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Written submission from Michel A. Duguay

Mémoire de Michel A. Duguay

In the Matter of the

À l'égard de l'

Ontario Power Generation Inc.

Ontario Power Generation Inc.

Request by Ontario Power Generation Inc. to request to remove the hold point associated with Licence Condition 16.3 of the Pickering Nuclear Generating Station Power Reactor Operating Licence

Demande par Ontario Power Generation Inc. visant à supprimer le point d'arrêt associé à la condition 16.3 du permis d'exploitation de la centrale nucléaire de Pickering

Commission Public Hearing

Audience publique de la Commission

May 7, 2014

Le 7 mai 2014

Pickering B life extension, coping with tubing rupture

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N.B. Paragraphs are numbered in order to facilitate later referencing. *Italics* are used for citations, names of organizations, and as usual for emphasis.

Introduction

-1. Over the last three years, several documents authored by *Ontario Power Generation* (OPG) and by the *Canadian Nuclear Safety Commission* (CNSC) have argued that it is safe to extend the service life of the Pickering B nuclear power station five years or more beyond its original design value, which was 30 years at a capacity factor of 80% (percentage of ON time), ie 210 000 equivalent hours at full power. OPG now proposes to run Pickering B to 247 000 equivalent hours or more, ie five years beyond the design value.

-2. In this paper submitted to CNSC staff and to the Commission, I argue that OPG is presenting the option of running the Pickering B reactors all the way to a point that is either just short of- or at the rupture of the high pressure degraded tubing system in a CANDU nuclear reactor. OPG and some CNSC (not all) documents argue that post-Fukushima defence-in-depth equipment, new procedures and well-trained power plant operators will mitigate a tubing system rupture to such an extent that the probability of a large release of radioactive elements into the environment is reasonably or acceptably low.

-3. In this submission I argue that life-extension of Pickering B beyond its design value is not acceptably safe and is not in the best interest of anyone, not even of its promoters. The starting point of my argument is Article 9 of the *Nuclear Control and Safety Act* (NSCA) of 1997, which briefly describes the CNSC's mission. The brief description can be summarized thus : paragraph (a) ''*to prevent unreasonable risk …..*'' (in its French version ''*que* *le niveau de risque ….. demeure acceptable*''), and paragraph (b) ''*to disseminate objective scientific, technical and regulatory information to the public concerning the activities of the Commission* ….''

-4. In this submission I will argue that the public has not been informed in an objective scientific manner, as mandated by the NSCA, so that the public cannot judge whether the nuclear risk level posed by the proposed life extension of Pickering B is acceptably safe. I will argue that OPG and the CNSC do not have sufficient information about the degraded Pickering B reactors to judge their safety level with adequate precision. There is a high degree of inherent uncertainty regarding what is likely to happen by running the degraded Pickering B reactors five years beyond their design value. A prudent choice for the public is therefore to assume that the level of nuclear risk could in fact be very high and is therefore unacceptable per Article 9 of the NSCA. I will argue that the risk assessment methodology used by OPG, and approved by CNSC staff, allow one to prudently assume that the probability of occurrence of an accident-initiating event, like a tubing system rupture, could be as high as 100% over the next five years.

Degraded feeder pipes

-5. The very complex geometry of a Pickering B CANDU nuclear reactor comprises an intricate and crowded array of 380 carbon-steel feeder pipes taking heavy water to and away from each face of the reactor, a large array of 380 zirconium-niobium alloy pressure tubes hosting uranium oxide fuel in the reactor core, and a small number of other pipes hosting various devices, such as neutron probes and neutron absorbers. OPG has presented the zirconium alloy pressure tubes as a possible life-limiting element, but many nuclear power specialists have also focused on degraded feeder pipes as life-limiting components in a CANDU nuclear reactor. Two degradation mechanisms are dominant in carbon steel feeder pipes : the first, wall-thinning due to so-called *flow-accelerated corrosion*, the second, micro-crack propagation, a phenomenon often referred to as ''*stress-corrosion cracking*''.

-6. The seriousness of feeder pipe degradation stems from the fact that the CANDU, like other nuclear reactors in the world, operates at a temperature of about 310 degrees Celsius and a pressure near 10 megapascals, that being the pressure at a depth of about 1000 meters in the ocean. Very few submarines can go to such a depth because of the crushing water pressure. A pressure tube or feeder pipe rupture in a nuclear reactor could cause a substantial loss of cooling water with possibly dangerous consequences. A loss of cooling accident is referred to by its acronym LOCA. Even when a reactor is shut down by stopping neutron-induced fission, the very large and long-lasting radioactive decay heat from the fission products must be taken away by cooling water in order to prevent local core melting. A large loss of cooling led to the nuclear catastrophe in Fukushima starting in March 2011, resulting from three nuclear reactor core meltdowns.

-7. In August 2007 CNSC staff members John C. Jin, Raoul Awad and Thomas Viglasky published an excellent paper on the impact of wall-thinning and stress corrosion cracking in degraded CANDU feeder pipes (see reference 1). Their paper was titled ''*Fitness for service assessment of degraded CANDU feeder piping – Canadian regulatory expectations*''; it was published as Paper # D02/3 in *Transactions, SMiRT 19, Toronto, August 2007* (SMiRT stands for *Structural Mechanics in Reactor Technology*).

-8. In the second paragraph of their paper Jin, Awad and Viglasky wrote the following about flow-accelerated corrosion (FAC) : *''Virtually all outlet feeder pipes at all CANDU plants are experiencing pipe wall thinning due to the FAC at a rate much higher than design allowance.''* The danger presented by wall-thinning is stated at the end of this paragraph, which reads : *''Several feeder pipes have been replaced when their wall thicknesses fell below pre-established minimum thickness criteria. Nevertheless, regulatory staff believes that on-power failure of a thinned feeder pipe cannot be ruled-out. In particular, the staff's major concern is that, in the absence of an adequate ageing management program, the ultimate failure mode of thinned feeder pipe would be sudden rupture without adequate prior warning by leakage, as has been known to occur in real-world cases.''*

-9. It's important to note that OPG has stated in their documents that they expect high-pressure tubing to leak before breaking. Some other authors in the list of references 1 to 12 below have also asserted that feeder pipes can suddenly rupture without a leakage warning. As an example, in a paper published in the journal *Nuclear Engineering and Design* in November 2012 (see ref. 8), authors Wael H. Ahmed*, Meamer A. El Nakla, Abdelsalam Alsarkhi, and Mufatiu M. Bello of the Department of Mechanical Engineering, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia, wrote the following: *''Flow Accelerated Corrosion (FAC) is a major safety and reliability issue affecting carbon-steel piping in nuclear and fossil power plants. This degradation mechanism results in wear and thinning of large areas of piping and fittings that can lead to sudden and sometimes to catastrophic failures, as well as a huge economic loss.''* Several other authors in the list of references 1-11 have also expressed their concerns about degraded feeder pipes.

-10. Coming back to CNSC staff members Jin, Awad and Viglasky, in the first paragraph of their section III, they wrote the following (NDE stands for *nondestructive evaluation*) :

''Although rupture of single feeder pipe falls within the envelope of design basis accidents considered in Safety Analyses for Canadian CANDU plants, the regulatory staff remains concerned about consequential effects, such as the potential for damage to other core components and the release of radioactivity to the public. Key factors contributing to this concern are current limitations in both our understanding of feeder pipe degradation mechanisms and in-service inspection capability. It is the regulator's view that reliable assessment of fitness for service of flawed components requires the integration of different aspects from several different disciplines; for example: a mechanistic understanding of degradation, material behavior, principles of engineering structural evaluation, NDE technology and so on. The limited knowledge regarding the causes of the degradation may lead to susceptible areas that are not inspected. Accordingly, regulatory staff has insisted that inspection planning and structural integrity assessments should take into account of these limitations in a conservative way. In practical terms, this means that regulatory staff allows a utility to continue operating

degraded feeder pipes only when they provide a conservative engineering evaluation of the observed degradation, and commit to an expanded inspection scope to identify other feeders with similar or potentially more severe degradation.''

-11. The three CNSC authors mention ''*susceptible areas that are not inspected*''. This is a crucial problem with CANDU reactors. There are about seven kilometers of high pressure tubing in a CANDU reactor. When a reactor is shut down for maintenance, at about 18-month intervals, it is impossible to inspect all carbon steel feeder pipes and all zirconium-niobium pressure tubes. During maintenance outages, only a sampling of degraded feeder pipes are inspected with specialized instrumentation. The high radiation field at the face of the reactor limits the time that any worker can spend there. Furthermore, the intricate and crowded nature of the array of 380 inlet and 380 outlet feeder pipes renders the inspection very difficult, and in many cases impossible, especially for parts of feeder pipes near the face of the reactor. OPG mentioned in their 27 March 2014 presentation that 10% of the pressure tubes in the core were inspected during a maintenance outage. Perhaps the same percentage (or less) applies to feeder tubes (see the note in ref. 12). In its 27 March 2014 presentation OPG has not given information about feeder pipes despite the fact that this is an area of major concern in the industry and with the CNSC.

-12. In November 2013 an important review of CANDU feeder degradation was published by Aman Usmani and Zane Walker who are both with the nuclear industry. In their excellent paper the authors describe the history of CANDU feeder pipe degradation problems over the last decade and the solutions that the Canadian nuclear industry has come up with. On paper it would seem that the feeder pipe problems will be eventually solved by using better materials (carbon steel with a minimum content 0.3% chromium by weight, for example, along with pipes with thicker walls) and better instrumentation for inspections.

-13. Nevertheless, when judging the wisdom of operating Pickering B five years or more beyond its original design value, one should consider the following paragraph from section 4.4 of Usmani's and Walker's article: ''*Due to some of the limitations associated with inspecting the complex feeder piping system in a radiation environment, the amount of inspection data available often leads to overly conservative outcomes when using deterministic analysis methods. As a consequence, probabilistic methods were developed to provide the required degree of confidence when estimating wall thinning rates, optimizing inspection sample size and in assessing the possible extent of degradation in the non-inspected feeder population*.''

-14. This last sentence confirms what Jin, Awad and Viglasky had written in 2007 about ''*susceptible areas that are not inspected*'', as quoted in paragraphs 10 and 11. Because of the congested layout of the five kilometers of feeder pipes, and because of the severe radiation field near the reactor, a large fraction of the pipes constitutes a ''*non-inspected feeder population*''. Usmani and Walker rely on a probabilistic method to estimate the status of the non-inspected feeder pipes, but that assumes that manufacturing, installation or subsequent repairs, did not create any defective pipe, ie any ''*outlier*'' with respect to probability distributions. Given the absence of numbers quantifying ''*an expanded inspection scope to identify other feeders with similar or potentially more severe degradation*'', which is the end of Jin-Awad-Viglasky's bottom sentence in paragraph 10, given the uncertainties and limitations of inspections, a prudent member of the public will be well advised to assume that the non-inspected feeder population comprises one or more pipes that the unstoppable degradation mechanisms will inevitably lead to failure, possibly a sudden rupture. OPG is confident that they can cope with such a rupture. That may be pushing one's luck. Would a well-informed prudent public accept such a situation ? Would a prudent public, once informed in an objective scientific manner, as stipulated by the NSCA, demand that Pickering B be shut down now, as had been originally planned ?

Historic NASA flaw in statistical analysis applied to Pickering B

-15. This prudent public line of reasoning is supported by the historic and catastrophic loss of the *Challenger Space Shuttle* on 28 January 1986 in a fireball over Cape Kennedy in Florida. Sociologist Diane Vaughan, now a professor at Columbia University, studied the root causes of this accident viewed worldwide on live television. Over a nine-year period Diane Vaughan interviewed many persons in and out of NASA, the *National Aeronautics and Space Administration*, and studied a large number of articles and books published on the root causes of major accidents in many different fields. In 1996 she published a book titled ''*The Challenger Launch Decision*''. In harmony with the research work of several other academic authors, Diane Vaughan showed in her book that deficiencies in the safety culture of large organizations often play a dominant role in major accidents. She coined the expression ''*the normalization of deviance*''. An example is the following. In seven Space Shuttle flights prior to 28 January 1986, Viton O-rings in the giant solid rocket boosters lifting the Space Shuttle had suffered damage caused by flames leaking through. Even though these O-rings did not meet previously established safety criteria, NASA managers had decided to let the Shuttle ‘’*fly as is*’’. Technical deviance had become ‘’*normalized*’’.

-16. In 1985 several professionals involved in NASA’s huge Space Shuttle program had voiced concern over the solid rocket booster O-rings. Engineer Roger Boisjoly, employee of *Morton Thiokol* in Utah, the company that designed and built the solid rocket boosters, had been especially active in alerting NASA managers about the O-ring problem. Boisjoly had noticed a correlation between O-ring damage and cold weather temperatures when launching, but he had been unable to prove it with robust data. On 27 January 1986, the predicted temperature for the following day at Cape Kennedy was near the freezing point. Roger Boisjoly and several other engineers attempted to convince NASA managers to delay the launch date. On 27 January they held two telephone conference calls in order to fully debate whether to launch or not. Late in the evening the pro-launch engineers and managers prevailed.

-17. In late morning on 28 January 1986, the ambient temperature at the launch pad at Cape Kennedy was 36 degrees Fahrenheit. At 11:38 Eastern Standard Time lift-off of the Challenger space shuttle started under the enormous power of the solid rocket boosters. On page 333 Diane Vaughan wrote : ‘’*The mission ended 73 seconds later as a fireball erupted and the Challenger disappeared in a huge cloud of smoke. Fragments dropped toward the Atlantic, nine miles below….. All seven crew members perished*.’’ When the solid rocket boosters were later picked up and studied, one could see that the O-rings had completely failed, allowing extremely hot combustion gases to melt their way through metal and ignite the shuttle's liquid hydrogen and oxygen tanks.

-18. One who is serious about nuclear power should consider reading Diane Vaughan's 575-page book, which has been widely read and praised in the USA. On pages 382 and 383 Professor Vaughan focused on the deficient statistical analysis in which many NASA staff members participated during 1985 and especially on the day preceding the catastrophe. Thiokol's engineers, as well as other people at the *Marshall Space Flight Center* in Huntsville, Alabama, had only examined and debated the data concerning the seven previous flights of the space shuttle in which O-ring damage had been observed. Because damage had been seen on cold days as well as on warm days, Thiokol's hypothesis that cold temperatures were correlated with O-ring damage was not well supported by these seven data points. The pro-launch advocates argued that Thiokol engineers did not have statistically significant data in support of the increased cold temperature risk hypothesis.

-19. On page 382 Diane Vaughan wrote: ''*More stunning is the observation that they <u>did</u> have the pertinent data*.'' Vaughan explains that two members of the Presidential Commission's investigative staff, Alton G. Keel, Jr., its Executive Director, and Randy R. Kehrli, a Department of Justice attorney, ''*two nonengineers*'' as Vaughan points out, had the idea of analyzing data for all 24 previous space shuttle missions. Keel and Kehrli drew a chart with all 24 data points of O-ring damage (also referred to as ''*O-ring anomalies*'') versus temperature (page 383 of Vaughan's book). On page 382 Diane Vaughan writes about that chart the following : ''*It shows that when all missions are taken into account, a correlation between O-ring anomalies and temperature appears. Of the flights launched above 65^{o}F, three out of* *seventeen, or 17.6 percent had anomalies. Of the flights launched below 65^{o}F, 100 percent had anomalies*.'' Launching at 36^{o}F on 28 January 1986 was therefore a sure recipe for O-ring damage. This flaw in the use and interpretation of statistical data was made by professionals of the same organization that had put men on the Moon, hundreds of men and women in orbit, and amazing robots on Mars. This is perhaps one more indication that no one is infallible.

-20. The 1986 loss of the Challenger is therefore a striking example of the extreme danger of basing a decision on partial statistics. In my view this is what OPG and the pro-life-extension members of CNSC staff are doing. Two flaws in their statistical approach can clearly be seen. The first flaw is the oft-made assertion that CANDU performance has been accident-free and therefore allows one to predict an accident-free future. This is not an appropriate use of statistics applied to complex accident-prone systems. When a tire blow-out caused the Concorde supersonic airliner to crash near Paris on 25 January 2000, one could have said that morning that it was a very safe plane because it had not had a major accident in 27 years. But the tires had blown out many times before and the American *National Transport Safety Board* (NTSB) had asked the French authorities to do something about it.

-21. I express the second flaw as a question to OPG and CNSC staff : from a scientific point of view is it well advised to base the Pickering B life extension decision on an analysis of incomplete data ? First of all, OPG and the CNSC have omitted discussing feeder pipes. Yet, virtually all authors dealing with

CANDU nuclear reactor safety discuss zirconium pressure tubes, carbon steel feeder pipes and the steam generators. Silence by OPG and CNSC staff on feeder pipes cannot be said to demonstrate the safety of operating the Pickering B reactors five years beyond their design value. Aman Usmani and Zane Walker (ref. 11) have discussed feeder pipes at length and paint a reassuring picture for the future. But the Pickering B reactors are rooted in the past. The feeder pipes in a Pickering B nuclear reactor extend over approximately five kilometers in an intricate and crowded pattern. Not only does the geometry make it difficult to examine these feeder pipes with appropriate instrumentation, but a strong radiation field present near the face of the reactor limits the length of time that a skilled worker can spend inspecting these pipes. The result is that OPG can only obtain a sampling of the feeder pipe condition. Inspection measurements are carried out on just part of a feeder tube; parts of feeders near the reactor face are nearly impossible to examine. During outages only certain feeder pipes are inspected for wall-thinning and micro-cracks. OPG and the CNSC have access to a limited portion of the huge six kilometers of feeder pipes. These limited statistics can be compared to what the situation was with the Challenger in 1986.

-22. Usmani and Walker extend their predictions to the non-inspected feeder population by relying on a probability curve obtained from the inspected feeder population. But that automatically leaves out the possibility that a feeder pipe had hidden flaws when it came out of manufacturing, or acquired flaws from subsequent faulty repairs. On 25 May 2002 China Airlines flight 611 broke up in flight because a hidden metal crack had progressed over 22 years and had finally caused the Boeing 747 to lose its tail section at an altitude of 35 000 feet, then crashing into the ocean, and thereby killing all

225 persons aboard. In the morning of that day one could have said that the Boeing 747 is an extremely safe airliner and that the probability of a fatal crash was less than one chance in a million. But the NTSB showed that a more rigorous inspection could have revealed a growing crack ; if one had known, a different prediction could have been made. In many parts of CANDU feeder pipes a rigorous inspection is impossible, and in most places the inspection has limitations as authors Jin, Awad, Viglasky, Usmani and Walker have mentioned (refs. 1, 2, 11). The most prudent hypothesis that one can make about the non-inspected feeder population is that one or more feeders have flaws which the degradation mechanisms will inevitably amplify to the point of failure, possibly to the point of sudden rupture.

-23. One conclusion is that the promising picture that Usmani and Walker describe must be tested against the reality of manufacturing, installing and repairing reactor feeder pipes, and minimizing their gradual degradation. There has been a great number of unpleasant surprises in the operation of CANDU reactors over the last 40 years.

-24. Another argument against life extension of Pickering B is the paper that John Waddington published in October 2009 (ref. 13). Waddington worked for many years at Atomic Energy Canada Limited (AECL) and then as a director at the CNSC for ten years. Waddington joined the analysis made by several academic researchers that major accidents have a root cause that originates in major part in the prevailing safety culture. In the case of nuclear power, the Canadian nuclear industry works closely with the CNSC. John Waddington has expressed his view that the Canadian nuclear regulatory process needs to be changed if we are going to decrease the probability of a severe accident by a factor of ten, which is the current wish of the international nuclear power community. The fact that the CNSC lets OPG calculate the probability of nuclear accidents lowers the level of confidence that one can have in the results. Many flexible assumptions go into these probability calculations. The NTSB has shown examples where a part that was not supposed to fail in 80 000 years, failed after a few years. Many accidents are caused by unpredicted combinations of events. Probability calculations that OPG presents, and that some CNSC staff members endorse, carry a high level of uncertainty. The Canadian public is not well informed of this situation.

-25. Much CNSC documentation has brought to light deficiencies at OPG with respect to safety. An example was the CNSC's rejection of OPG's *Safety Analysis Safety Factors Report* on 7 April 2008 (identified as E-DOCS # 3232348 / 2.01). A letter dated 7 April 2008 from CNSC Director T.E Schaubel to OPG Senior Vice President Patrick McNeil, rejected this report and was accompanied by a 48-page attachment that was very critical of OPG's deficiencies and that described outstanding problems of the CANDU technology. In this attachment the word ''*discrepancy*'' (akin to Diane Vaughan's ''*technical deviance''*) appeared 40 times, and the expression ''*pipe rupture*'' appeared five times. In the CANDU, four carbon steel inlet and outlet feeder pipes and two zirconium alloy pressure tubes form one hydraulic cooling circuit, so that a feeder pipe rupture will impair cooling much as would occur in case of a pressure tube rupture.

-26. On 29 January 2013 Mr. Thierry Vandal, president of Hydro-Québec, testified in a *Commission Parlementaire* in the Québec Parliament having to do with the shutdown of the Gentilly-2 nuclear reactor. Opposition deputies wanted to know if it might not be possible to operate Gentilly-2 for more years, past its 30 years already registered. Here follows my translation of what Vandal said in reply to the life extension question.

"This is an important issue and I would like to take the time to explain it well. While it is true that we have an operating licence from the CNSC, the permit that we received for continued operation included an important condition: that there be a mandatory stop at the end of 2012, after which we would do one of two things: Either we would shut down the plant, which is what we have done, or we would begin the refurbishment."

"We asked ourselves, what should we do because we really wanted to have a close look before proceeding. We looked at this question in the context of, what for us, is the ultimate date, what I would call the extreme limit of operation, the 210 000 hours which is the design value for this power plant.

When we shut down the plant, we were almost there, within a few hours, having run the plant for 198 000 hours since the very beginning. These are the hours of operation at full power.

It is a measure of ageing, if you will, of the plant components. So for how many hours could we continue to operate from a safety point of view? I can tell you that Hydro Quebec's management in no way would have considered to go beyond 210 000 hours even if it was made possible. I would no more operate Gentilly-2 beyond 210 000 hours than I would climb onto an airplane that does not have its permits and that does not meet the standards. So it's out of question for us to put anyone, i.e., us, the workers, the public and the company in a situation of risk in the nuclear domain."

-27. The CNSC itself is on record for having favored that the Gentilly-2 nuclear power plant be shut down in December 2012. When the CNSC issued its decision document in July 2011 authorizing Gentilly-2 refurbishment (document title « Compte Rendu des délibérations, y compris les motifs de décision », it also urged Hydro-Québec to do the following:

Paragraphe 8 : «*La Commission s'attend fortement qu'Hydro-Québec commence les activités de réfection aussitôt que possible, si elle est décidée à s'engager dans cette voie.*»

Translation : *''The Commission strongly expects that Hydro-Québec will start refurbishment activities as soon as possible, if it has decided to go into this direction.''*

So, one can see that in July 2011 the Commission was not recommending life extension for Gentilly-2.

-28. In conclusion, one can see from the considerable documentation of the CNSC and of many authors in the nuclear power field, that extending the life of a CANDU nuclear reactor is very risky. Americans are doing it, but their pressure vessels have a wall thickness of 200 millimeters or more. The feeder pipes in a CANDU have a wall thickness of about six millimeters, and wall-thinning degradation mechanisms can eat away two millimeters or more in a matter of 25 years. The Point Lepreau nuclear reactor had to be refurbished after 25 years of operation. In an American reactor corrosion to the tune of a few millimeters will not weaken much the pressure vessel. In a CANDU the two main degradation mechanisms could lead to feeder pipe rupture within a five-year time interval past the 30 years already registered. Public opinion polls taken by the *Canadian Nuclear Association* have shown that only a minority of Canadians favor new investments in nuclear technology. A feeder pipe rupture in Pickering B will not increase public support for the Canadian nuclear industry. Given the large uncertainties about inspected, all the more about non-inspected, feeder pipe populations, the Canadian public will be well advised to think that a feeder pipe rupture could have a probability of occurrence as high as 100% over the next five years. It is probably in the best interest of everybody to support the permanent shutdown of Pickering B, as had originally been planned.

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-10. ‘’*Risk-Reduction Strategies used to Manage Cracking of Carbon Steel Primary Coolant Piping at the Point Lepreau Generating Station*’’, John P. Slade (1), Tracy S. Gendron (2)

(1) New Brunswick Power Nuclear, Point Lepreau Generating Station, P.O. Box 600, Lepreau, New Brunswick, E5J 2S6

- (2) Atomic Energy of Canada Ltd. Chalk River Laboratories, Chalk River, Ontario, K0J 1J0

-11. Aman Usmani and Zane Walker, ‘’*Overview and lessons from more than a decade of feeder life management*’’, Journal of Energy and Power Engineering 7 (2013) 2164-2173.

-12. The Commission could ask CNSC staff what percentage of feeder pipes are measured for wall-thinning and micro-cracks during a planned outage, especially for the feeder bends close to the reactor face.

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