *MCERTS Performance Standards and Test Procedures for Continuous Emission Monitoring Systems* Version 3.4, issued July 2012.

It turns out that the most important input data required for uncertainty calculations of a station's airborne tritium emissions are the stack flows and their standard deviations over a given time period. By way of an example of such data consider the values presented in a CANDU Station's Stack Test Reports for the years 2000 – 2010:

Stack Flow Data (in units of m³/s) from 2000 to 2010

Year	5CON	6CON	7CON	8CON	5NCON	6NCON	7NCON	8NCON	CSA	ASB
2000	35.61	32.51	35.04	33.01	72.27	99.17	101.92	68.05	69.44	41.56
2001	36.24	23.96	27.47	30.69	58.06	97.71	35.24	56.45	64.06	38.75
2002	31.61	27.04	26.63	19.09	97	74.63	63.85	77.92	56.52	31.47
2003	34.89	23.42	25.47	21.86	73.15	90.08	93.2	97.5	57.29	38
2004	34.46	28.27	25.48	20.89	95.84	90.44	94.08	65.85	65.46	40.44
2005	28.23	28.1	27.27	19.38	97.88	88.39	95.79	97.27	63.42	37.8
2006	28.9	28.86	24.18	17.26	95.85	83.52	104.98	82.41	63.09	38.54
2007	10.4	18.09	26.71	25.3	102.87	54.24	118.87	94.45	54.82	41.55
2008	33.62	14.15	24.24	25.40	97.83	56.48	97.51	98.94	62.02	31.08
2009	25.62	14.81	19.88	20.57	74.22	73.34	45.77	43.10	50.65	38.02
2010	30.43	27.76	23.76	23.72	93.32	87.01	98.68	93.71	65.28	37.02
Average	33.00	26.70	28.61	25.72	95.83	89.50	94.99	87.57	67.21	41.42
Std Dev	7.33	6.09	3.69	4.92	14.81	15.14	26.24	19.05	5.56	3.50

The average contaminated stack flow rate determined from the data in the above Table is **28.51 m³/s**. However, the standard deviations listed in the last row of the Table, which are derived from the year-to-year variability of

the four contaminated stack flows, suggest that a value of about 5 m³/s should be used for the standard deviation in question. This constitutes 17.5 % of the contaminated stack flow.

The situation is quite similar for the non-contaminated stack flow rates. Thus, the tabulated data yield a value of **91.97 m³/s** for the average of the Unit 5 – 8 non-contaminated stack flow rates. However, as shown by the data in the last row of Table 1, the year-to-year variability in the non-contaminated stack flow data average about 18 m³/s, which corresponds to 21 % of the non-contaminated stack flow.

Thus, we conclude that even though the CNSC apparently feels justified in quoting airborne tritium emissions data to a precision of at least ± 1%, the true precision of such data is undoubtedly no better than ± 10%.

It should finally be noted that, since all airborne effluent monitoring data rely on the same stack flow measurements, the precision attainable for station airborne emissions data for carbon-14, radioiodine, etc, will also be > ± 10%.

Conclusions:

1. In this submission/intervention I have addressed the issue of the fitness-for-service of pressure tubes, and in particular, Darlington, Pickering and Bruce Unit's adherence to Standard CSA N285.4. I have demonstrated that the data presented in *Appendix G* of the CNSC's 2018 *Regulatory Oversight Report*, (ROR), show that all currently operating Bruce and Darlington Units *exceed* the limits on the rate of change of H_{eq} specified in CSA N285.4.

2. In this submission/intervention I also focused on the quality of data reported in the CNSC's 2018 *Regulatory Oversight Report*, (ROR), with regard to its true precision and accuracy:

(i) With regard to estimates of pressure tube H_{eq} data, and (ii) With regard to station effluent monitoring data.

In both cases I have demonstrated that much of the data presented by the CNSC on these issues is best described as *misinformation that is lacking in scientific rigor*. I say this because the CNSC appears to be unaware of the concept of the *precision and accuracy* of analytical measurements. However, while changing the reported data to include uncertainty estimates should be a simple matter, accomplishing this feat within such a behemoth as the CNSC appears to be impossible. Thus, in March 2014 I wrote to a Senior Vice President at the CNSC and raised the following concern:

*Consider the CNSC Report CMD 10-H19, issued in September 2010, on steam generator waste from Bruce Power's Units 1 & 2. This Report summarizes the radionuclide inventory in steam generators from Bruce A in **Table 1** on page 10 of CMD 10-H19. As a scientist who has taught chemistry at a number of Universities and Colleges in Europe and North America, I find CNSC's **Table 1** unworthy of a passing grade for a first-year chemistry student! Do you really believe that a Bruce Unit 1 steam generator contains precisely 0.126033 grams of Am-241 while a Unit 2 steam generator contains precisely 0.103412 grams? These numbers tell me the CNSC is capable of estimating Am-241 inventories to within 1 µg in a massive 100-ton component! Could you please explain how the CNSC is able to do this? And when you do, please keep in mind what real measurements of the radionuclide content of a steam generator show...*

These data, abstracted from a Report published in 2008, show that the measured activity of Am-241 in a Bruce steam generator varies considerably from one tube to another; from a low value of 130 Bq/cm to a high value of 990 Bq/cm. This is a factor of more than 7! Yet the CNSC report activities to a precision of 1 part in a million! Does the CNSC recognize the concept of measurement uncertainty?

Sincerely, etc

Evidently, little has changed at the CNSC over the past 5-years

Sincerely,

Dr. F. R. Greening