Canadian Nuclear Safety Commission   Commission canadienne de sûreté nucléaire

**Written Submission from
Dr. Frank Greening**

**Mémoire de
Dr. Frank Greening**

In the matter of

À l'égard de

Bruce Power

Bruce Power

Application to amend the licensing basis for Bruce A and B nuclear generating stations to operate Units 7 and 8 pressure tubes beyond 300,000 effective full power hours

Demande visant à modifier le fondement d'autorisation des centrales nucléaires de Bruce-A et B afin d'exploiter les tubes de force des tranches 7 et 8 au-delà des 300 000 heures équivalentes pleine puissance

Hearing in Writing

Audience par écrit

August 2026

Août 2026

Canada

Dear Annik,

In view of the CNSC's wish to discuss my Formal Complaint concerning Bruce Power's request, (to operate pressure tubes beyond 300,000 EFPH), on March 24th, 2026, please accept the additional comments on this issue, as presented below:

To whom it may concern:

1.0 Introduction

Following a two-part public hearing held on March 14, 2018 in Ottawa, and from May 28 to 31, 2018 in Kincardine, Ontario, the CNSC announced its decision to renew the Nuclear Power Reactor Operating Licence, (PROL), issued to Bruce Power Inc for the operation of Bruce A & B Units, from October 1, 2018 until September 30, 2028, to a maximum of 300,000 Equivalent Full Power Hours or EFPH.

However, in September 2025, in a letter to the CNSC, (See Bruce Power document: BP-CORR-00531-06660), Bruce Power submitted "*a Review of the Fuel Channel Fitness for Service Program*" which included a request for approval to extend operation of Bruce B Units 7 and 8 up to 310,000 Equivalent Full Power Hours. The only reason offered by Bruce Power for this licence amendment was "*to help ensure the safe and efficient execution of Bruce Power's MCR program*". In support of the requested amendment Bruce Power includes a Table 1 which provides an estimate of 278,500 EFPH for Unit 7, as of June 1, 2025, rising to 305,500 EFPH at the time of the projected Unit 7 MCR outage in June 2028. This indicates that Bruce Unit7 will add 9000 EFPH per year over the next 3 years.

There is already a problem with this prediction by Bruce Power because the calculation of a Unit's Equivalent Full Power Hours is based on 1 year of plant operation, so, with 24 × 365 hours in a year, *8760 hours is the maximum possible value of a Unit's EFPH*. It is also important to note that Bruce Unit 7 first came on line in 1986 so it has been operating for 39 years. If Unit 7 is currently at 278,500 EFPH, it has averaged 278,500/39 EFPH per year = 7141 EFPH per year, implying an average lifetime capacity factor of 81.5%. However, by comparison, the IAEA Power Reactor Information System, or PRIS, reports the lifetime average capacity factor for Bruce Unit 7 to be 85.3 %. This implies that a more realistic annual EFPH for Bruce Unit 7 would be 7474 EFPH, rather than 7141 EFPH, in which case the current total EFPH for Bruce Unit 7 is 291,484 EFPH or about 13,000 hours *higher* than Bruce Power's estimate. This discrepancy is examined in detail in this intervention. I believe that Bruce Power should be denied approval to proceed with operating Units 7 and 8 until this question is resolved.

2.0 The Thermal Power Output of Bruce Units 1 – 8

To determine the status of a reactor core Bruce Power uses the *Simulation of Reactor Operation* (SORO) code to ensure compliance with channel and bundle power limits. The SORO code output also contains all the information needed to plan fuel scheduling including the detailed channel and bundle power distributions and the irradiation of each bundle in core. The power produced in these channels is proportional to the core coolant mass flow rate and the temperature difference between the inlet and outlet of each fuel channel, denoted by the symbol ΔT. When calculated for different fuel channels it can be averaged and multiplied by the total number of fuel channels in core to provide a relatively accurate figure for the total (gross) reactor thermal power.

This relationship may be expressed mathematically by the equation:

$$Q = N.m.C.\Delta T$$

Where:
Q = Reactor gross thermal power (Watts [thermal])
N = The number of fuel channels per core
m = Coolant D_2O mass flow rate (kg/s)
C = Coolant specific heat at core temperature (J/kg °C)
$\Delta T = (T_{out} - T_{in})$ for the channel (°C)

For a Bruce B Unit, we have used the following values for these parameters:

$N = 480$
$m = 25$ (kg/s)
$C = 4720$ (J/kg °C)
$\Delta T = (300 - 250) = 50$ (°C)

In which case,

$Q = 2832$ MW$_{th}$

This calculated value for Q is identical to the value of Q, namely 2832 MW$_{th}$, quoted in Bruce Power SORO reports covering the period from 2003 to the present.

3.0 Hot Hours

In a letter by OPG dated June 12, 2018, CD# P-CORR-00531-05392 to Mr. M. A. Leblanc, Commission Secretary Canadian Nuclear Safety Commission, we read:

Dear Mr. Leblanc: Pickering NGS Part 2 Hearing- Supplemental OPG Written Submission Application for the Renewal of Power Reactor Operating Licence

> *There are established relationships between temperature, flux and their impact on fuel channel aging. For example, deuterium ingress to the pressure tube material is a function of temperature and time, so time spent with the heat transport system hot ("hot hours") is used to model deuterium ingress. Equivalent full power hours, which is a measure of time spent under full power neutron flux conditions, is used to model mechanisms associated with flux, such as pressure tube deformation. The appropriate metric that is applicable to an aging mechanism is used where required, with a conversion factor that enables interchanging the two measures for modelling purposes.*

The distinction between hot hours and equivalent full power hours is important because, when a Bruce Unit's accumulated hot hours of operation are tallied up, we find the total hot hours are typically up to 10 % *higher* than the Unit's EFPHs. This means that after many years of Unit operation there is an increasing amount of time during which a Unit would have been in a condition known as "zero power hot" when the Unit is at operating temperature, *but not producing electrical power*. It follows that the time for a Bruce Unit to reach an operating limit measured in hot hours is up to 10% _less_ than the time to reach the same limit measured in effective full power hours.

The importance of using hot hours to assess a Unit's end of life, rather than EFPHs, is recognized in one of the Standards that governs the safe operation of a CANDU reactor's fuel channels - namely CSA N285.4. This Standard stipulates that the rate of change of the hydrogen/deuterium picked up by a pressure tube operating at an outlet temperature of 300 °C, should be less than *2 ppm per 10,000 hot hours*.

OPG has published a considerable amount of data on a Unit's performance using both EFPH data and hot hour data. Table 1, below, provides examples of such data that includes the ratio of these quantities which is a useful conversion factor that enables an interchange of these two measures.

Table 1: Examples of EFPH and Hot Hour data for some CANDU Units

CANDU Unit	Year	EFPH	Hot Hours	Ratio (HH/EFPH)
B3	1988	74100	84340	1.138
B3	1993	101850	116610	1.145
B3	1994	105680	122900	1.163
B3	1995	111880	131900	1.179
B3	1996	114560	135620	1.184
P5	1992	65950	69730	1.057
P5	1995	81570	86590	1.062
P5	2020	260306	268000	1.030
P5	2021	266744	273000	1.024
P6	2022	271844	288000	1.059
P7	2020	256928	267000	1.040
P8	2022	261735	270000	1.032
D1	2020	222931	233000	1.045
D4	2020	214275	223500	1.043

The data in Table 1 show that the ratio (HH/EFPH) varies somewhat from Unit to Unit and from year to year. However, the average value for the most recent data is 1.04 ± 0.04.

4.0 The Electrical Power Output of Bruce Units 1 - 8

The thermal power of a CANDU reactor is converted into electrical power via the Unit's steam generators and turbines. This process is very inefficient because most of the thermal energy generated by a CANDU reactor is lost as waste heat, W (Watts), that is discharged by the Unit's condenser cooling water, (CCW), into Lake Huron. It is possible to calculate W by applying the same methodology used above for the calculation of the thermal power, Q, as follows:

$$W = m.C.\Delta T$$

Where,

W = Reactor waste power (Watts [thermal])
m = CCW mass flow rate (kg/s)
C = Coolant specific heat at lake water temperature (J/kg °C)
$\Delta T = (T_{out} - T_{in})$ for the CCW (°C)

For a Bruce B Unit, we have the following values for these parameters:

m = 39,000 (kg/s)
C = 4180 (J/kg °C)
ΔT = 12.35 (°C)

In which case,

W = 2013 MW$_{th}$

It follows that the electrical power output of a Bruce B Unit, E(Watts) is given by:

**$E = Q - W = 2832 - 2013 = 819$ MW$_{el}$**

This calculated value of E is very close to the reported electrical power output of 817 MW$_{el}$ for a Bruce B Unit. From this relationship we may calculate the efficiency, ε, of a Bruce Unit as follows:

ε = Electrical Power / Thermal Power = 817 / 2832 = 0.29

However, it turns out that nuclear reactors are generally unable to maintain constant electrical power output due to variable conditions such as the circulating water temperature. As a consequence, to accurately account for such changes, hourly generator output power data, such as the data published by the Independent Electricity System Operator (IESO) are of great value. Figure 1, below, is an example of the IESO power output data for Bruce Unit 7 plotted for an arbitrarily selected date and time interval. It shows Unit 7's August 2018 output varying between a maximum value of 831 MW$_{el}$ and a minimum of 790 MW$_{el}$ over a time interval of about 40 days.

Figure 1:

BRUCE UNIT 7 Electric Power Output July - August 2018

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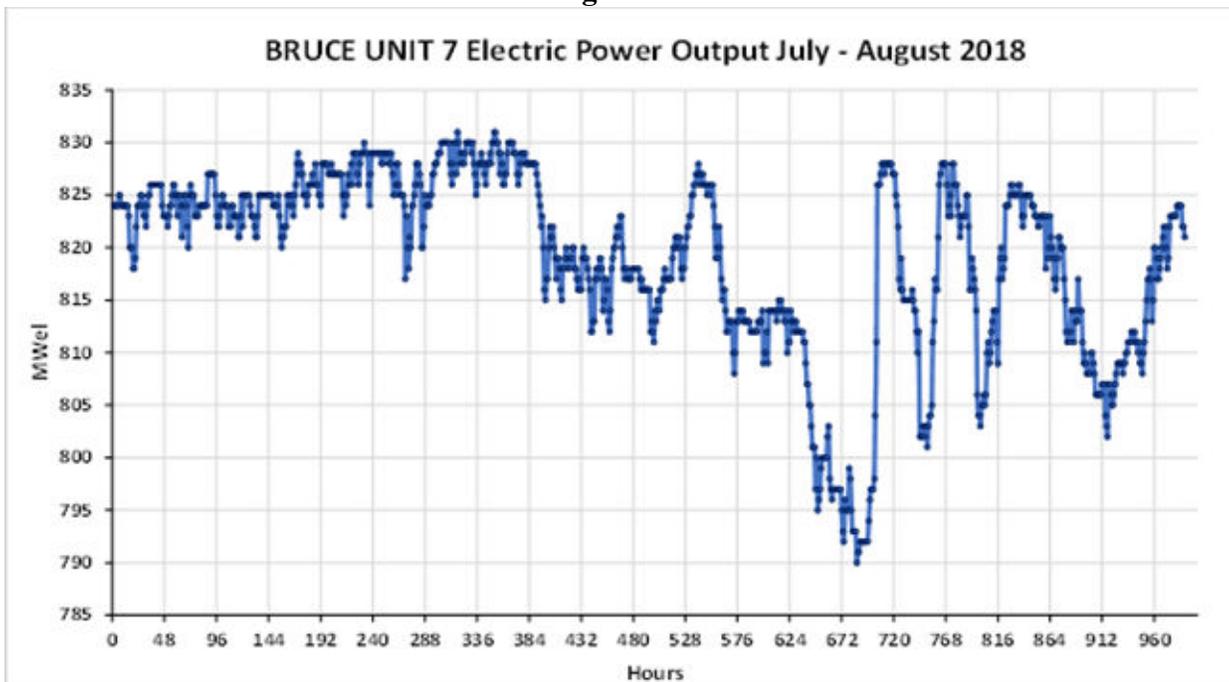
Such data provide a very detailed, full accounting, of a nuclear reactor's power output over a selected time interval.

For this intervention I have determined Bruce Unit 7's power output using three sources:

1. The PRIS data for the GWh$_{el}$ output reported by the IAEA from 1986 to the present
2. The SORO code data for the GWh$_{th}$ reported by Bruce Power from 2003 to 2022
3. The hourly output MW$_{el}$ data reported by the IESO from 2015 to 2018

The selected data from items 1. and 2. above are summarized in Table 1, below.

TABLE 1: Bruce Unit 7 Annual and Cumulative Total EFPH from IAEA PRIS and SORO Code Calculations

YEAR	Years of Operation	MWh(el)	Ref Power (MW)	EFPH	Cumulative EFPH	SORO EFPH	SORO Cumulative
1986	1	5256620	837	6280	6280		
1987	2	6288050	837	7513	13793		
1988	3	4866190	860	5658	19451		
1989	4	7280790	860	8466	27917		
1990	5	6659400	860	7743	35661		
1991	6	5733630	860	6667	42328		
1992	7	6413410	860	7457	49785		
1993	8	5802330	860	6747	56532		
1994	9	5496710	860	6392	62924		
1995	10	6285100	860	7308	70232		
1996	11	5475680	860	6367	76599		
1997	12	6154480	860	7156	83755		
1998	13	4990760	785	6358	90113		
1999	14	6315740	785	8046	98159		
2000	15	5322680	785	6780	104939		
2001	16	7026300	790	8894	113833		
2002	17	4819350	790	6100	119934		
2003	18	6730240	790	8519	128453	7716	123263
2004	19	6428770	790	8138	136591	7354	130618
2005	20	4890450	806	6068	142658	5657	136274
2006	21	6740470	822	8200	150858	7704	143977
2007	22	6969910	822	8479	159337	7963	151941
2008	23	5763740	817	7055	166392	6552	158493
2009	24	6475330	817	7926	174318	7505	165997
2010	25	6726640	817	8233	182551	7716	173713
2011	26	5761530	817	7052	189603	6598	180311
2012	27	7055970	817	8636	198240	8105	188416
2013	28	7003570	817	8572	206812	8134	196549
2014	29	5479210	817	6706	213519	6583	203133
2015	30	6324100	817	7741	221259	7474	210608
2016	31	4983380	817	6100	227359	5902	216509
2017	32	6643160	817	8131	235490	7810	224318
2018	33	7116790	817	8711	244201	8074	232391
2019	34	4849090	817	5935	250136	5563	237954
2020	35	7036810	817	8613	258749	8016	245970
2021	36	5948950	817	7281	266030	6746	252717
2022	37	6676030	817	8171	274202	7618	260333
2023	38	7176720	817	8784	282986	7839	268172
2024	39	5916230	817	7241	290228	7039	275211
2025	40	6313212	817	7727	297955	7239	282450
2026	41	6313212	817	7727	305682	7239	289689
2027	42	6313212	817	7727	313409	7239	296928
2028	43	6313212	817	7727	321136	7239	304167

Note: Data in red are based on a linear extrapolation from pre-2025 data

IESO electrical output data are very extensive consisting of 8760 hourly data values per year for each nuclear Unit operating in Ontario. For Bruce Unit 7, to simplify the evaluation of so many data points, I have limited

the IESO data analysis to six randomly selected years, namely 2015 to 2020, and compared the annual capacity factors for the IESO data to the corresponding capacity factors determined from IAEA PRIS and SORO code data sets as shown in Table 2, below, where each capacity factor is calculated as a percent using the following equation:

Capacity Factor (%) = 100 × (Reported Power Output / Maximum Potential Power Output)

Table 2: Capacity Factors for Bruce Unit 7 Reported Using Data from Three Different Sources: IAEA PRIS, the SORO Code and IESO

Year of Operation	Total Years of Operation	PRIS Capacity Factor (%)	SORO Capacity Factor (%)	IESO Capacity Factor (%)
2015	30	88.4	85.3	88.6
2016	31	69.6	67.4	69.7
2017	32	92.8	89.2	93.0
2018	33	99.4	92.2	99.7
2019	34	67.8	63.5	67.8
2020	35	98.3	91.5	98.5

Table 2 shows that there is excellent correspondence between the PRIS capacity factor values and the IESO capacity factor values for Bruce Unit 7 between 2015 and 2020, with agreement to within about 0.3%. By comparison, the corresponding SORO capacity factors are consistently *lower* than the PRIS or IESO values by 3 or more percent.

5.0 Full Power Days and Unit Outages

A nuclear power reactor has three basic modes of operation:

(i) Complete shutdown (Usually for routine or emergency maintenance)
(ii) Zero power hot (Thermally at full power but with no electrical power production)
(iii) Full power (The Unit is producing electricity at its maximum rated output)

If a Unit runs at full thermal power all year, its maximum thermal output is the rated output in $MW_{th} \times 8760$ hours in a year. For a Bruce B Unit, the rated thermal output is $2832\ MW_{th} \times 8760\ hrs = 24,808\ GWh_{th}$ per year. This being the case, a station only needs to record when and for how long a Unit is shutdown, (for whatever reason), to calculate the Unit's hot hours. As previously explained in Section 3.0 of this intervention, a Unit's hot hours is a quantity that is independent of its electrical power output. By comparison, the equivalent full power hours, EFPH, refers to a Unit's electrical output. This is related to its thermal output power through the Unit's thermal efficiency, ε, defined as follows:

ε = Electrical Power / Thermal Power

Then, for a nominal Bruce B Unit, we have: $\varepsilon = 817 / 2832 = 0.29$, or 29 %.

Although thermal uprating of a CANDU reactor is technically feasible, Bruce Power's published data indicate that the value noted above – namely, $2832\ MW_{th}$ – is consistently used in conjunction with the SORO code to calculate a quantity referred to as Full Power Days such that:

One Full Power Day (FPD) = 2832 MW × 24 hours or 67968 MW$_{th}$.hours

Or,

FPD (SORO) = GW$_{th}$.hours / (2832 × 24 ×0.001)

To make a direct comparison of the SORO-derived FPDs, I have also calculated the FPDs for Bruce Unit 7 based on its electrical power output in GW$_{el}$.hours, as reported on the IAEA PRIS website. Bruce Unit 7's Full Power Days are then calculated using the simple relation:

FPD (IAEA) = [GW$_{el}$.hours / Reference Electrical Power (GW$_{el}$)]/24

Table 3, below, lists the Full Power Days for Bruce Unit 7 that was determined from IAEA PRIS data and from the equivalent SORO data, with the thermal power set at 2832 MW, for the period of interest, namely, 2003 to 2022.

Table 3: Bruce Unit 7 Full Power Hours Calculated using IAEA PRIS and SORO CODE Data

YEAR	IAEA PRIS Full Power Days	SORO CODE Full Power Days	[PRIS – SORO] Full Power Days
2003	355.0	321.5	33.5
2004	339.0	306.4	32.7
2005	252.8	235.7	17.1
2006	341.7	321.0	20.7
2007	353.3	331.8	21.5
2008	294.0	273.0	19.0
2009	330.2	312.7	17.5
2010	343.1	321.5	21.6
2011	293.8	274.9	18.9
2012	359.9	337.7	22.2
2013	357.2	338.9	18.3
2014	279.4	274.3	5.1
2015	322.5	311.4	11.1
2016	254.2	245.9	8.3
2017	338.8	325.4	13.4
2018	363.0	336.4	26.6
2019	247.3	231.8	15.5
2020	359.9	334.0	24.9
2021	303.4	281.1	22.3
2022	340.5	317.4	23.1

The data in Table 3 show that the Bruce Unit 7 IAEA PRIS Full Power Days are consistently *higher* than the equivalent SORO code Full Power Days by up to 33.5 days. This observation is highly problematic because a Unit's electrical Full Power Days cannot, by definition, exceed the Unit's thermal Full Power Days. At the most basic level, a nuclear reactor is either "on", or "off". And when a reactor is turned "off" it is incapable of producing any electrical energy, and every day that passes with the reactor in this condition reduces the Unit's annual Full Power Day total. Bruce Power has published data on the number of outages, planned and unplanned, per Bruce Unit per year. Subtracting these outage days from the 365 days in a year gives a useful estimate of a Unit's actual Full Power Days. An example of such data for the period 2014 to 2019 is presented in Table 4, below.

Table 4: Full Power Days Data for Bruce Unit 7 Reported by Three Different Sources

Year	Outage Days	Resulting FPD	PRIS FPD	SORO FPD	% Diff PRIS	% Diff SORO
2013	0.0	365.0	357.18	338.9	0.5415	1.8540
2014	73.5	291.5	279.44	274.3	1.0564	1.5200
2015	26.3	338.7	322.53	311.4	1.2230	2.0997
2016	101.2	263.8	254.15	245.9	0.9315	1.7559
2017	11.0	354.0	338.80	325.4	1.0971	2.1048
2018	1.0	364.0	362.95	336.4	0.0720	1.9703
2019	113.5	251.5	247.30	231.8	0.4208	2.0381
2020	2.0	363.0	358.87	334.0	0.2858	2.0803

Table 4 shows there is a problem with the SORO data for Bruce Unit 7 in the reported time period which means that the assumed thermal power of B7, namely 2832 MW$_{th}$, must be incorrect. In Section 2.0 of this intervention, it was noted that it is possible to estimate the thermal power of a nuclear reactor using the equation:

$$Q = N.m.C.\Delta T$$

Where:
Q = Reactor thermal power (Watts [thermal])
N = The number of fuel channels per core
m = Coolant mass flow rate (kg/s)
C = Coolant specific heat at core temperature (J/kg ºC)
$\Delta T = (T_{out} - T_{in})$ for a fuel channel (°C)

For a Bruce B Unit, we have used the following values for these parameters:

$N = 480$
$m = 25$ (kg/s)
$C = 4720$ (J/kg ºC)
$\Delta T = (300 - 250) = 50$ (°C)

In which case,

Q = 2832 MW$_{th}$

This calculation shows there are two parameters that may be varied to control the thermal power of a reactor: the coolant mass flow rate, symbolized by **m**, and the reactor inlet/outlet temperature difference symbolized by **ΔT**. Varying a Unit's coolant mass flow rate is theoretically possible; however, there are severe practical limits on an achievable flow rate due to limitations on the system pressure for a given pressure tube wall thickness. This leaves varying $\Delta T = (T_{out} - T_{in})$ for a fuel channel as the most practical way to change a Unit's thermal power output. However, there are issues with controlling a Unit's inlet/outlet ΔT because of unavoidable aging effects that influence a Unit's inlet temperature, as explained below.

Measurements of the inside diameter of pressure tubes in CANDU reactors show that the tube's diameter increases over time. This diametral expansion of the pressure tube is considered to be a major aging mechanism governing the heat transfer and hydraulic degradation within the primary heat transport system of a reactor. Diametrical expansion results in a reduction of the fuel cooling owing to the increased bypass flow, thus

limiting the operating power of the reactor. Operating CANDU pressure tubes have been observed with up to 5.4% diametral increase. However, when the diametral expansion exceeds about 3 %, coolant flow bypass needs to be addressed because it inevitably leads to the affected Unit being derated. Thus, as a CANDU Unit ages, the Reactor Inlet Header (RIH) temperature becomes an increasingly important factor that limits the performance of the Unit. Ideally, RIH temperature should be as low as possible, but this cannot be done without improving the heat transfer performance of the boilers and feedwater pre-heaters. Unfortunately, the physical performance of the boilers and pre-heaters also decays over time due to the accumulation of flow limiting corrosion product deposits on the surfaces of the steam generator tubing and support plates.

Studies of the CANDU 6 Unit at Point Lepreau have shown that the Inlet Header Temperature, over 15 years of plant operation, increased by about 4 °C, with a corresponding output power loss of about 5.0 %. For Bruce B's four Units, published values for the inlet and outlet header temperatures are available for different stages of the life of these Unit, as shown in Table 5, below.

Table 5: Bruce B Inlet and Outlet Header Temperatures at Different Unit Ages

Steam Generator Temperature (ºC)	BRUCE B UNIT AGE STATUS (years)			
	New (up to 10 years)	Mature (10 to 20 years)	Old (20 to 30 years)	End of Life (~ 40 years)
Inlet Header	250	251	253	255.5
Outlet Header	300	300	301	302
ΔT (ºC)	50	49	48	46.5

Given that Bruce Unit 7 is currently approaching 40 years of operation it is expected that the inlet/outlet ΔT of this Unit is close to 46.5 °C. In view of this expectation, I have recalculated Bruce Unit 7's thermal power, Q, using the equation $Q = N.m.C.\Delta T$, with ΔT set at 46.5 °C. This gives a Q value of 2634 MW$_{th}$, which is considerably less than the Q value of 2832 MW$_{th}$ used by Bruce Power to determine a Unit's Full Power Hours regardless of the age of the Unit.

It is instructive to recalculate the SORO FPD data derived using a Q value of 2832 MW with a more realistic Q value of 2634 MW. This involves multiplying the original SORO data by a factor of 1.075. The resulting FPD calculated data show agreement to within 1 % of the observed (reported) values.

6.0 Surplus Baseload Generation

In Section 5.0 of this intervention, it was stated that for CANDU reactors there are three basic modes of operation:

(i)   Complete shutdown (Usually for routine or emergency maintenance)
(ii)   Zero power hot (Thermally at full power but with no electrical power production)
(iii)   Full power (The Unit is producing electricity at its maximum rated output)

However, to be more precise, it should be noted that there is an additional mode of operation of a CANDU reactor related to the issue of surplus baseload generation. It turns out that the performance of some of Ontario's nuclear generating stations is affected by so-called surplus baseload generation (SBG) which first became an issue for IESO about 15 years ago. At that time IESO established an agreement with Bruce Power that some Bruce nuclear Units would undergo electricity output reductions during periods of surplus baseload generation (SBG). This was accomplished for selected Units by diverting steam from the turbine directly to the condenser at a rate of about 300 kg/sec thereby reducing the Unit's electrical output by up to 300 MW while

imposing very little actual reduction to the Unit's thermal power output. Data listing the outage days and surplus baseload generation events for Bruce B Units between 2014 and 2019 are shown in Tables 6 and 7 below.

Table 6: Bruce B Power Outage Days 2014 to 2019

UNIT	2014	2015	2016	2017	2018	2019
5	55.0	34.0	7.1	99	0	107.5
6	7.1	86.1	7.6	67	2	23.1
7	73.5	26.3	101.2	11	3	113.5
8	0	31.7	103.0	0	117	0

Table 7: Bruce B Surplus Baseload Generation Events 2014 to 2019

UNIT	2014	2015	2016	2017	2018	2019
5	84	126	84	65	29	29
6	90	29	47	39	29	33
7	143	106	89	104	11	26
8	128	83	42	87	4	47

I raised the question of the impact of surplus baseload generation with Maury Burton, Bruce Power's Director of Regulatory Affairs, in May 2023, to which he replied:

"*I discussed the IESO grid derates using steam bypass (dump to the condensers) with our engineering staff. They note that these electrical power derates do not impact on the SORO-code or EFPH calculations as reactor power remains constant during these derates*".

In order to verify this claim, it is useful to consider examples of Bruce B Units having zero power outages for an entire year, such as Unit 5 in 2018 and Unit 8 in 2017. Cases of zero power outages are useful because they imply capacity factors close to 100 % which should be reflected in the power output data for Unit 5 in 2018 and Unit 8 in 2017. The IESO data for these two examples are summarized in Table 8, below.

Table 8: IESO and IAEA PRIS Data for Bruce Units with Close to 100 % Capacity Factors

IESO Parameter	BRUCE UNIT 5 2018	BRUCE UNIT 8 2017
Maximum Energy Supplied (TW.h_{el})	7.1569	7.1569
IESO Energy Supplied (TW.h_{el})	7.0930	6.9608
Energy Loss from SBG (TW.h_{el})	0.0639	0.1961
Capacity Factor (%)	99.11	97.26

IAEA PRIS Parameter	BRUCE UNIT 5 2018	BRUCE UNIT 8 2017
IAEA Energy Supplied (TW h$_{el}$)	7.0767	6.9925
Capacity Factor (%)	98.90	97.70
Difference (IESO vs. IAEA) (%)	0.21	0.44

The data in Table 8 show that there is very good agreement, (to within less than 0.5%), between the IESO data and the equivalent IAEA PRIS data for Bruce Unit 5 in 2018 and Bruce Unit 8 in 2017. This shows that for these two examples the electrical energy lost due to surplus baseload generation is a very small fraction of the total annual electrical energy output. This conclusion supports Bruce Power's claim that these electrical power derates to compensate for surplus baseload generation, (SBG), do not impact on the SORO-code FPH calculations because the reactor power remains essentially constant during these derates. However, SBG derates do become significant in cases such as Bruce Unit 7 in 2014, and Bruce Unit 5 in 2015, when the number of SBG events far exceeds the number of power outage days.

7.0 Variability and Uncertainty in the Output Power of Bruce B Units

As noted in Section 2.0 of this intervention, SORO-code data are not directly comparable to the IESO and IAEA PRIS data because the SORO-code calculates the *thermal power* output of a Unit, rather than its *electrical power*. However, there is the additional issue of the licence limits set by the CNSC on Bruce B Units which have varied over the years due to various derates and uprates.

It is useful to consider how the reported output power of Bruce B Units has varied over the years. Examples of values quoted in the past by various authorities are summarized in Table 9, below:

Table 9: Values of the Output Power of Bruce B Units Quoted in Official Documents

Unit Electrical Output (MW$_{el}$)	Source of Data
911	Bruce Safety Report 2012
900	CNSC Bruce Power Hearing 2014
880	Bruce Power Unit 7 2024
872	Gross Capacity IAEA PRIS 2025
817	Reference Capacity IAEA PRIS 2025

It is also important to note that since 2008 the thermal output power of all Bruce B Units has been limited to 2634 MW, or 93 % of the maximum design limit of 2832 MW.

8.0 CNSC Regulatory Guide G-144 and Pressure Tube Diametral Expansion

The CNSC Regulatory Guide G-144 describes the performance requirements for a reactor's shutdown system(s) for all design basis accidents and are such that the fuel integrity and the primary heat transport system integrity should not be jeopardized. Regulatory Guide G-144 notes that the avoidance of fuel sheath dry-out and consequential pressure tube failure is a major safety concern for CANDU reactor operators. G-144 sets

operational limits that if exceeded require immediate reactor shutdown to maintain fuel integrity. These limits include a maximum fuel sheath temperature of 600 ºC for no more than 60 seconds and a pressure tube diametral creep limit of 5%. Since as-installed pressure tubes have an ID of 103.4 mm, the maximum allowable pressure tube diameter is 108.6 mm.

To obtain diametral measurements for a pressure tube, the Channel Inspection and Gauging Apparatus for Reactors (CIGAR), based on ultrasonic transducers, is used as specified in CSA Standard N285.4. However, the drawbacks of this approach include the need to shut down the reactor and empty the fuel channels, which are both lengthy and costly activities. Diametral measurements that have been made show significant variability from one pressure tube to another, leaving an uncertainty of about ± 0.5 % in the predicted diameter of a heavily irradiated pressure tube near its EoL. The data also show that the variability is not attributable to different reactor operating conditions but to changes in the pressure tube manufacturing process such as the ingot composition, (e.g. iron content), and the extrusion process conditions. This makes it difficult to accurately predict the diametral expansion of pressure tubes with high EFPHs.

Nevertheless, based on available data, an empirical correlation may be derived and used to predict local pressure tube diameters using the local fast neutron fluence, ψ [n/(m²s)], and the time averaged local temperature, T [°C]. This correlation takes the form:

$$D = [A_1 + A_2\,(\psi/10^{25}) + A_4\,(\{T - T_o\}/\,10^2)]\,D_o + D_o$$

where D is the mean diameter of the crept pressure tube, and D_o is the initial diameter of the pressure tube. The coefficients A_1, A_2, A_4, and T_o are determined from a least squares fit of the inspection data. The values determined for these coefficients are 0.0002717, 0.00114, 0.02064 and 273.77, respectively.

A plot of the predicted maximum diametral expansion data for Bruce Unit 7 pressure tubes is presented in Figure 2, below, which shows that this Unit will have already exceeded the 108.6 mm diameter limit at 300,000 EFPH. One therefore has to ask if Bruce Power can guarantee that Bruce Unit 7 will not be subject to fuel sheath dry-out if operated beyond 300,000 EFPH?

Figure 2: Bruce Unit 7 Diametral Expansion
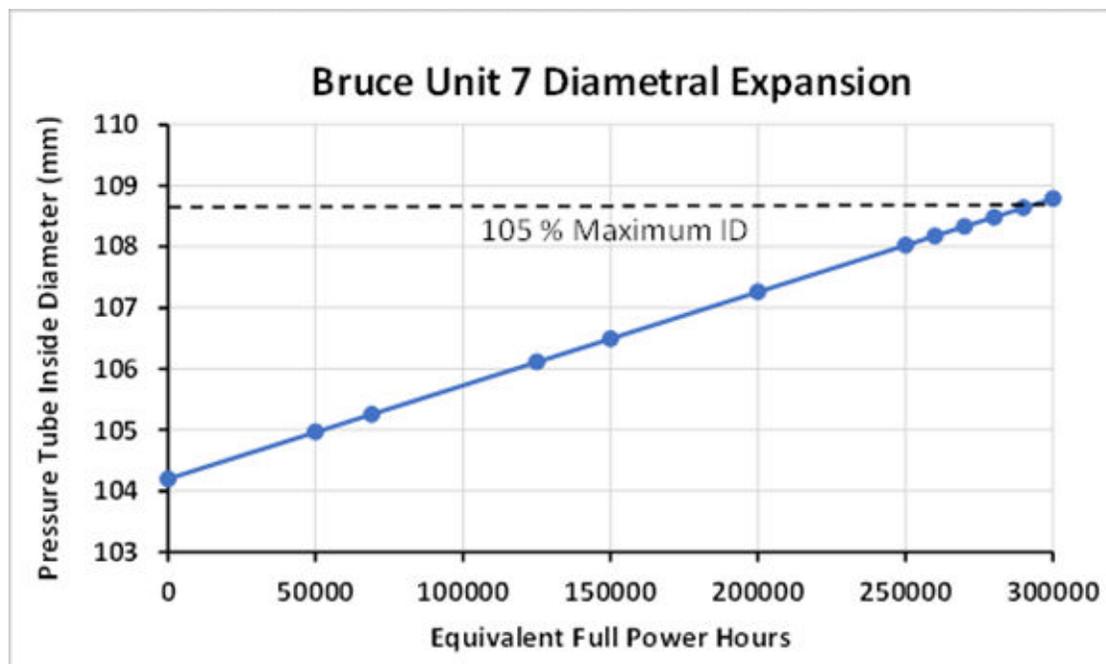
9.0 Bruce Unit 5 EFPH Data

Although Unit 5 is not part of Bruce Power's 2025 request for approval to extend selected Bruce B Units operation up to 310,000 Equivalent Full Power Hours, Bruce Unit 5 is nonetheless a useful example of the different values of a Unit's EFPHs when calculated using IAEA's PRIS data or Bruce Power's SORO code. This is illustrated in Table 10, below.

Table 10: Bruce Unit 5 EFPH Calculated using the IAEA PRIS Data vs. The SORO Code

YEAR	PRIS BRUCE 5 EFPH	PRIS B5 CUMULATIVE EFPH	SORO BRUCE 5 EFPH	SORO B5 CUMULATIVE EFPH
1984	510	510		
1985	7163	7673		
1986	8675	16348		
1987	7197	23545		
1988	7824	31369		
1989	8589	39958		
1990	6656	46614		
1991	8130	54744		
1992	7636	62380		
1993	7457	69837		
1994	7671	77508		
1995	7859	85367		
1996	7153	92520		
1997	8148	100668		
1998	7305	107973		
1999	6719	114692		
2000	8719	123411		
2001	6220	129631		
2002	7630	137261		
2003	6783	144044	6075	131044
2004	7543	151587	6762	137806
2005	6678	158265	5943	143749
2006	8694	166959	7793	151542
2007	8760	175719	7755	159297
2008	6943	182662	6433	165730
2009	8597	191259	7982	173712
2010	8368	199627	7709	181421
2011	7666	207293	7111	188532
2012	8690	215983	8002	196534
2013	8141	224124	7494	204028
2014	7487	231611	6895	210923
2015	7978	239589	7371	218294
2016	8613	248202	7920	226215
2017	6394	254596	5924	232138
2018	8760	263356	8118	240256
2019	6173	269529	5659	245915
2020	7682	277211	7145	253059
2021	8760	285971	8115	261174
2022	6776	292747	6314	267488
2023	8527	301274	7500	274988
2024	8262	309536	7500	282488
2025	7702	317238	7500	289988
2026	7702	324940	7500	297488
2027	7702	332642	7500	304988

Note: Data in red are based on a linear extrapolation from pre-2025 data

The data in Table 10 show that Bruce Unit 5 EFPHs are consistently reported to be higher by the IAEA's PRIS website compared to the data derived from the SORO code, as was previously shown to be the case for Bruce

Unit 7 – see Table 1 of this intervention. The PRIS data also shows that Bruce Unit 5 exceeded 300,000 EFPH by mid-2023, while the SORO Code data shows Unit 5 not reaching 300,000 EFPH until early in 2027.

10.0 Discussion

In July 2023 I submitted an intervention to the CNSC for a public meeting, scheduled for September 20th, 2023, to discuss Bruce Power's mid-term update on licensed activities at the Bruce Nuclear Site – See CNSC reference 2023-M-27. The CNSC Document CMD 18-H4, dated March 14th, 2018, lays out the terms and conditions of Bruce Power's PROL at that time which authorized Bruce Power to operate Units 4 to 8 at Bruce A & B up to a maximum of 300,000 Equivalent Full Power Hours (EFPH). And, as stated in CMD 18-H4, this was the maximum operational time expected for these Units before they entered an MCR outage during which each Unit's pressure tubes, and other major reactor components, will be replaced.

For assessment of the fitness for service of a reactor core, the dominant contributor to the risk of pressure tube failure is deuterium uptake, measured by the hydrogen equivalent concentration [Heq]. CSA Standard N285.8 has developed fracture toughness models for [Heq] up to 120 ppm. However, for operations up to 300,000 EFPH, Bruce Power has estimated that [Heq] could reach levels as high as 147 ppm (i.e., a [Heq] well in excess of 120 ppm). Bruce Unit 5 was predicted to be the first Bruce Unit to go beyond a [Heq] of 120 ppm in March 2020. Table 16 below, taken from CMD 18-H4, provides estimated EFPH/dates at 120 ppm and EFPH/dates prior to MCR for Bruce Units 3 - 8.

Table 16: Bruce Units 3-8 with estimated EFPH/dates at 120ppm and EFPH/dates prior to MCR

Unit	Estimated EFPH at 120 ppm	Estimated Date Unit will reach 120 ppm	Estimated EFPH at time of MCR	MCR Outage Year
3	Units will not reach 120 ppm prior to MCR outage		242,000	2023
4			251,000	2025
5	247,609	March 2020	294,000	2026
6	243,128	December 2019	243,000	2020
7	252,818	January 2022	297,000	2028
8	274,126	February 2027	298,000	2030

Analysis of the data in Table 16 shows that the EFPH dates estimated for each Bruce Unit to reach 120 ppm, *are based on the assumption that the EFPH of a Bruce B Unit increases by about 7000 hours per year*. The selection of 7000 operational hours per year for these Units is itself based on the original *design equation* of a CANDU reactor, where it was conservatively assumed that a Unit would be operating 80% of the 8760 hours in a year, meaning that the Unit was generating power 0.8 × 8760 hrs, or 7008 hours per year. However, the choice of 7008 hours is unnecessary *when real data on the actual EFPH per year are readily available*. Inspection of such data shows that 7008 EFPH per year underestimates the true operational history of all four Bruce B Units. Thus, for example, the IAEA PRIS data shows that the average operational EFPH per year, and the associated capacity factors for Bruce Units 5 – 8 from their first power in the mid-1980s to 2022, are as follows:

<div style="text-align:center">

Bruce 5 = 7703 hours; Capacity Factor = 87.9 %
Bruce 6 = 7427 hours; Capacity Factor = 84.8 %
Bruce 7 = 7747 hours; Capacity Factor = 88.4 %

</div>

Bruce 8 = 7597 hours; Capacity Factor = 86.5 %

These values are all well in excess of 7000 hours per year and show that these Bruce Units are reaching important milestones – such as the need to initiate a MCR project – much sooner than the CNSC predictions in Table 16. This issue was part of my 2023 intervention and was addressed by CNSC President Rumina Velshi during the Public Hearing held on September 20th, 2023, as follows:

> **THE PRESIDENT:** So, I do have a question from one of our intervenors that I wanted clarity from Bruce Power on, and this is from Dr. Greening, and it was around equivalent full power hours and how those get calculated. So, let me see if I have understood his intervention right. I'll start with Bruce Power. So, your licence has a limit of 300,000 equivalent full power hours, and implicit in that calculation is an 80 percent capacity factor; except you're being a lot more efficient than that with a higher capacity factor so that you would reach 300,000 equivalent full power hours earlier than what your schedule for your MCR is estimating. And I wanted you to comment on both the calculation of equivalent full power hours and the capacity factor that's built in, and does that have any implications on your MCR schedule?

Unfortunately, at the September 2023 Hearing, Bruce Power was unable to provide a satisfactory answer to President Velshi's question. Nevertheless, by December 2023, Bruce Power was granted approval by the CNSC to operate Units 7 and 8 to 300,000 Equivalent Full Power Hours. However, in a September 2025 letter to the CNSC, Bruce Power requested approval to extend operation of Bruce B Units 7 and 8 up to 310,000 EFPH. In support of the requested amendment Bruce Power provided an estimate of 278,500 EFPH for Unit 7, as of June 1, 2025, rising to 305,500 EFPH at the time of the projected Unit 7 MCR outage in June 2028.

As I have pointed out in this and previous interventions, there are serious problems with Bruce Power's timeline for Units 7 and 8 to their projected MCR outages. The root cause of these problems is that there are two sets of EFPH data for these Units: one set reported by the IAEA on its PRIS website, and the other set reported by the CNSC based on SORO-code calculations. What is most interesting about these two data sets is that the IAEA set is consistently *higher* than the SORO-code data set by about 1.6 % per year. This may not appear to be a very large difference, but when summed over the lifetime of Bruce Unit 7 it adds up to over 15,000 hours or roughly 2-years' difference. This means that Bruce Unit 7 gains 2-years of operation to reach 310,000 EFPH by using SORO-code predictions, rather than the IAEA predictions. But under the terms of its current PROL, Bruce Power is not allowed to operate any of its B Units at full power, as stated by the CNSC in its Bruce Licence Conditions Handbook as shown below.

LCH PR 18.04/2028 R005: SECTION 3 SCA – OPERATING PERFORMANCE

Bruce B

Total thermal power from the reactor fuel	Shall not exceed 2634 megawatts (93% full power) under steady-state operating conditions

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Furthermore, in a letter from Bruce Power to the CNSC dated August 19, 2025, (See BP-CORR-00531-06659), we have a request from Bruce Power to the CNSC to approve changes to the Reactor Power Limits as spelled out in the PROL Licence Conditions Handbook issued in April 2018. An Executive Summary of Bruce Power's 2025 letter reads as follows:

> *This document serves as Bruce Power's formal notification to the Canadian Nuclear Safety Commission (CNSC), pursuant to Licence Condition G.2 of the Power Reactor Operating Licence PROL 18.04/2028 and the associated Licence Conditions Handbook (LCH), LCH PR 18.04/2028 R005, of a proposed change to operation. The submission seeks Commission approval pursuant to Licence Condition G.1 to recover the reactor, channel, and bundle power limits at the Bruce B Nuclear Generating Station (NGS), as part*

*of the staged implementation of Project 2030. Although the original design basis for Bruce B support operation up to 100% FP, current power limits authorize Bruce B to operate up to 93% FP. Through this submission, Bruce Power proposes a two-step process to demonstrate safety margins for recovering reactor power up to 100%FP: **Step 1**: Bruce Power demonstrates the safety margins are effectively maintained for operation of the reactor units up to intermediate power levels (IPLs) (96% FP at Bruce B).*

The current 93 % full power limit on Bruce B Units implies these Units have a maximum thermal output of 2634 MW, which is identical to the value calculated for this quantity in Section 5.0 of this intervention. Given this fact, it is puzzling that Bruce Power still uses 2832 MW to calculate Bruce B's EFPH. This means that (i) The EFPH will be consistently *lower* than the values calculated using the correct thermal output of 2634 MW. And (ii), Bruce Unit 7 will be allowed to operate for an extra 2 years even though it will actually reach 310,000 EFPH by June 2026. However, if Bruce Power used the appropriate derated thermal output of 2634 MW, Unit 7 actually *exceeded 300,000 hours in March 2025* and therefore will have been in violation of its current PROL for over a year by the time the CNSC holds a Hearing on this issue, (currently set for July 2026). See the figure below for a graphical representation of this issue:

BRUCE UNIT 7: EFPH from IAEA PRIS vs. SORO-CODE

9.0 Conclusions and Recommendations

Before any Public Meetings or Hearings on Bruce Power's requested amendment to its current (2018 to 2028) PROL, the CNSC should recognize and acknowledge that Bruce Power became in violation of the licence limit for Bruce Unit 7 (of 300,000 equivalent full power hours) in March 2025, and therefore should not have been allowed to operate beyond this date.

The fact that Bruce Unit 7 is already in violation of its current licence EFPH limit raises serious questions about the CNSC's position on this issue. Is the CNSC aware of this problem, but chooses to ignore it? Or is the CNSC unaware of this problem due to a lack of understanding of how Bruce Power is using an incorrect reactor thermal power to calculate EFPDs? Either way the CNSC is not fulfilling its mandate to ensure the safety of Canadian nuclear reactors.

I am therefore requesting that the CNSC clarify its position on Bruce Power's current methodology for calculating EFPHs for its CANDU Units. In addition, I recommend that the CNSC stipulate in its Licence

Conditions Handbook *how EFPHs should be calculated* and I believe that IESO is the best source of reliable and comprehensive reactor power data for calculating EFPHs for Canadian CANDU Units in Ontario.

Dr. F. R. Greening