From: Interventions (CNSC/CCSN)
Sent: December 17, 2019 4:17 PM
To: Consultation (CNSC/CCSN)
Cc: Interventions (CNSC/CCSN)
Subject: RE: Decommissioning REGDOC-2.11.2 Intervention

Good afternoon,

This is for your group. I have not acknowledge receipt.

Louise

From: Frank Greening <personal information redacted>
Sent: December 17, 2019 3:44 PM
To: Interventions (CNSC/CCSN) <cnsc.interventions.ccsn@canada.ca>
Cc: Levert, Louise (CNSC/CCSN) <personal information redacted>
Subject: Decommissioning REGDOC-2.11.2 Intervention

To whom it may concern:

Please accept this email as an intervention concerning the CNSC's REGDOC-2.11.2, entitled *Decommissioning*, issued July 2019. I wish to thank the CNSC for providing an opportunity for interested parties to contribute to the debate on the vitally important issue of nuclear power plant, (NPP), decommissioning.

Having reviewed the 20 or so pages of text that constitute the issues addressed by REGDOC-2.11.2, my first reaction is that the document as it now stands is of little practical value to a reactor owner/operator wishing to decommission a nuclear facility, largely because of its non-prescriptive approach. Nevertheless, in looking at the interventions that have already been submitted to the CNSC with regard to REGDOC-2.11.2, it appears that there are *three* approaches to NPP decommissioning that need to be considered:

(i) Immediate dismantling of the facility
(ii) Delayed or deferred dismantling of the facility for periods up to 50 years
(iii) Entombment of the facility

Generally speaking, option (i) is favored by environmentalists, while options (ii) and (iii) are favored by NPP owner/operators. However, it is worth noting that the International Atomic Energy Agency, the IAEA, has tacitly rejected option (iii), facility entombment, as a viable approach to decommissioning. Thus, in the IAEA document entitled: *Decommissioning of Facilities,* General Safety Requirements Part 6, GSR Part 6, issued in 2014, we read:

> *Entombment, in which all or part of the facility is encased in a structurally long-lived material, is not considered a decommissioning strategy and is not an option in the case of planned permanent shutdown. It may be considered a solution only under exceptional circumstances (e.g., following a severe accident).*

The rationale behind this opinion from the IAEA will not be discussed in this intervention. Therefore, we shall restrict our evaluation of decommissioning strategies to the relative *pros and cons* of options (i) and (ii): immediate dismantling and delayed dismantling, respectively.

1a. Immediate Dismantling, Pros:

The main positive attribute of Immediate Dismantling of an NPP as a decommissioning strategy is that it fast-tracks the removal/disposal of something that has served its design purpose and is no longer capable of further safe, reliable operation. In this "no longer of any use" state, a shutdown nuclear facility is universally regarded as an eyesore – a structure that despoils a potentially pleasant landscape, and therefore something that should be removed as quickly and as efficiently as possible.

In this regard, most people consider a shutdown nuclear reactor as something akin to an old car that sits abandoned on a downtown lot. And to continue this analogy, environmentalists dream of this old car being towed away to a scrap yard with a minimum of fuss, and the lot converted into a park or children's playground – the ideal *green field* final state for a former nuclear site.

1b. Immediate Dismantling, Cons:

A preference for, and the positive picture painted by many environmentalists of the immediate dismantlement of an NPP needs to be tempered by the fact that the radiation fields emanating from a nuclear reactor are at their *maximum* immediately after reactor shutdown; the good news being that these fields decay at a predictable rate thereafter. Thus, delayed dismantlement is a simple way to reduce reactor shutdown radiation fields to more acceptable levels and thereby reduce the radiation exposure of workers assigned to tasks requiring close proximity to a reactor's core, where the fields are very, and frequently unacceptably high.

It is tempting to estimate the radiation doses expected for workers involved in a CANDU *decommissioning* by referring to the known doses for workers involved in reactor *refurbishments* such as those that have been successfully carried out on Units 1 & 2 at Bruce A. However, the dismantlement of a CANDU reactor involves cutting up *reactor core components* that are much more radioactive than the pressure tubes, calandria tubes and feeder pipes that constitute the main radioactive wastes associated with CANDU refurbishments.

Thus, the radiation field emanating from removed pressure tubes is about 800 rem/hr – which, in the absence of shielding, will give a lethal dose to an exposed individual in less than 5 minutes; by comparison, the radiation fields coming off reactor core components such as the thermal shield, calandria shell and dump tank are 260,000 rem/hr, 49,000 rem/hr and 12,000 rem/hr, respectively. These are truly dangerous radiation fields that are lethal in less than 1 minute of exposure and are impractical to shield!

The predicted radioactivity of such CANDU core components is described in detail in OPG's *Preliminary Nuclear Decommissioning Cost Study*, issued in 1981 For the present discussion, Co-60 is the most important radionuclide since it is the principal gamma-emitter in the decommissioning waste for a mature reactor, at least for the first 50 years or so after reactor shutdown. Thus, in Table 5-4 of OPG's 1981 report we find estimates of the Pickering A shutdown activity of Co-60 in components of interest as follows:

Pressure Tubes = 3,300 TBq
Calandria Tubes = 1,200 TBq
End Fittings = 19,000 TBq

This gives the total Co-60 activity of Pickering A's <u>*refurbishment waste*</u> at shutdown of 23,500 TBq.

By comparison, OPG's 2016 prediction of the Co-60 shutdown activity of Pickering A, (See *Preliminary Decommissioning Plan – Pickering Generating Stations A & B*), is 75,000 TBq, or about 3 times the refurbishment waste activity.

Fortunately, Table 5-4 of OPG's 1981 *Decommissioning Cost Study* also provides estimates of the Pickering A shutdown activity of Co-60 for the major core components as follows:

Calandria Shell = 37,000 TBq
Thermal Shield = 19,000 TBq
Calandria Tube-sheet = 8,500 TBq
Containment Shell = 4,100 TBq
Adjuster Rod Guide Tube = 520 TBq
Shutoff Rod Guide Tubes = 410 TBq
Moderator Dump Tank = 3000 TBq

This gives a total Co-60 activity of Pickering A's *decommissioning waste* of 72,530 TBq, or about 3 times the refurbishment waste activity of 23,500 TBq noted above. As described below, these activities, and the associated doses to decommissioning workers, may be significantly reduced by allowing time for radioactive decay.

2a. Deferred Dismantling, Pros:

The main reason to defer the decommissioning of a CANDU reactor is to allow the shutdown activity to decay to acceptable levels. As previously noted, Co-60, with a half-life of 5.27 years, is the main activity responsible for over 90% of the reactor's radiation field at shutdown. For this reason, decay periods measured in tens of years are required to achieve significant reductions in the radiation fields, as shown in Table 1 below.

Table 1: Decay of Cobalt-60 as a Function of Time

Decay Period	(Years After Shutdown)					
	0	10	20	30	40	50
Decay Factor	1	0.269	0.072	0.019	0.0052	0.0014

From Table 1 we see that a decay of 50 years reduces a Co-60 radiation field to a mere 0.14 % of its shutdown activity. Such a means of dose reduction is in line with the ALARA (As Low As Reasonably Achievable), principle of radiation protection by reducing a worker's dose commitment from decommissioning activities to an acceptable level.

2b. Deferred Dismantling, Cons:

The main disadvantage of deferring the dismantlement of an NPP, apart from the public's perception of a problem left unresolved, is that the facility has to be monitored on a 24-hour/7-days-a-week basis for an extended period of time – potentially up to 50 years. However, this monitoring, and the associated staffing of the facility, will be far less than the staffing that would be required for a normally operating facility.

Discussion:

So far in this intervention the radio-activation of an NPP's physical structure has been considered as the only radiological factor of concern in the dismantlement of the facility. However, in the case of Pickering NGS, and to a lesser extent Bruce NGS, tritium that has escaped from containment and entered the local aquifer is a very significant issue that must be dispositioned, especially if the ultimate goal of the decommissioning is to return these facilities to a green-field state. For this reason, we shall review what is known about the extent of this tritium escape problem with particular focus on Pickering NGS.

The main source of tritium in a CANDU reactor is the moderator system which typically contains about 300,000 kilograms of heavy water, or D_2O. Virgin D_2O contains no tritium, but tritium (as DTO) builds up in a moderator during reactor operation at an initial rate of about 2 Ci/kg per year; with a combination of decay and de-tritiation, an "equilibrium" state is attained whereby the reactor operates with about 10 Ci of tritium per kilogram of D_2O. Thus, a mature CANDU moderator contains 10 (Ci/kg) × 300,000 (kg) of tritium, which equals 3 million Curies or 1.11×10^{17} Bq of tritium.

In the early years of operation of the CANDU Units at Pickering and Bruce, heavy water leaks and spills were quite common, resulting in the following average leakage rates:

PNGS 'A' heavy water leakage rate (1978 estimate): 3.3 ± 0.2 kg/hour
PNGS 'A' heavy water spillage rate (1978 estimate): 8.5 ± 1.2 kg/hour

Total: 11.8 kg/hour

Total per year: $11.8 \times 24 \times 365 = 103{,}368$ kg

Bruce 'A' moderator heavy water leakage (1982): 0.48 kg/hr = 16,800 kg/year
Bruce 'A' PHTS (IX and filter room) leakage (1982): 0.50 kg/hr = 17,500 kg/year

However, during this period, most of the heavy water that leaked or was spilt was recovered. Thus, for PNGS 'A' Units, in comparison to the data given above, only 11,000 kg of heavy water per year was actually lost, about 50% via airborne and 50% by waterborne emissions. Similarly (in 1979), the Bruce 'A' heavy water loss was estimated to be 0.735 kg/hour per Unit. Thus, the total heavy water loss for four Bruce 'A' Units in 1979, (again about 50% via airborne and 50% by waterborne emissions), was equal to $0.735 \times 4 \times 24 \times 365$, or 25,754 kg/year.

Station condition records for the first decade of operation of Units at Pickering and Bruce show that accidental spills and unexpected leaks were quickly dealt with and contained. Furthermore, there is no evidence from that time period of any chronic escape of tritiated water from containment. However, in 1997, for the very first time, OPG acknowledged the presence of tritium in Pickering A groundwater samples. The samples in question were collected in monitoring wells and groundwater tubes located adjacent to the Heavy Water Upgrader Plant and the Auxiliary Irradiated Fuel Bay. In addition, in the year 2000, very high levels of tritium were observed to be leaking into the site groundwater via the Unit 1 moderator pit.

Between the years 2000 and 2005, highly elevated levels of tritium were identified in groundwater samples collected at various locations, both at PNGS A and at PNGS B. The samples listed below revealed just how serious groundwater contamination was at that time:

• PNGS A Unit1 moderator purification room pit had tritium concentrations up to 1.04×10^{10} Bq/L

• PNGS A & B foundation drain sumps had tritium concentrations up to 1.3×10^{5} Bq/L

• PNGS A reactor auxiliary bay sumps had tritium concentrations up to 1.9×10^{8} Bq/L

• PNGS B reactor auxiliary bay sumps had tritium concentrations up to 8.0×10^{6} Bq/L

• PNGS B irradiated fuel bay ground-tubes had tritium concentrations up to 4.0×10^{6} Bq/L

It is important to note that several of these samples show Pickering groundwater with contamination levels that are well above the CNSC limit of 3×10^{6} Bq/L for tritium in non-potable water, (See Footnote 1). Indeed, tritium concentration contour maps of the Pickering site measured between 2000 and 2003 show an area centered on Unit 1, Unit 2 and the Vacuum Building with a groundwater tritium concentration over 32,000,000 Bq/liter.

More recent data on Pickering groundwater samples show that Unit 1 foundation drains continue to exhibit very high levels of tritium, with concentrations as high as 1.19×10^{9} Bq/L measured as recently as the first quarter of 2018. Other Pickering site locations tend to show somewhat lower tritium activities but many sampling locations, (for example the Irradiated Fuel Bay between Units 2 and 3 and Monitoring Wells, (MWs), Nos 235-30, 239-30 and 273-20), have consistently exhibited tritium concentrations above the CNSC limit of 3×10^{6} Bq/L over the past ten years.

So, we need to ask: what is the impact of these elevated levels of tritium in Pickering's groundwater on the decommissioning of this site? OPG's position on this was made quite clear in its 2016 Report P-PLAN-00960-00001 entitled *Preliminary Decommissioning Plan – Pickering Generating Stations A & B*, where we read:

> *Localized areas of slightly elevated tritium concentrations are present in the groundwater located within the protected area of the Pickering site. The sources of these historical releases were identified by previous assessments and subsequently eliminated through procedural and/or operational changes, with steps taken to mitigate the risk of future releases. Previous Environmental Assessments (EAs) indicate that tritium concentrations are not migrating off-site and that no effects result from the tritium in groundwater on biota are likely. The groundwater monitoring program will continue to track, monitor, and report on the groundwater quality on site.*

Furthermore, at the CNSC Licence Renewal Hearing for OPG's Pickering Nuclear Generating Station, held on April 4th 2018, the Commission concluded:

> *Tritium in groundwater is mainly localized within the station's Protected Area. The foundation drains act as hydraulic sinks that capture most of the tritium plumes in the groundwater. The groundwater monitoring program results confirmed the site perimeter concentrations remain low, indicating no off-site impacts.*

Thus, we have statements by OPG and the CNSC that make two significant claims:

(i) OPG considers Pickering groundwater samples to exhibit only "*slightly elevated tritium concentrations*", even though many samples have consistently exhibited tritium concentrations well above the CNSC limit of 3×10^6 Bq/L over the past ten years.

(ii) Tritium in Pickering groundwater is "*not migrating off-site*" because "*the foundation drains act as hydraulic sinks that capture most of the tritium plumes in the groundwater.*"

However, in stark contradiction to claim (ii), we are also told in OPG's *Preliminary Decommissioning Plan – Pickering Generating Stations A & B*, that:

> *After the PNGS A and B Units are shut down and all the sources of tritium leakage have been terminated, significant decreases in overall groundwater tritium concentrations can be expected to occur over the course of the 30-year Safe Storage period due to dispersion and radioactive decay over time. As such, tritium concentrations will naturally decrease to levels that would meet the release criteria for the site.*

Thus, when it comes to decommissioning, in spite of it being captured in a "*hydraulic sink*", OPG believes that Pickering's groundwater tritium activity will "*significantly decrease*" due to "*dispersion and radioactive decay over time*". The amount of radioactive decay of tritium may be precisely determined from its half-life of 12.3 years, as shown in Table 2, below.

Table 2:

Decay of Tritium as a Function of Time

Decay Period	(Years After Shutdown)					
	0	10	20	30	40	50
Decay Factor	1	0.569	0.324	0.184	0.105	0.0598

From Table 2, we see that for a decay of 30 years, the tritium activity will be 18.4% of its value at shutdown. Thus, for example, an initial tritium activity of 32×10^6 Bq/L will have decayed in 30 years to 5.9×10^6 Bq/L, which is still well above the CNSC limit of 3×10^6 Bq/L for tritium in non-potable water.

And I would ask OPG to explain by what mechanism the tritium currently "*captured*" beneath the Pickering facility will be "*dispersed*", especially in view of OPG's and the CNSC's claim that "*Environmental Assessments indicate that tritium is not migrating off-site*".

Tritium in Groundwater: The Source Term for Pickering NGS

As we have seen, very high levels of tritium are known to be present in the groundwater located beneath the foundations of Pickering NGS. However, in order to quantify the impact of this radioactive contamination on the decommissioning of this facility we need a precise estimate of the tritium in groundwater source term. Unfortunately, detailed records of when, where, and how much tritium has leaked into Pickering's foundation drains since the commissioning of this facility in the early 1970s, (Pickering A), and early 1980s, (Pickering B), have not been published by OPG – quite often because such data were not always collected. Thus, some tritiated heavy water leaks at Pickering NGS were first "discovered" at some point in time that was evidently long *after* the leak began. Indeed, many heavy water leaks in CANDU reactors are initially too small to detect – typically less than 1 gram/hr – but increase with time until they eventually become detectable.

Nevertheless, some *average* leak rate data have been published in documents such as the annual COG *D_2O Management Reports* that allow an estimate to be made of the current source term for tritium in Pickering's groundwater. These reports show that Pickering's D_2O loss rate for the mature station has typically been about 0.8 kg/hour/Unit. It is also known that the main sources of D_2O escape are moderator purification and heat exchanger maintenance, especially during spent moderator resin and drum handling. These activities result in an average loss rate of "*high-Curie*" D_2O of about 0.4 kg/hour/Unit for which we estimate an average tritium concentration of 0.5 Ci/kg. In addition, we shall assume about half of this D_2O, or 0.2 kg/hour/Unit has entered the groundwater beneath Pickering, which is equivalent to 1750 kg/year/Unit.

Starting with these assumptions, the Pickering tritium in groundwater source term, S_{GW}(Bq), may be determined using the following equation and parameter values:

$$S_{GW}(Bq) = R(kg/year) \times C(Ci/kg) \times N(Units) \times T(years) \times D(decay\ factor) \times 3.7 \times 10^{10}\ (Bq/Ci)$$

Where,

R is the rate of ingress of D_2O into Pickering groundwater = 1750 kg/year/Unit

C is the average Curie content of the D_2O = 0.5 Ci/kg

N is the number of operating Units = 2 PNGS A + 4 PNGS B = 6 Units

T is the effective operating time for each Unit = 30 years

D is an average decay factor for tritium taken as a decay of 15 years = 0.43

Hence,

S_{GW}(Bq) = 1750 (kg/year/Unit) × 0.5 (Ci/kg) × 6 (Units) × 30 (years) × 0.43 × 3.7 × 10^{10} (Bq/Ci)

$$S_{GW}(Bq) = 2.5 \times 10^{15} \text{ Bq}$$

Furthermore, if we assume the contaminated groundwater occupies a volume equal to the Pickering A & B site area of (750 × 200) m^2 extending to a depth of 2 meters, we have an effective average tritium in groundwater concentration of 8.3 × 10^6 Bq/L; this is well within the range of tritium concentrations measured in monitoring wells at Pickering, as previously discussed.

To provide some perspective on these tritium amounts and concentrations it is useful to consider some comparative data:

Tritium inventory accumulated at Pickering NGS site at shutdown = 7.0 × 10^{17} Bq

Tritium source term for Pickering groundwater = 2.5 × 10^{15} Bq = 0.36% of the station inventory

Tritium average concentration in Pickering groundwater = 8.3 × 10^6 Bq/L

Tritium inventory in OPG's proposed DGR = 1.5 × 10^{14} Bq

Tritium average concentration in DGR waste = 1.5 × 10^6 Bq/L

Tritium inventory in CNL's proposed NSDF = 8.9 × 10^{14} Bq

Tritium average concentration in NSDF waste = 1.0 × 10^6 Bq/L

These data show that Pickering groundwater is contaminated with tritium to a level that is significantly ***higher*** than the Low and Intermediate Level wastes slated for disposal in a DGR or NSDF facility.

Interestingly, however, OPG *does* address the issue of the disposal of contaminated soil at Pickering NGS in its 2016 *Preliminary Decommissioning Plan* report, where we read:

> *The longer half-life radionuclides that are typically found during decommissioning are Co-60, Cs-137 and Sr-90. This contamination is likely to be found in soil relatively close (within a few meters) to the underside of the structure or components from which the leakage occurred. Remediation would likely entail excavation of the affected soil, with off-site disposal of the soil as radioactive waste. A preliminary estimate has been made, which indicates six affected locations with an affected soil volume of 6,730 m^3 that will have to be excavated and disposed.*

Clearly, OPG's "plan" does ***not even mention*** tritium as a contaminant of concern in Pickering's near-surface soil; but I would argue that this tritium contamination must be properly dealt with during the decommissioning of this facility simply on the basis of its high specific activity in the site's foundation drains. It also follows that the amount of soil requiring excavation and disposal will be orders of magnitude greater that the 6,730 m^3 estimated by OPG. Indeed, if tritium contamination of the Pickering site is taken seriously, it could well prove to be a proverbial "show stopper" because of the sheer volume of contaminated material involved and the cost entailed in its removal, shipping and emplacement in an appropriate disposal facility.

Footnote 1:

As first pointed out by W. Ruland in his October 2019 report for *Lake Ontario Waterkeepers,* the CNSC limit of 3×10^6 Bq/L for tritium in non-potable water appears to have no scientific basis, and is much higher than the US NRC Regulatory Limit of 37,000 Bq/L for the release of tritium to groundwater. In addition, a large nuclear power station such as Pickering, Bruce and Darlington, is restricted in its tritium contaminated liquid effluent discharges to its DRL limited concentration of about 0.5×10^6 Bq/L, or 6 times *lower* than the CNSC's "*non-potable water*" discharge limit of 3×10^6 Bq/L. The CNSC needs to explain these anomalies.

Conclusions:

(i) Deferred or delayed dismantling of the Pickering, Bruce and Darlington NPPs is the *only* viable option for the safe, ALARA decommissioning of these facilities.

(ii) The high levels of tritium in groundwater currently located beneath the foundations of Pickering NGS pose a serious waste disposal problem that threatens the economic viability of the decommissioning of this site and could potentially prevent it from ever being returned to a true *green field* state.

> *For which of you, desiring to build a tower, does not first sit down and count the cost, whether he has enough to complete it?*
>
> *Luke 14:28*

F. R. Greening
Hamilton, ON
December 2019