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Written submission from Frank Greening

Mémoire de Frank Greening

Bruce Power

Bruce Power

Bruce Power Mid-Term Update of Licensed Activities

Rapport de mi-parcours au sujet des activités autorisées de Bruce Power

Commission Meeting

Réunion de la Commission

September 20 and 21, 2023

Le 20 et 21 septembre 2023

Canada

From:	Frank Greening
Sent:	July 28, 2023 9:04 AM
To:	Velshi, Rumina; Saumure, Denis; Viktorov, Alexandre
Cc:	Levert, Louise; Zenobi, Adam; Interventions / Interventions (CNSC/CCSN)
Subject:	BRUCE INTERVENTION
Attachments:	BRINT23.docx

Dear President Velshi,

Please accept this email, and the attached word file "BRINT23", as my intervention for the upcoming 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 current PROL in which Bruce Power is authorized 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 is the maximum operational time expected for the Units before they enter an MCR outage, during which a Unit's pressure tubes, and other major reactor components, are 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] in excess of 120 ppm). Bruce Unit 5 is predicted to be the first Bruce Unit to go beyond a [Heq] of 120 ppm in approximately 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 proposed 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 a Bruce Unit 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 arbitrary and unnecessary *when real data on the actual EFPH per year are readily available*. Furthermore, these data sets show that 7008 EFPH per year seriously underestimates the true operational history of all four Bruce B Units. (See Bruce Power data on this in Appendix B).

Thus, for example, the internationally accepted IAEA PRIS, (Power Reactor Information System), 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:

Bruce 5 = 7703 hours; Capacity Factor = 87.9 %
Bruce 6 = 7427 hours; Capacity Factor = 84.8 %
Bruce 7 = 7747 hours; Capacity Factor = 88.4 %
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. For example, the CNSC estimates that Bruce Unit 5 will reach 294,000 EFPH, by 2026, while the IAEA PRIS data show that Unit 5 will exceed 300,000 EFPH as early as 2024. And it is worth noting that Bruce Power is apparently also basing its EFPH calculations on an assumed capacity factor of 80 % when, as shown above, capacity factors in the range 84 to 89 % are the actual lifetime average capacity factors for Bruce B Units, as reported by the IAEA PRIS website.

A good example of the misleading EFPH data reported by Bruce Power may be seen in the Bruce Unit 6 data presented in Bruce Power's September 2021 submission to the CNSC: CMD 21-M37.1. Here we read in an Attachment A that "*Unit 6 was shut down (in November 2019) after 271,729 hot hours (243,773 Effective Full Power Hours)*." This shutdown occurred after 34.8 years of Unit operation. Then, assuming an 80 % capacity factor, we have a total of 7008 hours per year × 34.8 years which equals 243,878 EFPH and is very close to the 243,773 hours reported by Bruce Power. However, if we use the *real* lifetime average capacity factor of 84.8 % for Bruce Unit 6, we have about 258,000 EFPH by the November 2019 shutdown of this Unit.

Another example of dubious EFPH data being reported by Bruce Power may be found in the data contained in a letter to the CNSC dated March 7th, 2019, (See Bruce B Report No: NK29-CORR-00531-15731). This letter includes a Table 4 described as "*Updated Bruce Power Time Predictions for 120 ppm*", which is reproduced in part for Bruce Units 7 and 8 in the table below:

Bruce Fuel Channel	EFPH to Reach 120 ppm	Date to Reach 120 ppm
B7M14	272,000	July 2024
B7P23	278,200	April 2025
B8E18	298,300	March 2030
B8P11	275,000	January 2027
B8E04	297,600	February 2030

These data may be plotted to determine the annual average rate of increase of EFPH for each Unit starting from their respective first-power dates – namely, February 1986 for Unit 7 and March 1987 for Unit 8. In this way it is calculated that an annual rate of increase close to 7000 hours was used by Bruce Power to determine the total EFPH reported in the Table above.

Unfortunately, as previously noted, EFPH data determined using an annual rate of increase of 7000 hours implies an 80% capacity factor which falls well short of the actual life-time capacity factors of 87 ± 2 % achieved by Bruce Units 7 & 8 over their 30+ years of operation. This results in discrepancies of up to 20,000 hours between Bruce Power data reported to the CNSC, and the IAEA-approved data. And these discrepancies are such that Bruce Power's EFPH data make each Unit look *younger* than it really is by 2 to 3 years.

It is significant that in December 2019 Dr. A. Viktorov, a CNSC Regulatory Program Director, had this to say about the EFPH data provided by Bruce Power in its Report No: NK29-CORR-00531-15731, (as shown in the table above):

> "*The EFPH values provided by Bruce Power are different than those presented by Bruce Power during its relicensing hearing by ~ 20,000 EFPH. This is a significant difference and can substantially affect overall licensing decisions…. These differences create difficulties for CNSC staff to have a clear understanding of [Heq] predictions to End of Life (EoL)*."

This comment by a senior CNSC staff member shows that as early as 2019 the CNSC had serious reservations about the EFPH data it was receiving from Bruce Power. Regrettably, however, the CNSC has failed to follow up on this issue. Nevertheless, the remaining material covered by my intervention (See the attached WORD Document "BRINT23") provides a detailed discussion of the question of the validity of Bruce Power's EFPH data and concludes that these data seriously <u>underestimate</u> the annual average EFPH for all four Bruce B Units which shows that the licensing limit of 300,000 EFPH for these Units will be reached <u>well in advance of Bruce Power's predictions</u>.

Indeed, the corrected EFPH data show that Bruce Unit 5 will reach 300,000 EFPH early in 2024. This being the case, the CNSC needs to revise Bruce Powers current PROL, which is valid until 2028, with the condition that *Unit operation is limited to a maximum of 300,000 Equivalent Full Power Hours (EFPH), <u>calculated using realistic annual operational hours, not the **assumed** 7000 hours</u>.*

President Velshi, to conclude, I am asking that you and your staff review the material I have presented in this intervention and acknowledge that the data used by Bruce Power to justify its EFPH predictions *<u>are seriously flawed and should be withdrawn</u>*. In addition, I trust that the CNSC will do the right thing and call for the immediate shutdown of a Unit when it reaches 300,000 EFPH – that is the *<u>true</u>*, not the *<u>faux</u>* total effective full power hours of the Unit.

Sincerely,

Dr. F. R. Greening

Attachment - File “BRINT23”

To whom it may concern:

A key issue with regard to the safe operation of a Nuclear Power Plant, (NPP), is the Fitness for Service of its life-limiting systems. For the CANDU reactors on the Bruce site, the operator, Bruce Power, has acknowledged that fuel channels are the key life-limiting component of each Unit, and has stated that the pressure tubes in each Unit are safe to operate, at least until the next fuel channel inspection which typically happens every 2-3 years.

Traditionally, two benchmarks have been used to quantify the safety of pressure tubes – CSA N285.4 and CSA N285.8. In the original version of these Standards, CSA N285.4 stipulated a maximum value of 2 ppm per 10,000 hot hours for the rate of H/D pickup, and CSA N285.8 stipulated a maximum acceptable value for the hydrogen equivalent concentration, [Heq], at a pressure tube outlet. This was originally set to a value of 100 ppm, but more recently was increased to 120 ppm.

With these Standards being of paramount importance to the continued operation of a Unit, Bruce Power has made several predictions of when each of its eight Units will reach these limits − two good examples of which, (published in 2018 and 2019), are reproduced in Tables 1 and 2, below:

Table 1: Bruce Power 2019 Predictions for a Unit to reach 120 ppm [Heq]

Unit	Channel	Zone	Max [H]initial	Time to reach 120 ppm (HH) [2]	Time to reach 120 ppm (kEFPH)	Time to reach 120 ppm (date)
1	B1J19	IZ	4.6	>302,220	>256	> Feb 2046
1	B1A11	OZ	5.0	>302,220	>256	> Feb 2046
2	Note 1	IZ	5.0	>302,220	>257	> Mar 2046
2	Note 1	OZ	5.0	>302,220	>257	> Mar 2046
3	B3H06	IZ	15.0	>302,220	>257	> MCR in 2023
3	B3X09	OZ	13.0	>302,220	>257	> MCR in 2023
4	B4E07	IZ	13.0	>359,160	>308	> MCR in 2025
4	B4D21	OZ	16.5	328,270	281.7	> MCR in 2025
5	B5F11	IZ	14.8	304,519	274.8	Sept 2023
5	B5A16	OZ	14.2	328,317	296.3	> MCR in 2026
6	B6P09	IZ	18.3	294,687	264.2	> MCR in 2020
6	B6A17	OZ	17.3	316,806	284.1	> MCR in 2020
7	B7M14	IZ	15.0	303,945	272.0	Jul 2024
7	B7P23	OZ	18.9	310,841	278.2	Apr 2025
8	B8E18	IZ	17.8	336,280	298.3	Mar 2030
8	B8P11	IZ-TG3	9.0	309,937	275.0	Jan 2027
8	B8E04	OZ	15.7	335,422	297.6	Feb 2030

Note 1: More than one channel has the same maximum value of 5 ppm [H]initial.
Note 2: For Units 1 through 3 the [Heq] predictions were generated for up to 302,220 HH and for Units 4 through 8 the H[eq] predictions were generated for up to 359,160 HH

Table 2: Bruce Power 2018 Predictions for a Unit to reach 120 ppm [Heq]

Bruce

Unit	Status as of January 1, 2019			Future situation			
	EFPH	Peak Heq concentration, ppm	Existing fracture toughness model valid?	Key date	Anticipated EFPH	Predicted maximum Heq conc., ppm	Existing fracture toughness model valid?
Unit 1	42,040	15.6 *	Yes	Time to reach 120 ppm Heq (beyond February 2046)	>256,000	< 120	Yes
Unit 2	42,596	No data available	Yes	Time to reach 120 ppm Heq (beyond March 2046)	>257,000	< 120	Yes
Unit 3	217,252	72.3 *	Yes	MCR (2023)	248,125	< 120	Yes
Unit 4	209,847	61.9 *	Yes	MCR (2025)	255,600	< 120	Yes
Unit 5	240,248	68.1 *	Yes	September 2023 – first pressure tube reaches 120 ppm	274,800	120 ppm	Yes – until September 2023 *
Unit 6	235,902	65.1 *	Yes	MCR (2020)	245,000 **	< 120	Yes
Unit 7	232,382	95 *	Yes	July 2024 – first pressure tube reaches 120 ppm	272,000	120 ppm	Yes – until July 2024 *
Unit 8	217,272	47.2 *	Yes	January 2027 – first pressure tube reaches 120 ppm	275,000	120 ppm	Yes – until January 2027 *

Because Bruce Units 3 and 6 are already undergoing major component replacement (MCR) projects, I will focus this intervention on predictions for Bruce Units 4, 5, 7 and 8. However, a comparison of the data in Table 1 with data in Table 2 shows major differences between the values reported for Bruce Unit 4. Thus, at least for now, I will further limit my discussion to Bruce Units 5, 7 and 8, key data for which are summarized in Table 3, below:

Table 3: Bruce Power Units 5, 7 and 8 EFPH vs. [Heq] Data

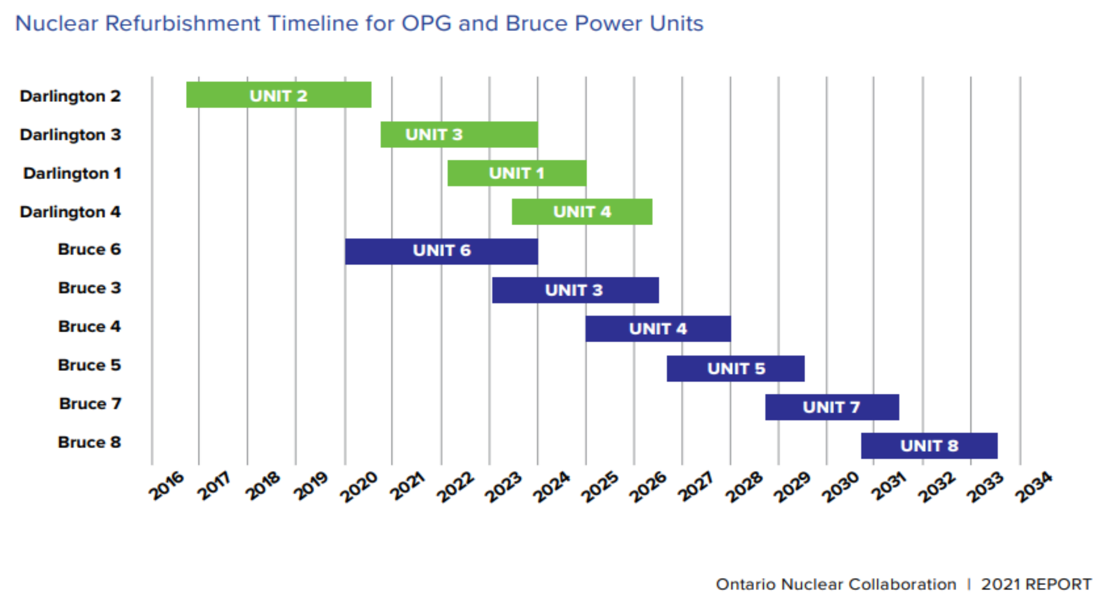
Bruce Unit	EFPH (2019)	[Heq] (ppm at 2019)	EFPH (At 120 ppm)	Date (At 120 ppm)	Δ[Heq] per 10,000 hours
5	240,248	68	274,800	Sept 2023	15.05
7	232,382	95	272,000	July 2024	6.31
8	217,272	47	275,000	Jan 2027	12.65

There are a number of important observations to be made concerning the data in Table 3:

(i) The values of Δ[Heq] /10,000 hours are all very high – far in excess of the 2 ppm /10,000 hours limit specified in CSA N285.4. Also, the H/D pickup rates from a Unit's first power to the 2019 EFPH are all less than 4 ppm/10,000 hours, especially after correcting for contributions from the initial [H]. It follows that the 2019 to end-of-life pickup rates constitute direct physical evidence for accelerating H/D pickup by these Units

(ii) The dates reported in Table 3 for each Unit's pressure tubes to reach 120 ppm are problematic as will be discussed in detail below

Before discussing item (ii), it is helpful to first consider the timeline published by OPG and Bruce Power in 2021, for the planned refurbishments of Bruce and Darlington Units:



It is reasonable to assume that when a pressure tube's [Heq] reaches 120 ppm it should act as a trigger for a Unit's pressure tube replacement project, as spelled out in CSA Standard N285.8. Thus, we would expect to see a close correspondence between the dates presented in the above timeline, and the dates presented in Table 3. However, the dates in question show a systematic delay of about 3 years between the pressure tubes reaching 120 ppm and the start of the Unit's refurbishment project, as summarized by the dates reported in Table 4, below:

Table 4: Dates: [Heq] exceeds 120 ppm vs. Shutdown for refurbishment

Bruce Unit	Date [Heq] Reaches 120 ppm (See Table 3)	Date of Shutdown for Refurbishment (See OPG and BP Timeline)
5	Sept 2023	July 2026
7	July 2024	Sept 2028
8	Jan 2027	Sept 2030

The significant differences between Bruce Power's estimates of the date when a pressure tube's [Heq] reaches 120 ppm, and when each Unit is slated to be refurbished, needs to be explained. To this end, I have compared the effective full power hour (EFPH) data reported by Bruce Power, (See Tables 3 and 4 above), to data reported on the IAEA's PRIS, (Power Reactor Information System), website at: https://pris.iaea.org/pris/countrystatistics/countrystatisticslandingpage.aspx .

Figure 1, below, shows the EFPH data for Bruce Units 5, 7 and 8 in the time period 2010 to 2022, as reported on the IAEA PRIS website, compared to data reported by Bruce Power, noted above. In addition, because these EFPH values increase linearly with time, I have extrapolated the data beyond 2022 to 2030.

Figure 1: A Comparison of data from PRIS vs. Data from Bruce Power

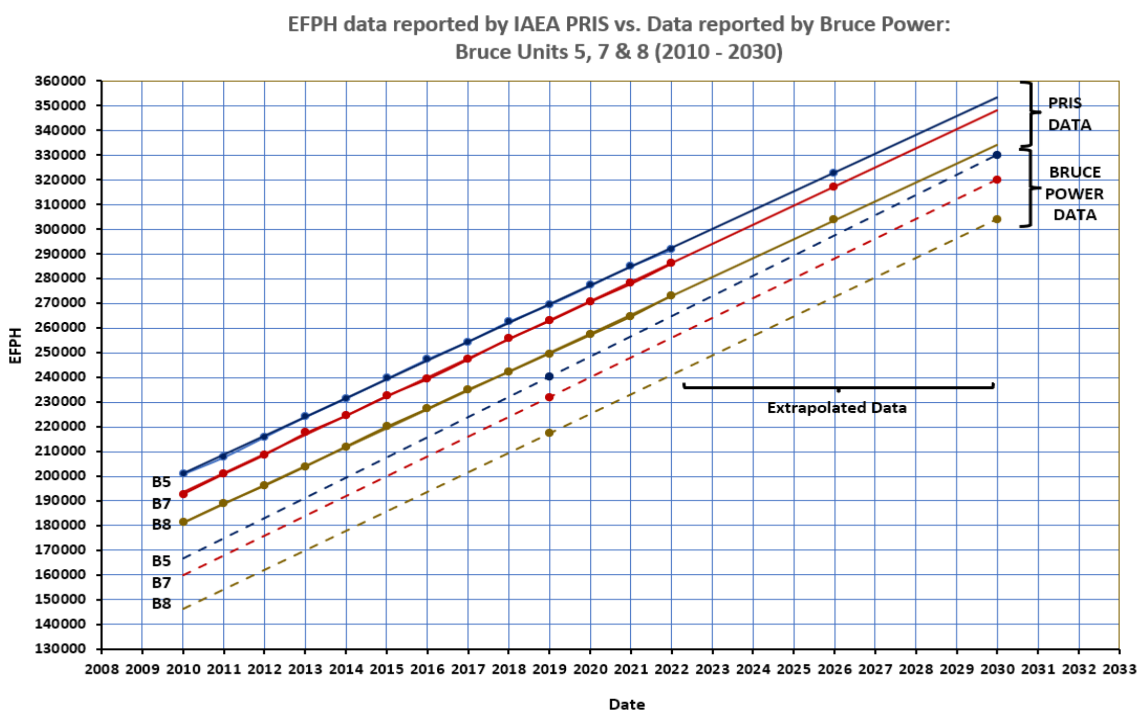


Figure 1 clearly shows that throughout the time period 2010 to 2022, Bruce Power's EFPH data are consistently ~ 20,000 hours *less* than the PRIS data. A clue to explaining this discrepancy may be found in Table 5, below, which shows that in 2018 the CNSC accepted without question that a Bruce Unit reaching 300,000 EFPH would be a trigger for starting a pressure tube replacement project; on this basis, the CNSC also accepted that the dates for Bruce Units 5, 7 and 8 to reach 300,000 EFPH are:

2026 for Bruce Unit 5

2028 for Bruce Unit 7

2030 for Bruce Unit 8

Table 5: Bruce Power's 2018 Predictions for the EFPH at a Unit's MCR

Commission Hearing, March 14, 2018
CMD 18-H4.A

Request 2: Operate up to 300,000 EFPH

Predicted [Heq] and EFPH

Unit	Estimated Year to reach 120 [Heq] ppm	MCR Outage Year	Estimated EFPH at MCR	Estimated [Heq] ppm at MCR
6	Dec 2019	2020	245,000	~121
3	n/a (will not reach 120)	2023	245,000	~102
4	n/a (will not reach 120)	2025	255,000	~104
5	2020	2026	300,000	~151
7	2022	2028	300,000	~147
8	2027	2030	300,000	~139

But is it possible to independently verify Bruce Power's estimates of the time to reach 300,000 EFPH thereby requiring to a major component replacement project? One way to do this is by looking at other sources of EFPH data for Bruce Units 5, 7 and 8. But first, it is useful to consider how Effective Full Power Hours are determined, which requires a precise definition of EFPH:

> *EFPH is defined as the heat generated in a given time interval divided by the licenced thermal power rating over the same time interval*

Or,

EFPH = Thermal Power Generated in MWh / Licenced Power Rating in MW

By this definition, a Unit's annual EFPH is independent of the electrical output of the Unit. However, the performance of a reactor is usually reported in terms of its *electrical energy output* in MWh – see for example the data reported by PRIS. A reactor's electrical energy output is related to the reactor's thermal energy output by an energy conversion efficiency factor, ε:

$$\varepsilon = MWh_{el} / MWh_{th}$$

For a Bruce B Unit, the electrical power rating is currently 817 MW and the thermal power rating is 2830 MW, so that ε = 817/ 2830 = 0.29. Now Bruce Power publishes values for its operating Unit's electrical energy output in its Annual Reports, as shown in Table 6 below for Unit 5 in the years 2015 to 2022.

Table 6: Bruce Unit 5 Performance Data 2015 to 2022: Bruce Power (BP) vs. PRIS Values

Year	BP TWh_{el}	BP (EFPH)	PRIS (EFPH)	% (BP - PRIS)
2015	6.19	7576	7565	0.146
2016	6.70	8201	8252	-0.625
2017	5.00	6120	6162	-0.678
2018	7.08	8666	8662	0.042
2019	4.86	5949	5956	-0.123
2020	6.23	7625	7623	0.032
2021	7.10	8690	8738	-0.548
2022	5.50	6732	6689	0.638
AVERAGE	6.08	7445	7456	-0.14

These data show excellent agreement between Bruce Power's published values and the values reported on IAEA's PRIS website, with a percentage difference between the two sets of data being consistently less than 1%. Then, using PRIS data for the cumulative EFPH values from the startup of Unit 5 in 1985 to the present (2022), we arrive at a total EFPH of approximately 292750 hours. From this total we see that Bruce Unit 5 will exceed 300,000 EFPH by the end of 2023.

If similar data are collected and analyzed for other Bruce B Units, they show that *the actual dates for Bruce Units 5, 7 and 8 to reach 300,000 EFPH are*:

2023 for Bruce Unit 5

2024 for Bruce Unit 7

2026 for Bruce Unit 8

However, this new timeline for MCR projects on Bruce Units 5, 7 and 8 has major implications for Bruce Power's safe operation of these Units during the second half of its current 2018 - 2028 PROL. This is because this new timeline requires that Unit 5 should be shut down before the end of 2023; Unit 7 should be shut down before the end of 2024; and Unit 8 should be shut down by the end of 2025. However, such a timeline poses logistical problems for Bruce Power because it lacks the resources to carry out more than *two* MCR projects at the same time.

But this new timeline raises another issue concerning Bruce Power's approach to dealing with high Heq concentrations in pressure tubes in its aging Units. This issue is revealed by the data in Figure 5, above, which show that at 300,000 EFPH, the estimated Heq concentrations are: 151 ppm for Unit 5; 147 ppm for Unit 7; and 139 ppm for Unit 8.

The fact that these concentrations vary from Unit to Unit is curious because we have been told for decades that the Heq concentration in a pressure tube determines its fracture toughness and therefore also determines its fitness for service. One would therefore expect that, once a pressure tube reaches a certain concentration of H/D, (regardless of whether it is 100, 120 or 140 ppm), *the Unit in question would no longer be safe to operate and should be shut down*.

I intentionally mention a number of different values for Heq because the CNSC has allowed this limit to vary, through changes to the applicable standard: CSA N285.8. Thus, a value of 100 ppm was accepted for many years, but was increased to 120 ppm in 2018. Nevertheless, with the urging of the Canadian nuclear industry, the CNSC is now considering increasing the Heq limit still further to 140 ppm.

Unfortunately, however, Table 5 shows that the decision to shut down a Bruce Unit for a MCR project is now being made based on the Unit reaching 300,000 EFPH, *rather than the Unit's Heq reaching a statutory limit*. In view of this radical change in how the safety of a reactor is assessed, I feel compelled to ask two questions:

(i) What is the scientific basis for choosing 300,000 hours as the operational limit of these Units, (rather than any other EFPH limit)?

(ii) Is a pressure tube's Heq, and how it changes with time, no longer considered as the ultimate determinant of a Unit's fitness for service?

Discussion:

On October 11th, 2022, Bruce Power applied for an Amendment to its Power Reactor Operating Licence. In this application, Bruce Power requested the removal of Licence Condition 15.3, which states that "*Before hydrogen equivalent concentrations ([Heq]) exceed 120 ppm, the licensee shall demonstrate that pressure tube fracture toughness will be sufficient for safe operation beyond 120 ppm.*" In lieu of Licence Condition 15.3, Bruce Power proposed a Licence Amendment that all fitness-for-service requirements related to pressure tubes be incorporated into the existing Licence condition 6.1, which states simply that "*The licensee shall implement and maintain a fitness for service program*."

On March 15th, 2023, CNSC released its latest position on Bruce Power's Licence Amendment Application, (See CMD 23-H103), and stated the following:

> *Based on the recent Commission decisions and CNSC staff assessments relating to elevated Heq in pressure tubes, CNSC staff are of the view that LC 15.3 is no longer applicable. CNSC staff recommend that the Commission amend Bruce Power's PROL to remove LC 15.3.*

Thus, here we see the CNSC recommending the removal from Bruce Power's current PROL any limit on a pressure tube's maximum [Heq]. And history shows that the CNSC Commissioners invariably abide by the recommendations of CNSC Staff. Nevertheless, this approval of Bruce Power's Licence Amendment stands in stark contrast to the CNSC's position on this issue from just a few years earlier, when Dr. Viktorov, CNSC Regulatory Program Director, stated in a letter dated December 5th, 2019:

> Finally, Bruce Power has provided an advanced copy [51] of an upcoming submission with predictions for all Units and time-to-reach 120 ppm. These values, presented in Figure 4 below, are different than those presented by Bruce Power during the relicensing hearing, as given in Figure 1 above. What becomes pertinent, is the change by ~ 20 kEFPH. This is a significant difference and can substantially affect overall licensing decisions.
>
> To conclude, it has become apparent that [H_{eq}] predictions to EoL are important since they are directly related to the 120 ppm limit for fracture toughness. At the same time, differences between probabilistic and deterministic methodologies, some of which are presented herein and in, and continuous updates and challenges to the models, create difficulties for CNSC staff to have a clear understanding of [H_{eq}] predictions to EoL.

Based on these comments by a senior CNSC Director, it is evident that, only 3-years ago, the CNSC was very concerned, (as I am concerned today), with the EFPH data being provided by Bruce Power for the time for a Unit to reach its end-of-life (EoL). And I have seen nothing that has been offered by Bruce Power in the intervening three years to alleviate the CNSC's or my concerns. But it is most unfortunate that the CNSC has abandoned CSA Standard N285.8 as a PROL requirement, even after saying quite recently: "*[Heq] predictions to EoL are important since they directly relate to the 120 ppm limit for fracture toughness.*"

But the debate on the EoL management of CANDU reactors can be traced back many years. Thus, in the CNSC document: *Comments received from public consultation on RD-360, Life Management of Nuclear Power Plants; First consultation: July 18 – September 19, 2011; Second consultation October 14 – October 28, 2011*, we have the following statement by Bruce Power:

> **Assumed Design Life**: *The proposed version of RD-360 defines station design-life based on fuel channel life. Bruce Power has consistently stated that while Effective Full Power Hours may be a suitable limit for pressure tubes operating life time, there is no technical basis to link it to a default value for the overall design life of a station. Plant design life is influenced by a number of factors associated with how the plant is designed, operated, and maintained as well as upgrades implemented over the years. The utilities are in the best position to technically define a current design life, and should be permitted to do so utilizing knowledge of component aging management, operating experience, inspections, research, and analysis associated with life cycle management activities.*

To this statement by Bruce Power, the CNSC responded with a comment on the wording for the revised RD-360 Document, as follows:

> *The nominal design life is defined as: "The period of operation that was originally anticipated at the design phase for the NPP. It is used as a reference or target for planning activities including the design of Systems and Components (SSC's) that can affect the safe operation of the NPP. For the purposes of this regulatory document and for the current operating CANDU power reactors, unless otherwise stated, the "nominal design life" of an NPP is 30 years, based on a 0.8 capacity factor of nominal full power."*

From this comment by the CNSC, we see that twelve years ago the design life of a CANDU reactor was assumed to be 30 years. Then, for a capacity factor of 0.8, we have an EFPH at a Unit's EoL of (8760 × 0.8 × 30) hours or 210,240 EFPH. However, at the same time, (i.e. ~ 2011), we see Bruce Power suggesting that "*there is no technical basis to link a reactor's EoL to a default value for the overall design life of a station.*"

Now, as previously noted, this is quite simply *not true* because for the past 40 years CANDU reactors have been operated under the assumption that a pressure tube's fitness for service is limited by its [Heq], which, if it exceeds the terminal solid solubility (TSS) of hydrogen in the zirconium matrix, leads to the formation of hydride precipitates that may eventually cause delayed hydride cracking of the tube. It is on this basis that the first *Design Equation* for Bruce Units predicted a pressure tube's [Heq] would exceed the TSS after about 30 years of operation which corresponds to about 210,000 EFPH based on a capacity factor of 0.8. Thus, 210,000 EFPH was for many years the accepted EoL for these Units.

Nevertheless, in 2017 Bruce Power requested in its licence renewal application to the CNSC that it be permitted to operate all Units at Bruce NGS A and B up to 300,000 EFPH, regardless of a Unit's [Heq]. Then, at the subsequent 2018 licence renewal hearing, the CNSC did indeed authorize operation of Bruce NGS A and B Units up to a maximum of 300,000 EFPH, as stated in the CNSC's *Record of Decision* issued on September 27th, 2018.

But this only creates confusion over what "*authorization to operate to 300,000 EFPH*" really means because there are different ways to calculate "300,000 EFPH" in terms of the associated EoL *dates* for a Bruce Unit. Thus, if we follow the calculation noted above, that is based on a capacity factor of 0.8, it follows that 300,000 EFPH is equivalent to 43 years of Unit operation. Then, using the published dates for the start of commercial operations of the Bruce Units of interest, (See Appendix), we have EoL dates as follows:

2027 for Bruce Unit 5

2029 for Bruce Unit 7

2030 for Bruce Unit 8

Now these dates are close to the dates proposed by Bruce Power, as presented in Table 5 of this intervention. However, as previously noted, these dates are quite simply *incorrect* because the assumption that the capacity factor for these Units is

0.8 *is incorrect*. The lifetime average capacity factor for these Units, (as reported by the IAEA's PRIS website – See Appendix), is actually 0.86 ± 0.02, equivalent to about 39 years of Unit operation, in which case the EoL dates for these Units now become, (as previously reported on page 5 of this intervention):

2023 for Bruce Unit 5

2024 for Bruce Unit 7

2026 for Bruce Unit 8

However, in view of these different estimates for the EoL dates for Bruce Units 5, 7 and 8, it is worth repeating that Bruce Power initially stated, (in 2011), that "*there is no technical basis to link a reactor's EoL to a default value for the overall design life of a station*", only to request in its 2017 licence renewal application that "*it be permitted to operate all Units at Bruce NGS A and B up to 300,000 EFPH*". This leads to the obvious question: Why did Bruce Power choose *300,000 EFPH*?

A search of the literature on this issue reveals that Bruce Power's desire to operate Units 5, 7 and 8 to 300,000 EFPH was first stated in a paper presented at the 2017 11th International Conference on CANDU Maintenance and Nuclear Components, entitled: *Delivering clean energy through CANDU life extension*, where we read:

> *The Safe, Reliable and Cost-Effective operation of the Ontario CANDU Reactors is a key element of the energy strategy for Ontario. The COG Fuel Channel Life Management Project is being undertaken by OPG, BP and CNL and is considered a key input to each utility's Asset Management Program as well as in support of license renewal. This multi-year R&D project was undertaken to advance the industry understanding of key fuel channel assembly fitness-for-service material properties, modeling, and methodologies for accelerated life-cycle conditions. In the limit, the ultimate objective was to ensure that fuel channel assembly fitness-for-service could be demonstrated to at least 300,000 EFPH. As a key input to the asset management programs, this is also a key enabler for the Ontario Provincial Government Long-Term-Energy Plan (LTEP) where Units at both OPG and BP must operate through to 2030.*

However, this still fails to explain where the number 300,000 EFPH originally came from, but a clue to resolving this mystery resides in the final words quoted above: "*BP <u>must</u> operate its Units through to 2030*". And the reason for the use of the categorical imperative "*must*" is revealed below.

On Dec, 3rd 2015, Bruce Power and the Independent Electricity System Operator (IESO) entered into an *Amended and Restated Bruce Power Refurbishment Implementation Agreement* to secure 6,400 megawatts (MW) of electricity from the Bruce Power site through a multi-year investment program. On page 49 of this Amended Agreement, we find a "*Refurbishment Outage Schedule*" that lists the starting dates for the MCR projects on Bruce Units 5, 7 and 8 that are required in order for Bruce Power to meet the terms of the agreement.

Thus, we see that *<u>2-years prior</u>* to Bruce Power's 2017 application to operate all Units at NGS A and B up to 300,000 EFPH, Bruce Power had signed a contract with the IESO that already stipulated refurbishment dates for Units 5, 7 and 8 that spanned the years 2020 to 2030, which required that each Unit operate to at least 300,000 EFPH. This suggests that Bruce Power was so confident that the CNSC would approve the required changes to its PROL that it signed a contract with a third party that required extending the EoL of three Units well beyond the 247,000 EFPH limit that applied at the time; and this third-party contract was signed in 2015, *<u>2 years before Bruce Power sought regulatory approval from the CNSC to operate to 300,000 EFPH</u>*.

<u>Conclusions</u>:

The evidence presented in this intervention raises several important issues:

(i) There are obvious errors in the EoL EFPH predictions for Bruce B Units provided by Bruce Power to the CNSC

(ii) These erroneous data are being used by Bruce Power to justify extending the operational life of Bruce Units 5, 7 and 8 by up to 5 years, but, if the correct data are used, all three Units would have exceeded 300,000 EFPH by 2026, as shown by the data presented in this intervention and also in the Appendix attached below

Dear Commissioners, in view of these conclusions, I am asking that you please consider the evidence I have presented in this intervention and call on the CNSC to limit the operation of Bruce Units 5, 7 and 8 to the end of 2023, (Unit 5), the end of 2024 (Unit 7), and the end of 2026, (Unit 8). The only other option would be to increase the operational limits of Bruce Units 5, 7 and 8 to ~ 340,000 EFPH, but this would only increase the risk of delayed hydride cracking in these Units.

Sincerely,

Dr. F. R. Greening

Comments Pertaining to Bruce Power's June 2023 Hearing Submission

On June 1st, 2023, Bruce Power provided its "Mid-Term Update" to the CNSC. Unfortunately, however, this 57-page document devotes just *one page* to the vitally important topic of high Heq levels observed in some Bruce pressure tubes. Thus, on page 36 of Bruce Power's "Mid-Term Update", under the heading Pressure Tube Integrity, we read:

> *An industry workshop on elevated hydrogen equivalent ([H]eq) concentration was held on March 25, 2022, to present the status on the work completed to-date to improve the mechanistic understanding of this behavior and predictive modelling capabilities and to solicit CNSC feedback on future work. Since the time they were noted in July 2021, Bruce Power has provided regular updates to the CNSC on the elevated [H]eq concentration observations through various correspondences and meetings.*

Clearly, this "update" is very light on detail or substance and certainly does not convey any useful information to the public, or the CNSC, on the root cause of the high Heq observed in some Bruce pressure tubes. Indeed, we see that the best Bruce Power has to offer on this very important topic is essentially one comment about the nuclear industry's work "*to improve the mechanistic understanding*" of elevated Heq.

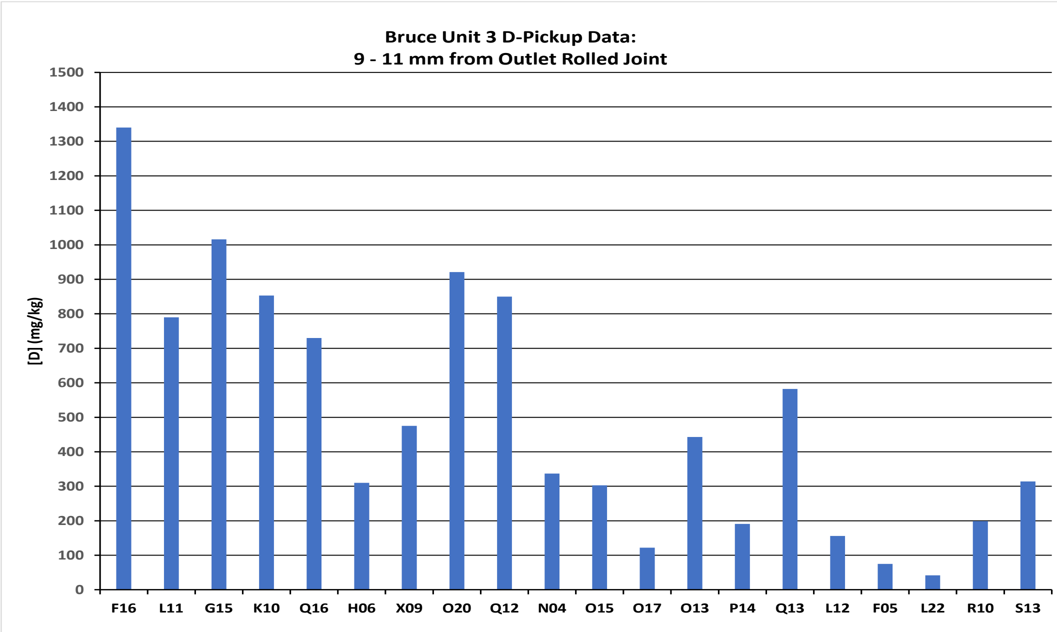
But let's consider the language being used here and in particular the use of the word *understanding*. The dictionary definition of the word *understanding*, in the scientific context of Bruce Power's "update," is as follows:

> *To know the cause of something to be able to explain how or why it happens*

From this definition we see that once one *knows the cause* of a phenomenon, one should then be able to create a model that is capable of providing predictions of the future behavior of the phenomenon – which, in this case, means providing estimates of the rate of increase of Heq at a specific location along the length of a randomly selected pressure tube.

In this regard, consider as an example the set of deuterium pickup data recently measured, (2021), by Bruce Power for samples collected about 10 mm from the outlet rolled joints of twenty Unit 3 pressure tubes. The data in question are presented in graphical form in Figure 1 below:

Figure 1: [D] measured near the outlet of 20 pressure tubes removed from Bruce Unit 3



The most striking feature of the data plotted in Figure 1 is the extreme *variability* of the deuterium concentrations, which vary from a high of 1340 ppm for tube F16, to a low of 42 ppm for tube L22. The average value of these concentrations is 502 ppm with a 2-sigma standard deviation of 612 ppm.

This remarkable variability shows why it is difficult to estimate the Heq for the full complement of 480 pressure tubes in a Bruce Unit. And it follows that it is next to impossible to *predict* how these hydrogen concentrations will vary with time, even in the near, (2-3 year), future. This problem with reliably predicting Heq values in pressure tubes has been an unresolved issue for the Canadian nuclear industry for more than 25 years; which has very little to show by way of definitive results.

An early approach to explaining the variability of H/D pickup was to look for a correlation between high H/D pickup pressure tubes and the concentration of impurities such as chlorine, carbon, and iron in these pressure tube's starting material. However, as early as 1997, it was concluded that "*there is no strong correlation between D uptake and the concentration of trace impurities*".

This lack of understanding of how H/D enters a pressure tube is even more evident when we look at H/D pickup near a pressure tube's inlet or outlet rolled joints. By 1985 researchers generally agreed that at least *five* pathways for H/D entry into a pressure tube at a rolled joint need to be considered, as follows:

(i) Entry from corrosion by the coolant at the inside surface of a pressure tube
(ii) Entry from the coolant through crevice corrosion within a rolled joint
(iii) Entry through the pressure tube outside surface from the annulus gas system
(iv) Entry from the stainless-steel end fitting involving galvanic coupling
(v) Entry through the end fitting from the annulus gas system

The scatter in the Heq data shown in Figure 1 suggests that more than one of these pathways is operative at any given time, and in addition, it appears that the relative contribution from each pathway varies from tube-to-tube in an entirely unpredictable manner.

The unpredictability of Heq measurements is clearly derived from the intractable nature of the processes involved in H/D pickup at a pressure tube rolled joint. And the fact that this problem has plagued the Canadian nuclear industry and the CNSC for many years is demonstrated by an intervention I submitted to the CNSC almost 10 years ago:

<u>April 2014 Submission for a CNSC Hearing on Pickering Continued Operation beyond 210,000 EFPH:</u>

Please consider the *Ontario Energy Board* hearing held on 17th Aug, 2010 (EB-2010-0008) and in particular *Interrogatory #014* where we find these statements:

> *Until recently, Pickering B was not expected to exceed EOL limits during the pressure tube nominal operating life of 210k EFPH. However, the hydrogen and deuterium profiles through the inlet and outlet rolled joint regions of surveillance tube P6 M14 have challenged this belief (report issued December 2008). It appears that P6 M14 has much higher deuterium uptake in the compressive regions of the pressure tube and* H_{eq} *exceeds the solubility limit at both inlet and outlet rolled joint burnish marks*.

> *Work to address the long-term integrity of pressure tubes has been ongoing for many years through the COG Fuel Channel R&D program, (however), the principal issues have only come to light fairly recently, relatively late in the life cycle of the units. For example, the issue of anomalous hydrogen pick-up in Pickering B Generating Station's rolled joints was highlighted by the results of the inspection of a surveillance tube removed in 2007.*

Thus, we see that the Canadian nuclear industry and the CNSC were well aware of the occurrence of "*anomalous hydrogen pickup*" by CANDU pressure tubes as early as 2008. And, most unfortunately, very little progress in our understanding of the mechanism(s) controlling H/D pickup by pressure tubes has been made since 2008. Indeed, *<u>if H/D pickup was understood</u>* there should be no more "unexpected" cases of high Heq observed in any Unit at Bruce, Pickering, or Darlington, which as the example below shows, is simply not the case, (my emphasis in red).

On March 24th 2022, Bruce Power issued the Event Initial Report CMD 22-M16, which stated in part:

> *Following the July 2021 discovery of elevated Heq near the outlet rolled joint, Bruce Power performed additional surveillance testing on the removed PT B6S13 and discovered that elevated Heq also exists near the inlet end of the PT. The reported Heq level from a through-wall punch sample was 126 ppm at approximately 10 mm in board of the burnish mark.*
>
> *Bruce Power does not have a mechanistic understanding of the phenomenon nor validated models as a result of this finding. In other words, their Heq model is invalid because the outputs of the Heq models do not align with the B6S13 measurement of 126 ppm at the inlet end of the PT. These Heq outputs are used as inputs into Fitness for Service Assessments such as leak-before-break (LBB) and fracture protection (FP) assessments. The uncertainty of the Heq inputs impact the LBB and FP assessments. CNSC staff are of the opinion that Bruce Power cannot confidently perform these assessments until the Heq phenomenon is understood and modelled.*

In light of this opinion, so clearly expressed by the CNSC just over a year ago, I believe it is high time for the CNSC to acknowledge that H/D pickup at a pressure tube rolled joint, (both at the tube's inlet and at its outlet ends), is essentially *<u>unpredictable</u>*. And as previously shown in this intervention, this unpredictability stems from the fact that there are many independent pathways by which H/D can enter an operating pressure tube, and there is no *a priori* reason to prefer one pathway over another.

And to make matters worse, there are other factors, not considered thus far in this intervention, that can potentially promote H/D entry into a pressure tube. These factors include the development of pressure tube inside surface flaws, bearing pad fretting, oxide porosity, oxide spalling, the formation of microcracks in outside surface oxides, etc., all of which are essentially incommensurable during reactor operation. This means that simply tweaking an existing model, that only considers *one* mode of H/D entry, is doomed to failure. But, most unfortunately the CNSC appears willing to wait for a new and improved model of H/D pickup to be developed by some nuclear industry genius – however long this takes.

Interestingly, it appears that the Canadian nuclear industry is like-minded in this regard, which may be seen in the timeline proposed to develop a new and improved [Heq] model, as first reported at an industry workshop on elevated hydrogen equivalent ([H]eq) concentration held on March 25th, 2022. In an account of this meeting, published by Bruce Power in July 2022, we find Attachment B which provides "*a path forward with a target schedule and summary of key deliverables to <u>improve hydrogen equivalent concentration predictions</u> in the inlet/outlet rolled joint regions of pressure tubes*". Action Item 5G in Attachment B, described as "The Development of a Comprehensive [Heq] Model", gives the target date for the completion and issuance of a "comprehensive [Heq] Model" as **<u>the 2nd Quarter of 2026</u>**.

Dear Commissioners, as I have amply demonstrated in this intervention, there will never be "an improved theory" of H/D pickup that is capable of providing reliable predictions of H/D pickup at pressure tube rolled joints; this is because it is not possible to model a multi-variate system with any acceptable degree of precision or accuracy. Waiting 3 years for the development of improved Heq predictions is a waste of time, especially if *the cause* of the higher-than-expected Heq in Bruce pressure tubes remains unknown.

What is really needed right now is for Bruce Power to issue a *<u>root cause report</u>* on the elevated Heq concentrations observed in Bruce Units 3 and 6 in July 2021. Without such a root cause report, it is impossible for Bruce Power to provide the CNSC with assurances that this high Heq problem will not recur in other Bruce Units. To do nothing, and let Bruce Power continue operating Units 5, 7 and 8, with no restrictions is surely not an option, and must not be permitted by the CNSC. Dear Commissioners, please do the right thing, and just say *<u>no</u>*!

APPENDIX A

Basic performance data for **Bruce Unit 5**, copied from the IAEA PRIS website:

REACTOR DETAILS

Reactor Type **PHWR**	Model **CANDU 750B**	Owner **Ontario Power Generation**	Operator **Bruce Power**
Reference Unit Power (Net Capacity) **817 MW_e**	Design Net Capacity **822 MW_e**	Gross Capacity **872 MW_e**	Thermal Capacity **2832 MW_t**
Construction Start Date **31 May, 1978**	First Criticality Date **14 Nov, 1984**		
First Grid Connection **01 Dec, 1984**	Commercial Operation Date **28 Feb, 1985**		

LIFETIME PERFORMANCE

Electricity Supplied	Energy Availability Factor	Operation Factor	Energy Unavailability Factor	Load Factor
230.78 TW.h	**85.4 %**	**87.9 %**	**14.6 %**	**84.8 %**

Lifetime performance calculated up to year 2022

Notice the IAEA PRIS data include *three* measures of the <u>lifetime performance</u> of Bruce Unit 5: (i) *The Energy Availability Factor; (ii) The Operation Factor; (iii) The Load Factor*. However, these factors differ only slightly and average 86 ± 2 %. This average value is significantly higher than the target 80 % capacity factor used to calculate the EFPH at a Unit's design EoL, namely, 8760 (hrs/y) × 0.8 × 30 (y) or 210,240 EFPH. This formula means that, at their commissioning, each Bruce B Unit was assumed to average 7008 EFPH per year, over a period of 30 years. Bruce Unit 5 started commercial operation in 1984, so it follows that it would reach 210,000 EFPH by the end of 2014, as noted below:

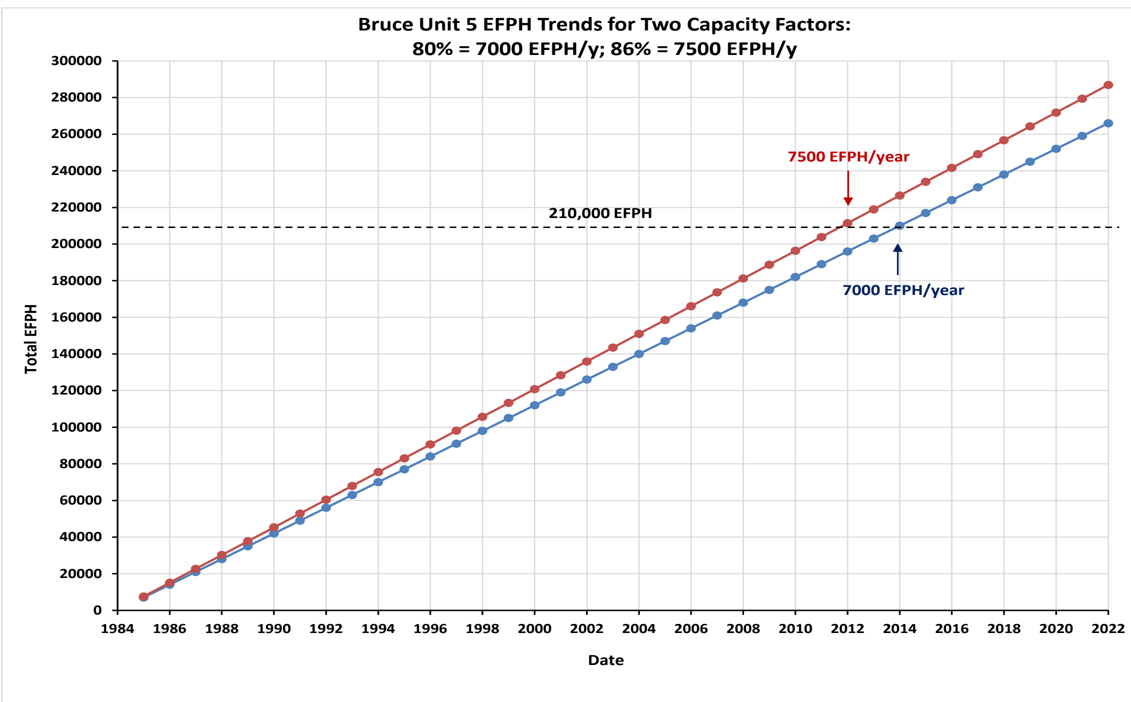
From a CNSC hearing dated 2014-09-17, (with my emphasis in red):

> *Bruce Power submitted a request for operating beyond 210,000 EFPH for Bruce B Unit 5, since the reactor is expected to reach the maximum EFPH in the fall of 2014. Bruce B unit 6 is predicted to reach the 210,000 EFPH limit in early spring 2015. The remaining units will not reach the maximum until the planned hearings for the renewal of the operating licence for the Bruce site and are therefore not at issue.*

However, as noted above, an analysis of the actual performance of Bruce Unit 5 between 1984 and 2022 shows an average capacity factor for this Unit of about 86 % which means the annual increase in Unit 5's EFPH has been ~ 7500 hours, or 500 hours per year *more than* the CNSC's assumed 80% capacity factor equivalent to 7000 EFPH per year.

The consequence of this difference is that Bruce Unit 5 accumulated 15,000 extra hours after 30 years of operation, compared to a Unit with a hypothetical 80% capacity factor. Thus, Unit 5 reached 210,000 EFPH about 2-years *earlier* than the date estimated by the CNSC at the 2014 Hearing, i.e., Bruce Unit 5 reached 210.000 EFPH in 2012, *not in 2014*, as shown in Figure A1, below.

Figure A1: Data Showing the Time to reach 210,000 EFPH



Given the fact that in 2014 the CNSC underestimated the rate of accumulation of EFPH for Bruce Unit 5 by a factor of about 500 hours per year, it is not surprising that the CNSC repeated this error in 2022 when it estimated the dates at which Units 5, 7 and 8 would reach 300,000 EFPH – thereby buying Bruce Power at least 2 years of extended operation at EFPH above this statutory limit. It is most disturbing that Canada's nuclear regulator should be so remiss as to not recognize this simple error, but hopefully it will now take steps to rectify this problem.

Figure A2: Data Showing the Time to Reach 300,000 EFPH

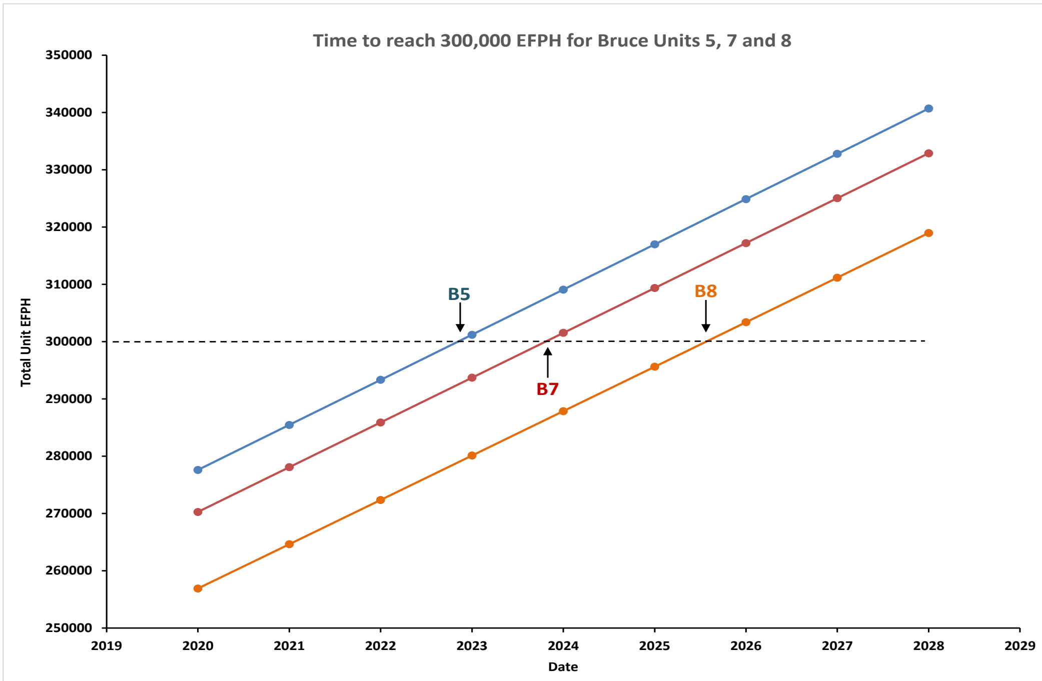


Figure A3: Data Showing Yearly Capacity Factors

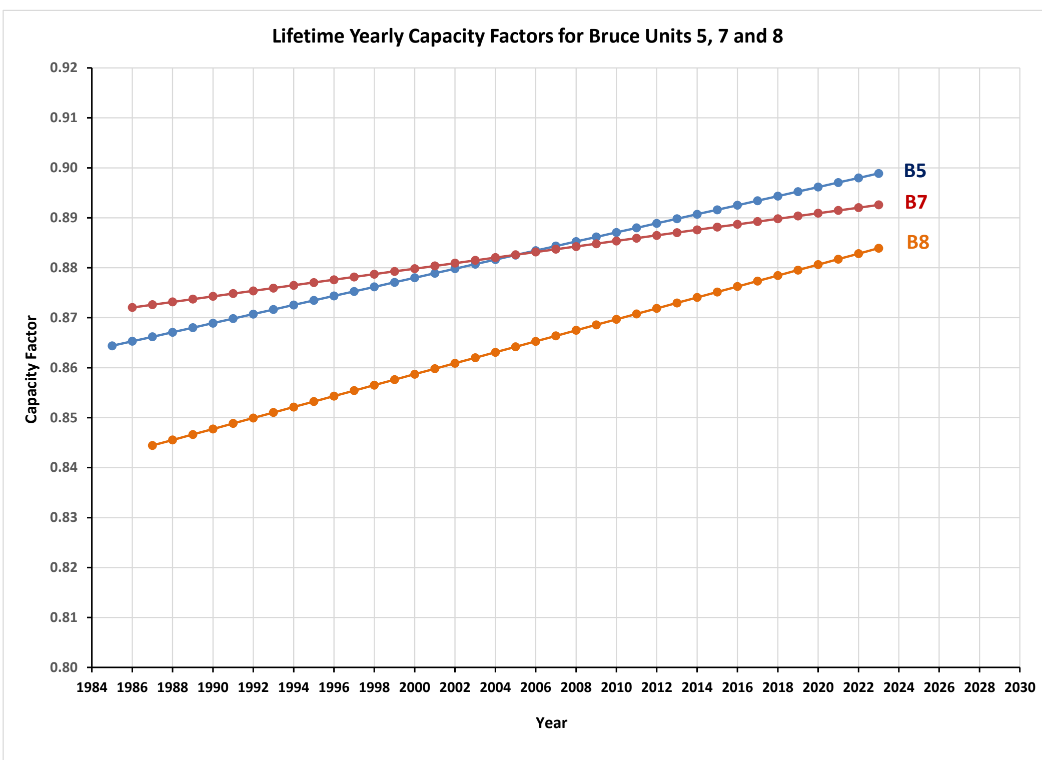


Figure A4: Data Showing Lifetime Trends in the Annual EFPH

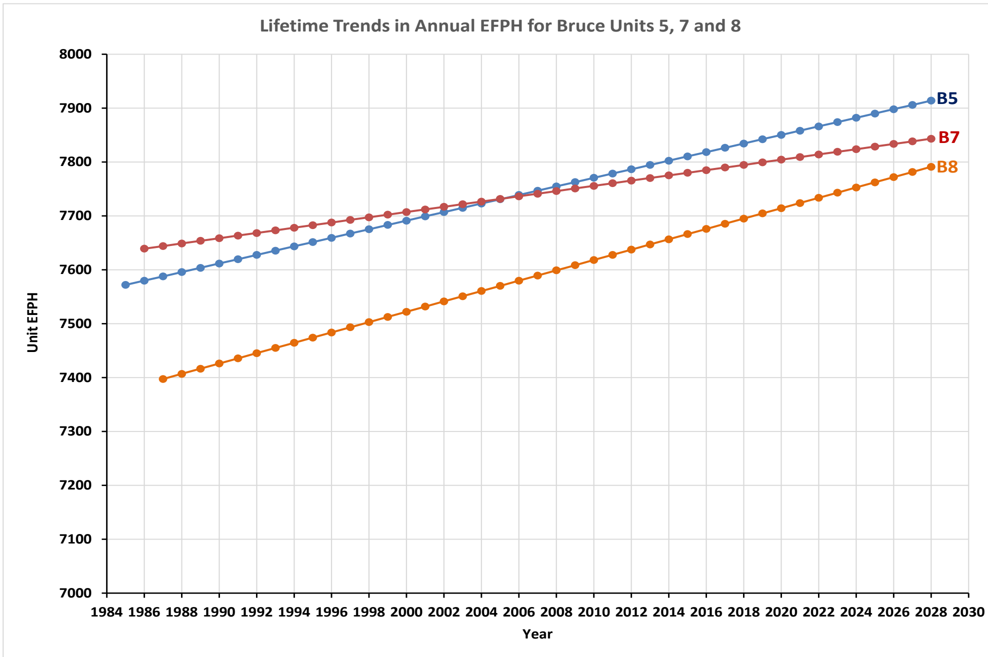


Table A1: Time to Reach 300,000 EFPH

YEAR	B5 EFPH	B7 EFPH	B8 EFPH
2020	277599	270262	256898
2021	285457	278071	264622
2022	293323	285885	272355
2023	301197	293704	280098
2024	309079	301528	287851
2025	316970	309357	295614
2026	324867	317190	303385
2027	332773	325029	311167
2028	340687	332872	318958

Unit Operating Time Expressed in Effective Full Power Hours vs. Hot Hours:

Pressure tube aging mechanisms such as hydrogen pickup, as well as feeder pipe wall thinning and steam generator tube corrosion, are all thermally activated processes which depend on the time a reactor is at its operating temperature. If follows that the appropriate metric for the aging of these components is the reactor's accumulated hot hours, (HH), *not it's effective full power hours, (EFPH)*.

Furthermore, when a Bruce Unit's accumulated hot hours of operation are tallied up, we find the total hot hours are typically about 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 power*. It follows that the time for a Bruce Unit to reach an operating limit measured in hot hours is about 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*.

By collecting available data on the cumulative EFPH for Bruce Units 5, 7 and 8, it is possible to estimate the current, (2022) EFPH and HH for these Units as shown in Table A2, below

Table A2: Current (2022) EFPH vs. Hot Hours for Bruce Units 5, 7 and 8

Bruce B	EFPH	HH
Unit 5	292747	322022
Unit 7	286278	314906
Unit 8	273246	300571

Table A2 shows that *these Bruce Units have already exceeded 300,000 hours of operation when measured in terms of their hot hours*. I would therefore ask the CNSC and Bruce Power to answer the following question: *Why* are EFPH being used when setting operating limits, instead of the more appropriate hot hours?

F. R. Greening

APPENDIX B

Presented below are performance data for Bruce B Units in the period 2016 to 2022 taken from Bruce Power's Annual Reports for the years in question:

Bruce Unit	TWh of Annual Electrical Energy Production						
	2022	2021	2020	2019	2018	2017	2016
B5	5.5	7.1	6.2	4.9	7.1	5.0	6.7
B6	0	0	0	6.5	7.1	5.7	6.9
B7	6.7	5.9	7.0	4.8	7.1	6.6	5.0
B8	7.0	6.9	4.9	7.1	4.8	7.0	5.0

These values may be converted to EFPH using the following equation:

Max Power Output (TWh) = Unit Electrical Power (MW_e) × 8760 hrs / 1000000

The electrical power rating of Bruce Units 5 to 8 is 817 MW_e, therefore:

Max Annual Power Output (TWh) = 7.157 TWh

A Unit's Capacity Factor may then be determined using the simple relation:

Capacity Factor (%) = [100 × Annual Electrical Energy Production] / 7.157

Calculated values of the Capacity Factors for Bruce B Units are presented below:

Bruce Unit	Annual Capacity Factor (%)						
	2022	2021	2020	2019	2018	2017	2016
B5	76.9	99.2	87.1	67.9	98.9	69.9	93.6
B6	0	0	0	90.8	98.6	79.6	96.4
B7	93.6	82.4	98.4	67.6	99.5	92.2	69.9
B8	97.8	96.4	69.0	98.9	67.4	97.8	69.9

From these Capacity Factors the EFPH for each Bruce B Unit may be calculated as presented below:

Bruce Unit	Bruce Power Data for the Annual Effective Full Power Hours							
	2022	2021	2020	2019	2018	2017	2016	Average
B5	6732	8690	7625	5949	8666	6120	8201	7426
B6	0	0	0	7956	8641	6977	8445	8005
B7	8201	7221	8617	5924	8715	8078	6120	7554
B8	8568	8445	6046	8666	5900	8568	6120	7473

We note that the average annual EFPH for Bruce B Units varies from Unit to Unit but is consistently well above the 7000 EFPH used by Bruce Power in the data it has reported to the CNSC.

Finally, the above data may be compared to the equivalent data reported by the IAEA PRIS website:

Bruce Unit	IAEA PRIS Data for the Annual Effective Full Power Hours							
	2022	2021	2020	2019	2018	2017	2016	Average
B5	6776	8760	7682	6173	8760	6394	8613	7594
B6	0	0	408	8224	8718	7164	8613	8282
B7	8208	7264	8664	6036	8715	8431	6332	7664
B8	8616	8472	6141	8760	6123	8760	6291	7595

We see that the two sets of data are quite close, but with the IAEA PRIS data being consistently about 2% higher than the Bruce Power data. This difference stems from the fact that the IAEA data are strictly speaking the so-called "annual time on line" values. The IAEA defines this quantity as: "*The total clock hours per year during which the Unit operated with breakers closed to the Unit bus*." This will always be slightly higher than the Effective Full Power Hours because there is invariably a time delay between connecting a Unit to the grid and attaining full power operation.