CMD 25-H2.75

Date: 2025-05-08

Written Submission from Northwatch

Mémoire de Northwatch

In the matter of the

À l'égard d'

Ontario Power Generation Inc.

Ontario Power Generation Inc.

Application to renew power reactor operating licence for the Darlington Nuclear Generating Station

Demande concernant le renouvellement du permis d'exploitation d'un réacteur de puissance pour la centrale nucléaire de Darlington

Commission Public Hearing Part-2

Audience publique de la Commission Partie-2

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Canadian Nuclear Safety Commission
280 Slater St
PO Box 1046 Stn B Ottawa ON K1P 5S9

Sent by email interventions@cnsc-ccsn.gc.ca **Ref. 2025-H-02**

Commission Members:

Re. **Ontario Power Generation's application to renew power reactor operating licence for the Darlington Nuclear Generating Station**

On March 18, 2024 the Canadian Nuclear Safety Commission (CNSC) announced that it would hold a 2-part public hearing on March 26, 2025, and June 24–26, 2025, to consider an application from Ontario Power Generation (OPG) to renew its power reactor operating licence for the Darlington Nuclear Generating Station (DNGS), located on the north shore of Lake Ontario in the Municipality of Clarington and 72 kilometres east of Toronto.

OPG's current power reactor operating licence for the DNGS is valid until November 30, 2025 and authorizes OPG to operate the DNGS, which consists of 4 nuclear reactors and their associated equipment.

It is notable that the Notice of Hearing does not indicate that Ontario Power Generation is applying for a license with the extraordinary 30-year license term.

For comparison, we reviewed the July 2022 Notice of Hearing on Ontario Power Generation's application to renew its Darlington Waste Management Facility operating licence (Ref.2023-H-09) and the May 2015 Notice of Hearing on the application by Ontario Power Generation Inc. to renew its power reactor operating licence for the Darlington Nuclear Generating Station (Ref. 2015-H-04). Both these notices clearly identified the length of term being requested by Ontario Power Generation, as do CNSC Notice of Hearings for license applications and renewals more generally.

Granting a 30-year license for a nuclear generating station in Ontario would be unprecedented and would be unacceptable. While it seems unlikely that the omission of this very important detail would be the result of a political decision on the part of CNSC staff to hide such an important and controversial aspect of the license application, given that CNSC staff's role is to support the Commission with fact-based information and analysis, rather than advocate for the licensee. However, it is understandable that the public's perception are affected by incidents such as this.

CNSC staff has concluded that OPG's application should be approved. Northwatch disagrees with these conclusions and with the CNSC staff recommendation, for the reasons set out in later sections of this submission.

Northwatch's Interest

Northwatch is a public interest organization concerned with environmental protection and social development in northeastern Ontario. Founded in 1988 to provide a representative regional voice in environmental decision-making and to address regional concerns with respect to energy, waste, mining and forestry related activities and initiatives, Northwatch has a long term and consistent interest in the nuclear chain, and its serial effects and potential effects with respect to northeastern Ontario, including issues related to uranium mining, refining, nuclear power generation, and various nuclear waste management initiatives and proposals as they may relate or have the potential to affect the lands, waters and/or people of northern Ontario.

Northwatch is interested in Ontario Power Generation's proposed approach to nuclear waste management and containment over various time frames. Northwatch's key areas of focus in licencing reviews are OPG's management of the radioactive wastes it generates, over various time frames. Throughout OPG's operations, Northwatch is interested in how operations and operational decisions affect fuel conditions, waste volumes, and waste attributes. In this review, Northwatch is particularly interested in how OPG has addressed the issues of waste generation, waste management in various time frames, and how safety and aging considerations are addressed in OPG's application and supporting documents and CNSC's staff review of the OPG application.

Northwatch's issues and concerns include the generation and management of the nuclear wastes that will result from Ontario Power Generation's operations at the Darlington Nuclear Generating Station. The wastes of concern include wastes from refurbishment activities and those wastes which will result in the extended / continued operations of the reactors at the Darlington Nuclear Generating Station.

Ontario Power Generation's established practice of transferring radioactive wastes from the Darlington NGS to the Western Waste Management Facility on the eastern shore of Lake Huron, the OPG controlled Nuclear Waste Management Organization's declared intention to transport, process, bury and then abandon all of Canada's high-level nuclear fuel waste at the Revell site in northern Ontario – including irradiated fuel from the Darlington station – make the generation of radioactive wastes through operations at the DNGS and their long term management are of direct interest to Northwatch.

For the record, Northwatch did not apply for or receive participant funding to support our review.

Context

The Darlington NGS is comprised of four CANDU nuclear reactors, four turbine generators, and associated equipment, services and facilities, including those related to the on-site management of the radioactive wastes generated through operations. The four reactor units were brought into service between October 1990 and June 1993, and are described by OPG as having a net electrical output of 881 MW per unit.[1]

Northwatch has previously intervened in license reviews for the Darlington Nuclear Generating Station, including in the 2015 review of Ontario Power Generation's application for a licence to operate the Darlington Nuclear Generating Station from 2015 to 2028, during which period they proposed to sequentially refurbish the four nuclear reactor units on-site. The 2015 review was, to some degree, a continuation of the 2012 review of the environmental assessment conducted by the Canadian Nuclear Safety Commission of the the proposal by Ontario Power Generation (OPG) for the Refurbishment and Continued Operation of the Darlington Nuclear Generating Station, in which Northwatch also intervened.

Northwatch's review of the 2012 environmental assessment focussed on matters related to the generation and management of nuclear wastes that would be associated with or a result of the proposed refurbishment and extended operations. For that review, Northwatch retained Dr. Gordon Thompson to provide technical support and a review of the irradiated fuel waste management on-site. Dr. Thompson's findings in that review remain relevant in this 2025 license review. They included:

- CNSC staff appropriately identified the Irradiated Fuel Bays (IFBs) and Dry Storage Casks (DSCs) as locations of potential events that could be major contributors to Spent Nuclear Fuel (SNF) radiological risk but did not conduct studies to identify and characterize a range of scenarios that could involve a release of radioactive material, with relevant characteristics of a release scenario including the magnitude, composition, timing, and pathway of the release.
- CNSC staff excluded malevolent acts from its consideration, assuming a probability of zero for an entire class of events that are technically feasible; the assumption was imprudent, and may lead to substantial under-estimation of SNF radiological risk.
- Completion of a credible EA process for refurbishment and continued operation of DNGS would require, among other ingredients, that OPG and CNSC demonstrate a thorough technical understanding of SNF radiological risk and risk-reduction options associated with DNGS.

[1] Darlington Nuclear Generation Station Application for Licence Renewal, Ontario Power Generation, December 2013, NK38-CORR-00531-16490 P

While Northwatch's 2012 submission and Dr. Thompson's report are directly relevant to the current review of OPG's license application, those comments are not repeated in this submission. Dr. Thompson's 2012 submission is included as Appendix 1.

At the time of the 2015 license review the refurbishment of Darlington Units 1-4 was proposed but not yet underway. Ontario Power Generation has now rebuilt three of the four reactors at the Darlington Nuclear Generating Station with the fourth, Unit 4, scheduled to be completed by the end of 2026. The status of Unit 4 as of OPG's statement in November 2024 was in "the reactor rebuilding phase". OPG described the refurbishment of the four reactors as a ten-year mega-project with a $12.8-billion price tag.[2]

Concurrent Projects at the Darlington Site

During the next ten years Ontario Power Generation intends to have four different major sets of activities underway at the Darlington site:

- Refurbishment of Unit 4
- Operation of the refurbished reactor units, and after 2026 – according to OPG's plan – the operation of all four reactors in the western portion of the Darlington site
- Construction of additional dry storage buildings at the Darlington Waste Management Facility in the central portion of the Darlington site
- Construction of between one and four boiling water reactors on the eastern portion of the Darlington site

Given the management challenges each of these sets of operations will pose (see, for example, the following section on operational incidents during the current license period) the prospect of Ontario Power Generation attempting to manage all four of these activity sets during the same period and on the same site is of concern. Northwatch notes that Ontario Power Generation does not acknowledge this challenge in their application or address issues related to their capacity or competency to concurrently manage these four large projects.

Non-Compliance Events During Current License Period

Northwatch has reviewed the very summary descriptions of events reports for the previous license period[3]. Previously referred to as "S-99 Reports" because they were incident reports filed in accordance with regulatory standard entitled S-99 Reporting Requirements for Operating Nuclear Power Plants and now referred to as "event report", these reports identify events at nuclear facilities that deviate from regulatory requirements or operating procedures.

[2] DARLINGTON NUCLEAR GENERATING STATION APPLICATION FOR LICENCE RENEWAL – ADDENDUM – January 2015
[3] See Appendix 2

In the period of 2015 through 2024 (excluding the fourth quarter of 2024, which is not yet available) there were over 400 event reports. Ontario Power Generation posts very minimal information about each event, generally speaking one brief line of text. Based on this minimal information, Northwatch has done some summary analysis of the events reported on over the last license period.
Based on the very summary descriptions, Northwatch grouped approximately half of the event reports into fifteen categories: unplanned power changes, emergency systems and responses, labelling and signage, power supply issues, unplanned releases, monitoring infractions, breaches of containment, worker-related issues, instances of mischief, radioactive contamination or dose exceedances, tritium issues, security failures, infractions related to fire safety, package and / or transport incidents, and unapproved storage or radioactive material.

Each of these categories has safety concerns associated with it.

For example, a "breach of containment" at Darlington Nuclear Generating Station (DNGS) generally refers to a scenario where the containment building, a structure designed to contain radioactive materials, is compromised, potentially leading to a release of radioactive material into the environment. Of the fifteen reported events of breaches of containment, many provided no description or detail in available reports. Others included a minimal description, such as “breach of Containment at Airlock”.

The 21 reports of power supply issues included emergency power generators being unavailable and standby power being unavailable; while minimal information was provided, it is reasonable to associate these power supply issues with safety concerns related to the power requirements of maintaining cooling functions of the irradiated fuel bay. While counted separately in Northwatch’s inventorying of the event reports, the 27 event reports Northwatch categorized as related to emergency systems and responses also included failures in emergency power systems and cooling systems, as well as incidents related to emergency lighting, emergency service water and fire hose and other fire related issues such as fire access routes and access to fire cabinets being blocked. An additional three fire related events were with respect to two actual fire incidents and fire alarm activation.

Similarly, while included in the group of nine incidents categorized by Northwatch as mischief, some of those “mischief” incidents, such as interference with the public address system and smoke detectors, were also impairments to the emergency systems and responses. Other mischief incidents included damages which were both surprising and concerning, given the increased risk they pose to workers. These included events that were reported as “equipment misuse”, such as multiple reports of damage to whole body monitors and to hand and foot monitor.

There were sixteen reports of non-compliance with monitoring requirements and 23 reports of infractions related to labelling and / or signage, including missing radiation hazard labels and inadequate posting of radiological hazards, unposted waste areas and radioactive drums and radioactive wastes being unlabeled, and radiation hazard signs not being visible or including in incorrect information.

The thirteen workforce related reports were for the most part related to Ontario Power Generation not having maintained the minimum staff complement but also included issues of an unqualified worker performing radioactive work and a "non-Dose Management System Active Worker" entering a radiological area, which we surmise means a worker entering a radiological area without either the proper training, protection or monitoring. In addition, there were eight accounts of radioactive contamination or dose exceedances.

Three transportation issues were flagged: the Trefoil symbols not being visible on a transportation package, an issue with contents of a legacy multi-purpose transportation package certificates and authorized radioactive, and a malfunction with a roadrunner transportation package. It was unclear from the minimal information provided if these were issues were limited to on-site transportation or extended to off-site shipments. Four security incidents related to drivers being left Unescorted in the Protected Area and members of the public speeding on-site. In one of the latter case, it was reported that "prohibited items" were discovered in the vehicle, but it was not stated whether these items heightened the security risk (e.g. a weapon).

Finally, there were twenty unplanned releases to the environment, including hydrocarbons and oil, multiple refrigerant leaks, and radiological releases to air, plus five non-compliance events or exceedances of tritium. There were also two incidents radioactive materials being found in "unapproved storage" or found "abandoned".

CNSC Assessment of Safety and Control Areas

Despite the more than 400 reportable events or incidents during the licence period, the licensee fared very well in the CNSC Assessment of Safety and Control Areas.
In the areas of Management System, Human Performance Management, Physical Design, Fitness for Service, Environmental Protection, Emergency Management and Fire Protection, Safeguards and Non-Proliferation, and Packaging and Transport OPG received a "satisfactory" grading in each area every years.

In the area of Radiation Protection, the licensee was deemed to be satisfactory in all years, except one, in which it was found to be "fully satisfactory". In the area of Waste Management, the licensee was deemed to be satisfactory in all years, except two, in which it was found to be "fully satisfactory". In the areas of Conventional Health and Safety, Operating Performance, and Safety Analysis the licensee was deemed to be satisfactory in all years, except three, in which it was found to be "fully satisfactory".

Substantive Issues

30-Year Licence Period

Ontario Power Generation is requesting a power reactor operating licence (PROL) for the Darlington Nuclear Generating Station (Darlington NGS) for an unprecedented period of 30 years.

CNSC staff provided the Commission with the following recommendation regarding the duration of the licence period:

> *Accept OPG's proposed licence length of 30 years. Introduce a new licence condition for OPG to conduct ongoing Indigenous engagement activities. The new licence condition would be a notable change to the licensing basis and ensure that OPG will continue engagement with Indigenous Nations and communities throughout the licence period.*

As staff noted in their CMD, in its recent decision to grant a 10-year licence to the Point Lepreau Nuclear Generating Station the Commission rejected New Brunswick Power's requestion for a longer licence period, noting "that providing opportunities for intervenors to voice their views and for the Commission to hear them is necessary to sustain a dialogue with members of the public and Indigenous Nations and communities", and therefore issued a decision which included a 10-year licence with a public proceeding at the mid point to provide such opportunities.

CNSC staff state that CNSC staff's basis for the support of the 30-year licence period were the following criteria:

- International Benchmarking
- Mature Canadian regulatory framework and regulatory oversight
- Transparency and Open Communication
- Input from Indigenous Nations and Communities
- OPG's basis for a 30-year licence period

Northwatch offers the following comments in response to each of those criteria:

- The Commission should not accept staff's very selective adoption of "International Benchmarking" with the adoption only in this instance where the selected samples support OPG's request; we would welcome a discussion paper and potentially subsequent regulatory review on a range of international benchmarks, including access to information and the operation of a public registry (such as the U.S. Nuclear Regulatory Commission's ADAMS registry) or the practice of setting performance standards for waste management as is seen in other jurisdictions
- CNSC staff argue that the "maturity" of the Canadian regulatory framework and regulatory oversight is evidenced (1) the use of the licence conditions handbook (LCH) to outline compliance verification criteria and guidance on how to meet the licence conditions, and (2) establishment of a requirement to conduct a Periodic Safety Review (PSR), as well as pointing to other reporting requirements such as the Environmental Protection Report and the

Probabilistic Safety Assessment; it must be noted that the only opportunity for the public to comment on or question these reports and their findings and suppositions is through the license review hearings; in addition, these are the only occasions where we have observed the Commission similarly questioning and discussing these reports and their findings

- CNSC staff suggest that "Transparency and Open Communication" is achieved through the Regulatory Oversight Reports, Status Report on Power Reactors updates, Event Initial Reports and license amendments; we vigorously disagree that these sufficiently provide "transparency and openness" or serve as a substitute for license terms of five to ten years; public interest intervenors and non-Indigenous residents of Durham region have no opportunity to speak before the Commission at the Commission meetings where the Regulatory Oversight Reports and status reports are presented to the Commission, and the regulatory oversight reports are relatively superficial and provide limited coverage or no coverage of issues that are included in licensing reviews, such as waste generation and waste management; we also note that license amendments are frequently done a hearings in writings, with no opportunity to present to the Commission or to observe or understand the Commission's examination of the case or evidence presented by the licensee or CNSC staff
- Input from Indigenous Nations and Communities which we have reviewed has not, by our assessment, supported OPG and CNSC staff's case for extending license length and reducing public hearings to occurring just three times per century; further, while CNSC staff appears to be offering additional meetings with First Nations, this is not a substitute for engagement directly with the Commission, and moving discussions with First Nations for a public hearing to private meetings with between First Nations and the CNSC staff denies both the Commission and the public the opportunity to hear directly from First Nations and learn from their teachings; Northwatch places great value on the interventions by Indigenous peoples, and have found the presentations by Williams Treaty nations and others – in particular Saugeen Ojibway Nation – to be wise and insightful and important to the proceedings
- OPG's basis for a 30-year licence period are a set of unconvincing arguments; the DNGS is going to be dramatically changed over the next license period, and could reasonably be expected to see significant changes in future decades as well; parts of the DNGS infrastructure are aging – such as the steam generators and the irradiated fuel bays – and significant issues could arise in the near and middle future as a result, which could constitute a significant change; as noted above, the various reporting items OPG cites are inadequate substitutes for a public license review process; OPG commitment with Indigenous Nations is not a substitute for engagement of the Commission with the Nations (OPG is not the Crown; while it could be argued that the federal Minister cannot delegate the Duty to Consult to the Commission, it cannot be argued that OPG is a stand-in for the Crown in the Duty to Consult or upholding the Honour of the Crown).

In addition to the points made above in response to CNSC staff's rationale for supporting OPG's request for a 30-year license term, we offer the following:

- A longer license period disadvantages public participation; already, license period have been lengthened from one to two to five years and more recently ten years, making the reviews larger, more detailed and more complex, and making it more difficult for public interest intervenors to build capacity and retain institutional memory over successive license reviews; a thirty-year license term would practically erase the potential for any capacity or carry-over of learning or institutional memory from one license period t the next

- A longer license period could reduce the effectiveness of Commission members, given that most members would be Commission members for only one license review per generating station, thereby reducing Commission members' ability to retain institutional memory over successive license reviews
- Commission hearings are the only opportunity for the Commission, the licensees, First Nations, CNSC staff, public interest groups and the public to hear directly from each other and interact directly; while there are many improvements could be made to the hearing process (such as affording intervenors the opportunity to pose questions) it is still a valuable and unique opportunity within Canada's nuclear regulatory system; moving to a hearing every thirty years reduces this opportunity to such a degree that it becomes moot; for practical purposes, the Commission will no longer be able to claim that it hears from Indigenous peoples, from the public, and from neighbours to the nuclear facilities it licenses if the occasion is reduced to three times per century per facility

In his letter of 25 March 2025 to the Commission registrar, Steve Gregoris, Chief Nuclear Officer for Ontario Power Generation Inc., acknowledged that through their engagement on the Licence Renewal Application, OPG had received feedback from Indigenous Rights Holders and key stakeholders with respect to the proposed 30-year licence term for the Darlington NGS, and that as a result "OPG is supportive of decennial reviews throughout the 30-year licence term, where Rights Holders and the public will have the opportunity to be heard before the Commission."

We appreciate Ontario Power Generation having made this concession in response to the feedback they are receiving. We propose that the "decennial review" referred to by OPG be in the form of a hearing to review an application by Ontario Power Generation for a ten-year license.

REQUEST: that the Commission reject Ontario Power Generation's request for a 30-year license term but instead issue a decision which grants a 10-year licence with a public proceeding at the mid-point which will provide the opportunity for First Nations and the public to make written and oral submissions to the Commission.

Nuclear Fuel Waste and its Long-Term Management

In their May 2024 application to renew their operating license for the Darlington Nuclear Generating Station OPG states that they "remains committed to the safe and permanent disposal of nuclear waste" but provide only one single paragraph of discussion, and that only to say that "the Nuclear Waste Management Organization (NWMO) is responsible for implementing Canada's plan

for the safe, long-term management of used nuclear fuel. Under the NWMO's plan" and that a deep geological repository for used fuel is expected to be in-service in the mid-2040s.[4]
That single paragraph creates multiple false impressions, including:

- It suggests or implies that the Nuclear Waste Management Organization is separate from Ontario Power Generation, as if arm's length; it is not. Ontario Power Generation has majority control of the NWMO and in 2024 provide 93% of the NWMO's funding
- It suggests or implies that the NWMO is wholly responsible for the irradiated fuel once it is created; it is not. OPG is responsible for the waste while it is on the site, and that will be for another century, at minimum; the NWMO published a "Deep Geological Repository Transportation System Conceptual Design Report" in 2021 which included a timeline for transfer of the wastes from the current location to the NWMO's (still conceptual) deep geological repository and the Darlington site was scheduled for 2088 as the "finish year", which will now be extended by 30 years of operations of the four refurbished CANDU reactors and by 60 years (post construction) of operation of the proposed BXRX-300 reactors, plus ten years of cooling on-site after the irradiated fuel is removed from the reactor core[5]
- While NWMO self-describes as being responsible for the transportation, processing, burial and abandonment of the fuel wastes at a centralized location, NWMO has clearly stated that it is not responsible for the extraction of the wastes from its on-site storage or for the transfer of the waste into transportation containers; NWMO states in the same report as referenced above that "At each interim storage facility, the waste owner is responsible for the retrieval of used fuel from storage, preparing and loading the transportation package with used fuel, and loading and securing the transportation package onto the conveyance";[6] the projected start date for transfers from the Darlington site is 2050,[7] meaning it falls within the 30-year period OPG is proposing be the license term (2025-2055); OPG's one paragraph description of is inadequate in its description of this technically challenging and unprecedented operation
- The NWMO further clarifies in that same report that "the conveyance (with secured transportation package) is prepared and ready for transport. As a result, transportation infrastructure, facility infrastructure, equipment for transportation package and conveyance loading at the storage facility are excluded from this (the NWMO's) report"; the reason they are excluded from the NWMO's transportation report is that they are the exclusive responsibility of Ontario Power Generation, and OPG has provided not even a passing reference to this major project which – according to the NWMO, who OPG both controls and defers to – is going to commence within the 30 years OPG is proposing be the license term.

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[4] 2.11.1.2 Long Term Disposal of Radioactive Waste, Darlington Nuclear Generating Station Power Reactor Operating Licence Renewal Application, Ontario Power Generation, May 2024, page 208
[5] Deep Geological Repository Transportation System Conceptual Design Report Crystalline / Sedimentary Rock APM-REP-00440-0209 R00, September 2021, Ashton Taylor, AECOM Canada Limited – Prepared for NWMO, page 16
[6] Deep Geological Repository Transportation System Conceptual Design Report Crystalline / Sedimentary Rock APM-REP-00440-0209 R00, September 2021, Ashton Taylor, AECOM Canada Limited – Prepared for NWMO, page 10
[7] Deep Geological Repository Transportation System Conceptual Design Report Crystalline / Sedimentary Rock APM-REP-00440-0209 R00, September 2021, Ashton Taylor, AECOM Canada Limited – Prepared for NWMO, page 16

Ontario Power Generation can't fit these puzzle pieces together: they are not responsible for the high-level wastes because the NWMO is, they are responsible for the waste transfer and transportation infrastructure because NWMO says they are, there are no proposed new activities within their proposed thirty-year license term, and the high-level waste will begin leaving the Darlington site in 25 years.

In the Supplemental Update to the OPG PROL Renewal Application Ontario Power Generation disrespects Wabigoon Lake Ojibway Nation and Grand Council Treaty #3.

In "Table 12: High Level Summary of Interests and/or Concerns Raised by Indigenous Nations and Communities" under the heading "Generation and Storage of Waste" OPG reports that they have received questions regarding the volume of waste that will be generated throughout the requested 30-year term, OPG responds:

> *OPG is supportive of the Nuclear Waste Management Organization's initiative to advance a permanent and safe storage solution for this waste stream with the willing host communities of Wabigoon Lake Ojibway Nation and the Township of Ignace.*[8]

Ontario Power Generation erroneously describes Wabigoon Lake Ojibway Nation as "willing host community", misrepresenting the Nation and WLON's decision-making process and decision. Further, the statement wholly overlooks the unanimous resolution passed by the Chiefs in Assembly of Grand Council Treaty #3 in October 2024. Grand Council Treaty #3 is comprised of 38 First Nations, including Wabigoon Lake Ojibway Nation. The Revell site is in the heart of Anishnabi Aki (Treaty 3 territory).

On October 3, 2024 Grand Council Treaty #3 Chiefs-in-Council Resolution CA-24-14, "Position on Nuclear Waste and Resource Development in Treaty #3" was passed, expressing "continuing support for the Elders' Declaration CA-11-14 that makes clear that a Deep Geological Repository for the storage of nuclear waste will not be developed at any point in the Treaty #3 Territory."[9]

On November 18, 2024 Wabigoon Lake Ojibway Nation announced that the community had reached a decision to allow the NWMO to move to site characterization phase in its investigation of the Revell site in northwestern Ontario. Wabigoon Lake Ojibway and stated very clearly that "The yes vote does not signify approval of the project."

On November 28th the NWMO announced that it had selected the Revell site as their preferred location for the development of their deep geological repository project. On that date, Wabigoon Lake Ojibway Nation released a statement acknowledging NWMO's site selection decision and announcing that the project will be subject to a determination from WLON's Sovereign regulatory decision-making process[10].

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[8] OPG PROL Renewal Application - Supplemental Update Page, December 2024, Page 57
[9] https://wethenuclearfreenorth.ca/wp-content/uploads/2024/11/ca-24-14-position-on-nuclear-waste-and-resource-development-in-treaty-3.pdf
[10] As posted at https://www.wabigoonlakeon.ca/_files/ugd/04fe7b_2ec4c7b04a2b45c0bdf8c78ce967478a.pdf

Further, the NWMO's selection of the Revell site is now the subject of a legal challenge from Eagle Lake First Nation.[11]

Eagle Lake First Nation has filed an application in Federal Court seeking a judicial review of the Nuclear Waste Management Organization's decision to build the deep geological repository in the Township of Ignace and Wabigoon Lake Ojibway Nation area. Eagle Lake First Nation says it was "unjustifiably" rejected as a host community and denied its own right to consent to the project and not for any fair, justifiable or defensible reasons, but because members of the First Nation had raised concerns about the nuclear waste site.

The court filing also names the federal minister of natural resources among the respondents and accuses the NWMO of acting in "bad faith" and seeks to have its decisions quashed.

REQUEST: The Commission should direct Ontario Power Generation to correct the record with respect to the statements made about the NWMO's role in the long-term management of high-level waste vs the responsibilities of OPG itself, and should withdraw its erroneous statements with respect to the "willingness" of First Nations on whose territory the Revell site in northwestern Ontario is located.

Fuel Defects

Fuel defects are a continued concern in reactor operations reviews in Ontario. Historically, there have been issues around fuel integrity at Pickering, Bruce and Darlington nuclear generating stations. During the 2013 licence review for the Pickering Nuclear Generating Station Northwatch raised concerns about fuel defects that had been reported during operations at the PNGS and the implications of those defects for long term waste management. During the 2015 license review for the Bruce NGS issues were flagged with respect to end-plate cracking. Fuel defects were also an issue during the last license review for the Darlington station. As reported in that license application[1], the application addendum[2] and OPG's August 2013 CMD[12], issues with fuel integrity were a matter of concern at the Darlington NGS.

Fuel defects have multiple consequences, including increased potential for worker exposure, additional radiological burdens in intermediate level wastes in the short, medium and long term. As was discussed during the Pickering licence review in 2013, over longer periods of time, even micro-defects in fuel bundles – which effectively become waste containers after removal from the reactor core – have increasingly more significant potential consequences. Long term storage – either dry storage on site or some form of centralized storage – rely on a multiple barrier approach. The weakening of the first barrier by any means – corrosion, dryout, temperature fluctuations – can

[11] https://globalnews.ca/news/10932606/ontario-first-nation-challenge-nuclear-ignace/#:~:text=A%20First%20Nation%20in%20northern,to%20have%20its%20decisions%20quashed.
[12] CMD 15H-8.1

potentially lead to failure. This, in turn, may lead to or hasten the release of radioactive materials into the storage container or even, ultimately, into the environment. [13]

As described by Ontario Power Generation, thirteen fuel defects were identified between 2010 and 2013[14] and an additional six fuel defects were detected between January and September 2014[15]. OPG reports having been "defect free" from October 2015 to August 2015.[16]

OPG did hypothesize during their 2013 Application that "*the trend suggests a change has occurred at the station or at the manufacturing facility*" and indicated that measures were being taken to "*mitigate this potential including slight adjustments in fuel manufacturing and close monitoring of bundles, bundle position, and channels that are more susceptible to fuel defects*" and that "*steps have been taken at both the manufacturing facilities and at the station to reduce contamination and foreign material during the fabrication and handling of the fuel bundles*". [17]Despite this number of defects identified, OPG also stated in the 2013 application that "the fuel condition remains within the design basis compliance envelope for wear and deformation", which raises questions about the rigour required to be in compliance with the "design basis".

OPG stated in their application for the current license that "the station goal is to operate with zero fuel defects, consistent with best industry practices in Canada and worldwide" and that "a significant amount of effort has been invested in achieving defect-free operation following an increase in fuel defects observed in the previous licence period."[18]

The single mention of fuel defects in the OPG application is in a listing of modifications and projects have been completed or are in progress during the current and upcoming licence terms which indicates that "due to obsolescence and aging issues, the feeder scanner system has been upgraded to a new system with improved data quality and data interpretation technologies to ensure reliable detection of fuel defects during outages.[19]"

We take this to be a positive, if indeed it improves detection of fuel defects, but find the application lacks sufficient discussion of what has been a significant operating concern across OPG's nuclear generating stations.

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[13] "Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel", United States Nuclear Waste Technical Review Board, December 2010
[14] Darlington Nuclear Generation Station Application for Licence Renewal, Ontario Power Generation, December 2013, NK38-CORR-00531-16490 P, page 47
[15] DARLINGTON NUCLEAR GENERATING STATION APPLICATION FOR LICENCE RENEWAL – ADDENDUM – January 2015, page 20-21
[16] CMD 15H-8.1, Page 34
[17] Darlington Nuclear Generation Station Application for Licence Renewal, Ontario Power Generation, December 2013, NK38-CORR-00531-16490 P, page 47
[18] CMD 15H-8.1, Page 34
[19] Darlington NGS – Application for Renewal of the Darlington Nuclear Generating Station Power Reactor Operating Licence 13.03/2025, Ontario Power Generation, May 2024, page 126

Similarly, the Darlington Nuclear Generating Station PROL Renewal Application - Supplemental Update included only single point of information about how OPG would address the longstanding issue of fuel defects, setting out in the table titled “Table 7: RP Provisions for Planning for Unusual Situations” under “Radiation and Monitoring Capacities” that “Gaseous Fission Product system includes sensitivity and alarms to key radionuclides associated with fuel defects”.[20]

Again, we take this to be a positive, if indeed it improves detection of fuel defects, but find that like the application, the supplemental update lacks sufficient discussion of what has been a significant operating concern across OPG’s nuclear generating stations.

It may be that OPG’s “the station goal is to operate with zero fuel defects” of ten years ago has in fact been achieved. However, it is problematic that the issue was not addressed, and the absence of reporting on progress made on this serious issue over the licence period does not lead one to assume that it is “problem solved”.

REQUEST: the Commission should require OPG to specifically report on the issue of fuel defects in any future applications, and a section on fuel defects should be included in the annual regulatory oversight reports on nuclear power plants.

Aging Management and Irradiated Fuel Bays

CNSC staff discusses OPG’s aging and obsolescence management programs, stating that OPG “continues to implement its aging and obsolescence management programs and processes within a systematic and integrated framework in accordance with CNSC REGDOC-2.6.3, Aging Management.”

The CNSC staff CMD then goes on to describe that fuel channels were replaced during the refurbishment (and will be for Unit 4), as is the case with the Fuel Channel Feeders. They also describe how Steam generators remain in a long-term operation managed under Steam Generators Life Cycle Management Plans.

The staff CMD sets out that “Reactor Components and Structures LCMP, N-PLAN-01060-10003 establishes the strategy or identifies necessary actions to ensure that aging effects on reactor components and structures are appropriately managed for the operating life of OPG’s fleet of nuclear units” and describes CNSC staff’s oversight and compliance and verification activities to confirm that OPG continues to meet regulatory expectations for the aging management, testing and inspection of civil structures, including containment.

[20] Darlington Nuclear Generating Station PROL Renewal Application - Supplemental Update, Ontario Power Generation, December 2024, Page 28

Neither CNSC staff of Ontario Power Generation address aging and aging management with respect to the irradiated fuel bays at the Darlington Nuclear Generating station.
For the previous licence review, Northwatch retained The WreathWood Group to assess the potential for risks and safety concerns associated with the irradiated fuel bays (IFBs) of DNGS that may arise from the extension of the operations by thirty years. The second area of focus for The WreathWood Group's review was the effects of aging on structural integrity of the irradiated fuel bays.
Simply put, The WreathWood Group reported that no evidence has been found in the documents listed in their reporting letter in 2015 to show that any reassessment has been made of the structural integrity that might be expected in the period of the license extension (i.e. from 2015 to 2025).
Similarly, Northwatch has reviewed the submission of Ontario Power Generation and CNSC staff and found no indication that the effects of aging on the irradiated fuel bays had even been considered.

The DGNS Application for the previous license renewal stated[21]:

- Response to potential loss of cooling capability in the IFBs has been enhanced and analysis has demonstrated that bay integrity will be maintained under elevated temperature conditions.
- Additional seismic assessments of the Darlington IFBs have been completed to confirm adequacy.

The WreathWood Group noted that there was no discussion about any consideration of any previous physical degradation of the IFBs because of the prior exposure to radiation effects from the fuel stored there.

In summary, the IFBs were not identified as being within the scope of the aging management program, nor is any mention made about DGNS having an aging management program specifically for the IFBs. There was no explanation of the extent to which any reanalysis of the IFB structural integrity has taken account of any aging effects of the IFBs. As a result, there is no basis for judging the integrity of the IFBs over the next 30 years of operation.

The WreathWood Group concluded in their 2015 review that the potential for failure due to aging appeared to not to be included in the aging management program (and therefore the potential for failure may increase). Combined with the absence of any operator guidance to keep the fuel cooled (or at least submerged) for failure of the IFBs, the possibility of releases in the future are increased. Concerns about the effects of aging on the performance of the irradiated fuel bays are supported by observations with respect to the aging Pickering Nuclear Generating Station.
As disclosed in the 2013 licence application for the Pickering Nuclear Generatng Station, there were two other serious incidents at the Pickering NGS involving leaks of tritiated water to groundwater, both associated with the aging pumps and pools . According to the brief descriptions, tritium in groundwater in the *Units 5-8 Irradiated Fuel Bay B (058 IFB) area* was due to the bay sumps not operating as designed, allowing tritium to escape to groundwater, beginning in 2005 and first noted

[21] OPG application, 2013 Page 128,

in 2007. Also in 2007, chronic leaks of active water to inactive *Unit 6 Reactor Building* foundation drainage sumps were identified as the cause of elevated tritium in groundwater.[22]

It is not clear if the two above noted incidents were as a result of station aging or were failures that should be attributed to more general failures in either design or maintenance, but it is reasonable to expect that incidents of this type are more likely to increase as the station goes beyond its design life. That having been the case with Pickering, it is a reasonable cause for concern with the Darlington Nuclear Generating Station as OPG proposed to extend its operations for up to thirty more years. The failure by OPG and CNSC staff to examine this potential for aging effects in the 2015 license review was unacceptable. Now, ten years later, with the unprecedented request for a 30-year license being brought to the Commission, it is impermissible.

REQUEST: that the Commission require Ontario Power Generation to carry out an assessment of the effect of aging on the irradiated fuel bay, and return to the Commission with this report for the Commission's consideration; a hold point should be included in the license to create an exit ramp if the report or its review identify elevated risk.

Conclusions

As outlined and for the reasons stated above, Northwatch is requesting that the Commission refuse Ontario Power Generation's request for a 30-year license and instead grant a 10-year licence with a public proceeding at the mid- point.

In addition, we request that the Commission:

- Direct Ontario Power Generation to correct the record with regarding the role and responsibilities of OPG vs NWMO role in the management of high-level
- Direct OPG o withdraw its erroneous statements with respect to the "willingness" of First Nations on whose territory the Revell site in northwestern Ontario is located.
- OPG to specifically report on the issue of fuel defects in any future applications,
- Direct staff to include a section on fuel defects in future regulatory oversight reports on nuclear power plants.
- require Ontario Power Generation to carry out an assessment of the effect of aging on irradiated fuel bays

All of which is respectfully submitted on behalf of Northwatch

Brennain Lloyd
Northwatch Project Coordinator

[22] Attachment 3 to OPG Letter, G. Jager to M. Leblanc, "Application for Renewal of Pickering Nuclear Generating Station Power Reactor Operating Licence",CD# P-CORR-00531-03719, page 117

INSTITUTE FOR RESOURCE AND SECURITY STUDIES
27 Ellsworth Avenue, Cambridge, Massachusetts 02139, USA
Phone: 617-491-5177   Fax: 617-491-6904
Email: gthompson@irss-usa.org

COMMENTS ON PROPOSED SCREENING REPORT ON ENVIRONMENTAL ASSESSMENT OF REFURBISHMENT & CONTINUED OPERATION OF DARLINGTON NUCLEAR GENERATING STATION

by
Gordon R. Thompson

12 October 2012

Prepared under the sponsorship of
Northwatch (Northeastern Ontario)

Abstract

The Canadian Nuclear Safety Commission (CNSC), and Fisheries and Oceans Canada (DFO), are conducting an environmental assessment (EA) process to consider a proposal by Ontario Power Generation (OPG). The proposal is to refurbish the Darlington Nuclear Generating Station (DNGS) and continue its operation thereafter. As part of the EA process, CNSC staff and DFO published in September 2012 a Proposed EA Screening Report, referred to here as the "Proposed Screening Report". A draft version of that document – referred to here as the "Draft Screening Report" – was published by CNSC and DFO in June 2012. This report provides comments on the Proposed Screening Report, focusing on a selected set of issues. Those issues pertain to the radiological risk arising from onsite management and storage of spent nuclear fuel (SNF) discharged from the nuclear reactors at DNGS. In addressing those issues, this report incorporates by reference, and attaches herewith, a report dated 16 July 2012 by the same author, which commented on the Draft Screening Report. From the perspective of this report, the Proposed Screening Report is identical to the Draft Screening Report.

About the Institute for Resource and Security Studies

The Institute for Resource and Security Studies (IRSS) is an independent, nonprofit, Massachusetts corporation, founded in 1984. Its objective is to promote sustainable use of natural resources and global human security. In pursuit of that mission, IRSS conducts technical and policy analysis, public education, and field programs. IRSS projects always reflect a concern for practical solutions to resource and security problems.

About the Author

Gordon Thompson is the executive director of IRSS and a senior research scientist at the George Perkins Marsh Institute, Clark University, Worcester, Massachusetts. He studied engineering at the University of New South Wales, practiced engineering in the electricity industry in Australia, and then received a doctorate in applied mathematics from Oxford University in 1973, for analyses of plasma undergoing thermonuclear fusion. Dr. Thompson has been based in the USA since 1979. His professional interests encompass a range of technical and policy issues related to sustainability and global human security. He has conducted numerous studies on environmental, security, and economic issues related to commercial and military nuclear facilities.

Acknowledgements

This report was prepared by IRSS under the sponsorship of Northwatch, a public-interest organization based in Northeastern Ontario. The author, Gordon Thompson, is solely responsible for the content of the report. Assistance by Brennain Lloyd of Northwatch in obtaining relevant documents is gratefully acknowledged.

Contents

Attachment

The following report is attached herewith:

Gordon R. Thompson, *Comments on Draft Screening Report on Environmental Assessment of Refurbishment and Continued Operation of Darlington Nuclear Generating Station* (Cambridge, Massachusetts: Institute for Resource and Security Studies, 16 July 2012).

1. Introduction

The Canadian Nuclear Safety Commission (CNSC), and Fisheries and Oceans Canada (DFO), are conducting an environmental assessment (EA) process to consider a proposal by Ontario Power Generation (OPG). The proposal is to refurbish the Darlington Nuclear Generating Station (DNGS) and continue its operation thereafter.

As part of the EA process, CNSC staff and DFO published in September 2012 a Proposed EA Screening Report.[1] That document is referred to here as the "Proposed Screening Report". A draft version of that document – referred to here as the "Draft Screening Report" – was published by CNSC and DFO in June 2012.[2]

This report provides comments on the Proposed Screening Report, focusing on a selected set of issues. Those issues pertain to the radiological risk arising from onsite management and storage of spent nuclear fuel (SNF) discharged from the nuclear reactors at DNGS. The term "radiological risk", as used here, refers to the potential for harm to humans as a result of their exposure to ionizing radiation due to an unplanned release of radioactive material.

This report incorporates by reference, and attaches herewith, a report dated 16 July 2012 by the same author, which commented on the Draft Screening Report.[3] That document is referred to here as the "Thompson Comments on the Draft Screening Report".

From the perspective of this report, as explained in Section 3, below, the Proposed Screening Report is identical to the Draft Screening Report. Thus, the Thompson Comments on the Draft Screening Report apply without alteration to the Proposed Screening Report.

2. Overview of Thompson Comments on the Draft Screening Report

The Thompson Comments on the Draft Screening Report contain nine conclusions and one recommendation, restated here with slight editing. The conclusions are:

C1. A number of credible studies show that management and storage of SNF discharged from commercial light-water reactors (LWRs) can create substantial radiological risk, and that options for reducing the risk are available. Experience with the Fukushima accident has highlighted the relevance of these studies to the regulation of nuclear generating stations.

C2. The major contributor to SNF radiological risk at LWR stations is the potential for SNF to be uncovered (exposed to air) due to loss of water from a spent-fuel pool. In that event, the zircaloy cladding of the SNF could undergo an exothermic reaction with steam

[1] CNSC and DFO, 2012a.
[2] CNSC and DFO, 2012b.
[3] Thompson, 2012.

and/or air, leading to a substantial release of radioactive material to the atmosphere. Also, a zircaloy-steam reaction would generate hydrogen gas, which could explode violently when mixed with air.

C3. While SNF radiological risk has been extensively studied in an LWR context, comparable studies have not been done for SNF discharged from CANDU reactors such as those used at DNGS. Nevertheless, the CNSC's Fukushima Task Force has acknowledged that a substantial radiological risk arises from storage of SNF under water in IFBs at stations such as DNGS.[4] The Task Force has acknowledged that uncovering of the SNF could cause the fuel to overheat, leading to a release of radioactive material and hydrogen gas.

C4. The Fukushima Task Force has implicitly recognized the lack of studies of SNF radiological risk at CANDU stations. The Task Force has called upon Canadian licensees to enhance their modeling capabilities in this area, and to conduct systematic analyses of beyond-design-basis accidents at irradiated fuel bays (IFBs). The Task Force has said that these analyses should include the estimation of releases, into the atmosphere and water, of radioactive material and hydrogen gas.

C5. A report prepared by SENES Consultants for OPG shows that OPG is aware that uncovering of SNF is an event to be feared.[5] Also, one could reasonably expect that OPG would be fully cognizant of the findings of the Fukushima Task Force.

C6. The Draft Screening Report cites the SENES report and the Fukushima Task Force report. Yet, the Draft Screening Report fails to acknowledge the risk associated with uncovering of SNF in an IFB. Instead, the Draft Screening Report focuses its discussion of SNF radiological risk on two comparatively minor events – drop of a dry storage container (DSC), and drop of an SNF storage module. In those cases, it seems that the Draft Screening Report has simply adopted the position of OPG.

C7. The Draft Screening Report explicitly excludes consideration of malevolent acts as contributors to radiological risk. That exclusion may lead to substantial under-estimation of risk.

C8. Technical understanding of SNF radiological risk and risk-reduction options in a CANDU context could be brought up to or beyond the present level of understanding of SNF radiological risk and risk-reduction options in an LWR context. Achieving that outcome would require the conduct of a number of independent, CANDU-focused studies that are openly published and subjected to peer review and public review.

[4] CNSC-FTF, 2011.
[5] SENES, 2011.

C9. Completion of a credible EA process for refurbishment and continued operation of DNGS would require, among other ingredients, that OPG and CNSC demonstrate a thorough technical understanding of SNF radiological risk and risk-reduction options associated with DNGS. The studies outlined in Conclusion C8 could provide that understanding, if conducted appropriately.

Based on these conclusions, the recommendation is:

R1. Completion of the EA process for refurbishment and continued operation of DNGS should be deferred until OPG and CNSC demonstrate a thorough technical understanding of SNF radiological risk and risk-reduction options associated with DNGS, and this understanding is clearly communicated to the public in relevant EA documents. (See Conclusions C8 and C9.)

3. The Proposed Screening Report's Response to Thompson Comments

The Proposed Screening Report responds to the Thompson Comments on the Draft Screening Report, doing so in its Appendix B, at pages B146 to B148. The nature of the response is evident from its first line: "No change to the EA Screening Report".

That statement has two implications. First, the Proposed Screening Report rejects the conclusions and recommendation set forth here in Section 2, above. Second, from the perspective of this report, the Proposed Screening Report is identical to the Draft Screening Report. Thus, the Thompson Comments on the Draft Screening Report apply without alteration to the Proposed Screening Report.

The Proposed Screening Report does offer some arguments, attributed to CNSC staff, for rejecting the conclusions and recommendation set forth in the Thompson Comments. The significant arguments are:

i. Loss of IFB cooling would be a slow-progressing event that could be mitigated by operator actions;
ii. There is no requirement under the Canadian Environmental Assessment (CEA) Act to consider malevolent actions;
iii. Licensee measures effectively counter the Design Basis Threat and mitigate the Beyond Design Basis Threat; and
iv. CANDU plant layout differs from LWR plant layout.

None of these arguments is compelling. They are addressed briefly in the following paragraphs.

Would loss of IFB cooling be a slow-progressing event that could be mitigated by operator actions?

This question misses the point. What matters most from the perspective of SNF radiological risk is the potential for fuel to be uncovered (exposed to air), and the outcome of that event.

Fuel could be uncovered at DNGS if water is lost from an IFB. Mechanisms for water loss include leakage, boiling away, siphoning, pumping, displacement by falling objects, or sloshing during an earthquake. These mechanisms could operate in various ways during an accident or an attack. Loss of water and loss of cooling are inter-related. It is likely that the cooling system for each IFB at DNGS extracts water from the top layer of the pool, and would therefore cease functioning after loss of a comparatively small amount of water. If water is extracted at a lower level, then a potential pathway exists for loss of water by siphoning.

CNSC, OPG, and other arms of the Canadian nuclear industry should systematically assess all potential scenarios whereby fuel could be uncovered in an IFB, whether at DNGS or another CANDU station. This author sees no evidence that such a systematic assessment has been performed or contemplated.

When the potential for spent fuel to be uncovered is understood, the next step would be to assess the outcome of this event. Most importantly, could the uncovered fuel self-ignite and burn? There is general agreement that this outcome could occur at a contemporary LWR station. CNSC and the Canadian nuclear industry should conduct thorough studies to determine if uncovered fuel could self-ignite and burn at a CANDU station.

Is there a requirement under the CEA Act to consider malevolent actions?

This question raises legal issues that are not addressed here. From the perspective of risk assessment, however, it is clear that malevolent actions could be major contributors to radiological risk at CANDU stations. Thus, when the Proposed Screening Report excludes consideration of malevolent actions, it denies the public a credible assessment of the radiological risk posed by DNGS. Moreover, that denial undermines the credibility of any statement by CNSC or the Canadian nuclear industry regarding the vulnerability of CANDU stations to attack. Experience shows that organizations which deny reality in a public context are prone to denying reality in their secret deliberations.

Can licensee measures effectively counter the
Design Basis Threat and mitigate the Beyond Design Basis Threat?

CNSC and the Canadian nuclear industry cannot provide a credible answer to this question. They have undermined their credibility by refusing to acknowledge publicly that CANDU stations were not designed to resist attack, and are therefore vulnerable in various respects. It would not be appropriate for these organizations, or any responsible party, to publicly discuss details about the vulnerability. What is appropriate is to provide the public with a realistic assessment of risk, and to support that assessment with secret analyses that are rigorous and consistent with public statements.

Does CANDU plant layout differ from LWR plant layout?

Clearly, the design of a CANDU station differs in many ways from that of an LWR station. For example, the fuel bundles are significantly different. CANDU fuel is driven to a comparatively low burnup, and can be stored under (light) water in a compact configuration without the presence of neutron-absorbing plates. However, CANDU fuel and LWR fuel both employ zircaloy cladding. Thus, they share the potential for exothermic reaction of zircaloy with steam or air.

Due to the differences between CANDU and LWR designs, findings about SNF radiological risk at LWR stations cannot be directly applied to CANDU stations. CNSC and the Canadian nuclear industry, as the principal custodians of CANDU technology, have an obligation to thoroughly investigate SNF radiological risk at CANDU stations.

4. Conclusions and Recommendations

Conclusions

C1. The Thompson Comments on the Draft Screening Report apply without alteration to the Proposed Screening Report. (The Thompson Comments are attached herewith, and are incorporated by reference.)

C2. The Proposed Screening Report does not provide a credible assessment of SNF radiological risk at DNGS.

Recommendations

R1. CNSC, OPG, and other arms of the Canadian nuclear industry should thoroughly assess SNF radiological risk and risk-reduction options at DNGS and other CANDU stations.

R2. Completion of the EA process for Darlington refurbishment should be deferred until EA documents provide the public with a credible account of SNF radiological risk and risk-reduction options.

5. Bibliography

(CNSC and DFO, 2012a)
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Gordon R. Thompson, *Comments on Draft Screening Report on Environmental Assessment of Refurbishment and Continued Operation of Darlington Nuclear Generating Station* (Cambridge, Massachusetts: Institute for Resource and Security Studies, 16 July 2012).

INSTITUTE FOR RESOURCE AND SECURITY STUDIES
27 Ellsworth Avenue, Cambridge, Massachusetts 02139, USA
Phone: 617-491-5177 Fax: 617-491-6904
Email: gthompson@irss-usa.org

COMMENTS ON DRAFT SCREENING REPORT ON ENVIRONMENTAL ASSESSMENT OF REFURBISHMENT & CONTINUED OPERATION OF DARLINGTON NUCLEAR GENERATING STATION

by
Gordon R. Thompson

16 July 2012

Prepared under the sponsorship of
Northwatch (Northeastern Ontario)

Abstract

The Canadian Nuclear Safety Commission (CNSC), and Fisheries and Oceans Canada (DFO), are conducting an environmental assessment (EA) process to consider a proposal by Ontario Power Generation (OPG). The proposal is to refurbish the Darlington Nuclear Generating Station (DNGS) and continue its operation thereafter. As part of the EA process, CNSC staff and DFO have prepared an EA Screening Report. A draft version of that document – referred to here as the "Draft Screening Report" – was published in June 2012. This report provides comments on the Draft Screening Report, focusing on a selected set of issues. Those issues pertain to the radiological risk arising from onsite management and storage of spent nuclear fuel (SNF) discharged from the nuclear reactors at DNGS. That risk has been extensively studied in the context of SNF discharged from light-water reactors (LWRs). Similar studies have not been done for SNF discharged from CANDU reactors, as are used at DNGS. Nevertheless, the CNSC's Fukushima Task Force has acknowledged that the uncovering of SNF stored under water, at stations such as DNGS, could lead to a substantial release of radioactive material. The Draft Screening Report does not discuss that threat, and focuses its discussion of SNF radiological risk on comparatively minor events.

About the Institute for Resource and Security Studies

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About the Author

Gordon Thompson is the executive director of IRSS and a senior research scientist at the George Perkins Marsh Institute, Clark University, Worcester, Massachusetts. He studied engineering at the University of New South Wales, practiced engineering in the electricity industry in Australia, and then received a doctorate in applied mathematics from Oxford University in 1973, for analyses of plasma undergoing thermonuclear fusion. Dr. Thompson has been based in the USA since 1979. His professional interests encompass a range of technical and policy issues related to sustainability and global human security. He has conducted numerous studies on environmental, security, and economic issues related to commercial and military nuclear facilities.

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Contents

(Tables and Figures are listed on the following pages.)

List of Tables and Figures
(These Tables and Figures appear after Section 10 of the report.)

Tables

Figures

1. Introduction

Ontario Power Generation (OPG) proposes to refurbish the Darlington Nuclear Generating Station (DNGS), and continue its operation thereafter. That proposal requires decisions under the Canadian Environmental Assessment Act (CEA) by the "Responsible Authorities" – the Canadian Nuclear Safety Commission (CNSC), and Fisheries and Oceans Canada (DFO). To guide those decisions, CNSC staff and DFO have prepared an Environmental Assessment (EA) Screening Report. A draft version of that document – referred to here as the "Draft Screening Report" – was published in June 2012.[6]

This report provides comments on the Draft Screening Report, focusing on a selected set of issues. Those issues pertain to the radiological risk arising from onsite management and storage of spent nuclear fuel (SNF) discharged from the nuclear reactors at the DNGS. The term "radiological risk" is discussed below.

The Institute for Resource and Security Studies (IRSS), an independent body based in Cambridge, Massachusetts, prepared this report under the sponsorship of Northwatch, a public-interest organization based in Northeastern Ontario.

Radiological risk associated with SNF

The term "radiological risk", as used in this report, refers to the potential for harm to humans as a result of their exposure to ionizing radiation due to an unplanned release of radioactive material. A more detailed discussion of radiological risk is provided in Section 4, below.

Credible studies, beginning in the late 1970s, as discussed in this report, show that management and storage of SNF discharged from commercial light-water reactors (LWRs) can create substantial radiological risk.[7] Experience with the 2011 accident at the Fukushima #1 site in Japan has highlighted the relevance of these studies to the regulation of nuclear generating stations.

Comparable studies have not been done for SNF discharged from CANDU reactors such as those used at DNGS.[8] Nevertheless, as discussed in this report, a Task Force established by the CNSC to investigate lessons learned from the Fukushima accident has acknowledged that substantial SNF radiological risk may exist at CANDU stations.[9]

Members of the public could reasonably expect that the Draft Screening Report would provide a thorough assessment of SNF radiological risk at DNGS, and a description of

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[6] CNSC and DFO, 2012.
[7] LWRs are cooled and moderated by ordinary (light) water. These reactors are either pressurized-water reactors (PWRs) or boiling-water reactors (BWRs).
[8] The term "CANDU" refers to a Canadian-designed pressurized-heavy-water reactor (PHWR) that is cooled and moderated by heavy water.
[9] CNSC-FTF, 2011.

options for reducing that risk. This report examines the extent to which the Draft Screening Report meets that expectation.

Structure of this report

The remainder of this report has nine sections. Section 2 summarizes the management and storage of SNF at DNGS. Section 3 reviews the discussion of SNF radiological risk in the Draft Screening Report, and in related documents prepared by OPG and CNSC. Then, Section 4 provides a general discussion of the definition and estimation of radiological risk. Section 5 describes the enhancement of public attention to SNF radiological risk that was stimulated by the Fukushima accident.

Section 6 reviews the state of technical understanding of SNF radiological risk in the LWR context, and Section 7 outlines options for risk reduction in that context. Section 8 outlines the steps needed to develop a technical understanding of SNF radiological risk and risk-reduction options in the CANDU context. Conclusions and recommendations are set forth in Section 9, and a bibliography is provided in Section 10. Citations throughout this report, if not provided directly, refer to entries in the bibliography.

2. Management and Storage of SNF at DNGS

Figure 2-1 shows a fuel bundle as used in the four DNGS reactors. The bundle contains 37 zirconium alloy (zircaloy) tubes containing uranium dioxide pellets made from natural uranium.[10] After a period of exposure in a reactor, the bundle becomes "spent" in the sense that it is no longer suitable for power production. The bundle is then discharged from the reactor, and is thereafter designated as SNF. Each SNF bundle contains a large inventory of radioactive isotopes that decay over time, and the decay generates a substantial amount of heat.

After being discharged from a DNGS reactor, an SNF bundle is transferred to one of two irradiated fuel bays (IFBs). One of these IFBs is located at each end of the long axis of the main DNGS building. At an IFB, an SNF bundle is placed in a storage module, which has a capacity of 96 bundles, and is then stored under water for a period of at least 10 years. The two IFBs have a combined total storage capacity of over 400,000 SNF bundles – enough for up to 20 station-years of operation.[11] These IFBs operate in the same general manner as spent-fuel pools at LWR stations. In both cases, water absorbs decay heat from the SNF and shields workers from the ionizing radiation emitted by the SNF. Figure 2-2 shows an IFB of the type used at DNGS.

After storage for at least 10 years in an IFB, an SNF bundle may be placed with other bundles into a dry storage container (DSC) and transferred to the Darlington Waste Management Facility (DWMF), which is located on the DNGS site. Figure 2-3 shows a

[10] OPG, 2011, Section 2.5.4.
[11] OPG, 2011, Section 2.5.4; OPG, 2010.

DSC, which has a capacity of 384 SNF bundles. At the DWMF, a DSC is stored inside a single-storey, concrete building, which has a capacity of 500 DSCs. One such building is now in use at the site, and OPG expects to construct second and third buildings in about 2013 and 2022, respectively. Refurbishment and continued operation of DNGS would require the construction of a fourth building in about 2031.[12]

3. Discussion of SNF Radiological Risk in the Draft Screening Report and Related Documents

The Draft Screening Report addresses radiological risk in its Section 7, titled "Malfunctions and Accidents". Section 7 opens with the statement:

> "The CEA Act requires that every EA of a project include consideration of the environmental effects of malfunctions or accidents that may occur in connection with the project. Malevolent events have not been considered in this environmental assessment, as CNSC staff are of the view that security issues are being appropriately managed by the ongoing regulatory process and that they do not warrant special consideration in this EA."

The categories of event considered in Section 7 of the Draft Screening Report are:

- Conventional malfunctions and accidents (Section 7.1)
- Radiological malfunctions and accidents (Section 7.2)
- Transportation accident (Section 7.3)
- Out-of-core criticality (Section 7.4)
- Nuclear accidents (Section 7.5)

According to the Draft Screening Report and OPG, out-of-core criticality is not a concern for SNF from DNGS, because this fuel will not become critical in either air or light water.[13] Also, "conventional" malfunctions and accidents are not relevant to radiological risk. Thus, radiological risk (as defined in this report) may pertain to the following three categories of event identified in the Draft Screening Report: (i) "radiological malfunctions and accidents"; (ii) "transportation accidents"; and (iii) "nuclear accidents". The first of those three categories features an inappropriate use of the word "radiological", because the category does not encompass all potential events that contribute to the radiological risk associated with continued operation of DNGS.

[12] OPG, 2011, Section 2.5.10; OPG, 2010.
[13] CNSC and DFO, 2012, Section 7.4; SENES, 2011, Section 7.0.

The Draft Screening Report identifies two events that contribute to SNF radiological risk. The events, described as "bounding scenarios", are:

- Drop of a DSC during on-site transport (Section 7.2.2)
- Drop of an SNF storage module onto the floor of an IFB (Section 7.2.4)

According to the Draft Screening Report (Section 7.2.2), the drop of a DSC during on-site transport could release to the atmosphere 1.02E+12 Bq of Hydrogen-3 (tritium) and 5.68E+12 Bq of Krypton-85. No other radioactive isotope would be released. The maximum dose to a worker would be 4.5 mSv, and the maximum dose to a member of the public would be 0.0015 mSv.

Also, according to the Draft Screening Report (Section 7.2.4), the drop of an SNF storage module (containing 96 fuel bundles) onto the floor of an IFB could lead to a release as follows: "The free inventory of noble gases is assumed to be instantly released followed by leaching from the fuel pellets." The isotopic composition, magnitude, release pathway, and timeframe of this release are not stated. The maximum dose to a member of the public would be 0.07 mSv, and the maximum dose to a worker is not estimated.

The SENES Report

The same two SNF-related events were discussed in a December 2011 report prepared by SENES Consultants for OPG, to provide technical support to this EA process.[14] Hereafter, that report is referred to as the "SENES Report". The SENES Report examined malfunctions and accidents relevant to the refurbishment and continued operation of DNGS. It employed the same five event categories as are used in Section 7 of the Draft Screening Report.

Section 4.4.2 of the SENES Report discussed the drop of a DSC during on-site transport. That discussion provided only slightly more detail than is provided in Section 7.2.2 of the Draft Screening Report. Also, Section 4.4.4 of the SENES Report discussed the drop of an SNF storage module onto the floor of an IFB. That discussion provided only slightly more detail than is provided in Section 7.2.4 of the Draft Screening Report. No other SNF event causing a radioactive release was considered in the SENES Report.

Thus, the Draft Screening Report and the SENES Report are in close alignment regarding "bounding scenarios" for events that contribute to SNF radiological risk. In this respect, it seems that the Draft Screening Report has simply adopted the position of OPG, as set forth in the SENES Report and related OPG documents.

A difference emerges in the way those two Reports address the implications of the 2011 Fukushima accident. The Draft Screening Report, in its Section 7.5.2, outlines safety improvements that OPG has implemented, or intends to implement, at DNGS. Some of

[14] SENES, 2011.

these improvements are said to respond to lessons learned from the Fukushima accident. None of the listed improvements is linked specifically to SNF radiological risk.[15]

By contrast, when the SENES Report discussed safety improvements at DNGS, including improvements that respond to lessons learned from the Fukushima accident, that Report opened up an issue that relates directly to SNF radiological risk.

In its Section 6.3.3.1, the SENES Report said, in the context of the DNGS design philosophy: "It is also a requirement that systems, other than the reactor proper, containing substantial amounts of radionuclides, (e.g., the irradiated fuel bays) not be unacceptably damaged." The issue of IFB-related damage was taken up again in Section 6.3.3.4 of the SENES Report (titled, "Safety Improvements to Respond to Fukushima"), where the following statement was made:

> "Preliminary analyses indicate that with current operational heat loads, at least 72 hours are available before any structural integrity issues arise for the DNGS IFBs (and it would take at least 13 days before fuel becomes uncovered due to boil-off of IFB water following a complete loss of IFB cooling and no operator action). Nonetheless, current operator response capabilities will be augmented by pre-staging provisions to allow for remote water addition to the IFBs using portable pumps. OPG has committed to complete confirmatory studies of these preliminary conclusions, and the studies are currently underway."

Thus, the SENES Report revealed that loss of water from an IFB, leading to uncovering of SNF, is an event to be feared. That information is not provided in the Draft Screening Report. Unfortunately, however, the SENES Report did not explain why the uncovering of SNF is an event to be feared, or what the outcome of that event might be. Moreover, the SENES Report showed that OPG had, as of December 2011, conducted only "preliminary analyses" of this issue.

The Fukushima Task Force Report

The issue of loss of water from an IFB was addressed in somewhat greater detail in the October 2011 report of a Task Force established by the CNSC to evaluate the implications of the Fukushima accident for Canadian nuclear power plants (NPPs).[16] That report is referred to here as the "Fukushima Task Force Report".

Section 4.2.3 of the Fukushima Task Force Report identified loss of cooling of an IFB as a safety concern, stating:

> "Existing Canadian NPPs and most of the proposed designs for new NPPs rely on active cooling for reactors, containment and irradiated fuel bays (spent fuel

[15] In its Section 7.5.2, the Draft Screening Report mentions OPG studies on the provision of portable pumps to allow for remote water addition to IFBs. The Report does not explain why that provision is significant.
[16] CNSC-FTF, 2011.

> pools). All designs have some degree of passive cooling capability. The effective duration for the various passive heat sinks varies with the design.
>
> Loss of cooling of the irradiated fuel bays is generally a lesser concern than loss of core cooling as much more time is available before fuel overheats. However, irradiated fuel bays generally have fewer alternative cooling options than the core; therefore the issue is still important."

In its Section 6.3.6, the Fukushima Task Force Report identified the uncovering of SNF, as a result of boiling and/or leakage of the water in an IFB, as an event to be feared. The Report then revealed that this event could generate hydrogen gas, which could form an explosive mixture in air. The Report said:

> "The licensees' submissions do not generally discuss the need for hydrogen mitigation in the IFB area. In their July 28, 2011, submission, licensees conclude that, as long as water inventory is maintained and the fuel remains submerged, hydrogen generation is not an issue. Nonetheless, the CNSC Task Force finds that the need for hydrogen mitigation in the IFB area should be evaluated."

In its Section 6.4.5, the Fukushima Task Force Report provided a partial explanation of why the uncovering of SNF is an event to be feared. The Report said:

> "Fuel bays contain significant quantities of irradiated fuel. Because of decay, fission product inventories in the spent fuel decrease over time. Nevertheless, the long-lived radioactive materials could pose a significant threat if the spent fuel is uncovered and subsequently overheats. To mitigate this threat, provisions are taken to ensure reliable cooling of the spent fuel bays and to maintain their structural integrity in credible external events, such as earthquakes. The CNSC Task Force expects all Canadian NPP licensees to perform comprehensive deterministic and probabilistic analyses of events affecting irradiated fuel bays, in order to demonstrate that the mitigation is sufficient for events as discussed in section 6.3.6."

In that statement, the Task Force called for "deterministic and probabilistic analyses" by licensees. Yet, elsewhere, the Task Force said that the methodology to properly perform those analyses may not exist. In its Section 6.4.3 (titled, "Assessments of severe accidents"), The Fukushima Task Force Report stated:

> "However, the existing modelling capabilities may not be adequate to consider events affecting multiple reactors on the same site (multi-unit events), **accidents with spent fuel** [emphasis added], or releases of radioactive products from a degraded reactor core into water."

The Task Force set forth specific recommendations for analyses pertaining to SNF radiological risk. In Clause 3 of its Section 10.1, the Fukushima Task Force Report said:

> "Licensees should enhance their modelling capabilities and conduct systematic analyses of beyond-design-basis accidents to include analyses of:
> a) multi-unit events
> b) accidents triggered by extreme external events
> c) **spent fuel bay accidents** [emphasis added]
>
> The analyses should include estimation of releases, into the atmosphere and water, of fission products, aerosols and combustible gases."

Summary

From the discussion above, it is clear that the CNSC's Fukushima Task Force was aware of a substantial radiological risk arising from storage of SNF under water in IFBs at stations such as DNGS. The Task Force did not fully explain the risk, but acknowledged at least three points. First, water could be lost from an IFB by boiling and/or leakage, causing SNF to be uncovered. Second, SNF that is uncovered could overheat, whereupon it could release radioactive material and hydrogen gas. Third, the capabilities of Canadian licensees to model these phenomena require substantial improvement.

The SENES Report implied that OPG was aware of this risk. At the very least, OPG was aware that uncovering of SNF is an event to be feared. Also, a person could reasonably expect that OPG would be fully cognizant of the findings of the Fukushima Task Force.

The Draft Screening Report cites the SENES Report and the Fukushima Task Force Report.[17] Yet, the Draft Screening Report fails to acknowledge the risk associated with uncovering of SNF in an IFB. Instead, the Draft Screening Report focuses its discussion of SNF radiological risk on two comparatively minor events – drop of a DSC, and drop of an SNF storage module. In those cases, it seems that the Draft Screening Report has simply adopted the position of OPG.

4. Defining and Estimating Radiological Risk

As stated in Section 1, above, in this report the term "radiological risk" refers to the potential for harm to humans as a result of their exposure to ionizing radiation due to an unplanned release of radioactive material. There is no single indicator of this risk. Instead, the potential for harm can be assessed by compiling a set of qualitative and quantitative information about the likelihood and characteristics of the harm. Our terminology is consistent with a generic definition of "risk" as the potential for harm due to an unplanned event. The US Nuclear Regulatory Commission (NRC) has articulated a similar definition.[18]

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[17] CNSC and DFO, 2012, Section 13.

[18] The NRC Glossary defines risk as: "The combined answer to three questions that consider (1) what can go wrong, (2) how likely it is, and (3) what its consequences might be. These three questions allow the NRC to understand likely outcomes, sensitivities, areas of importance, system interactions, and areas of

Other perspectives on risk

In the nuclear industry and elsewhere, one often encounters a more limited definition, in which risk is the arithmetic product of a numerical indicator of harmful impact and a numerical indicator of the impact's probability.[19] That definition is hereafter designated as the "arithmetic" definition of risk. The arithmetic definition can be seriously misleading in two respects. First, the full spectrum of impact and/or probability may not be susceptible to numerical estimation, or numerical estimates may be highly uncertain. Second, many subscribers to the arithmetic definition argue that equal levels of the numerically-estimated risk should be equally acceptable to citizens. Their argument may be given a scientific gloss, but is actually a statement laden with subjective values and interests.

Quantitative analysis is essential to science, engineering, and other fields. Yet, the limitations of quantitative analysis should be recognized. Analysts should be especially careful to avoid the intellectual trap of ignoring issues that are difficult to quantify. Many practitioners of radiological risk assessment fall into that trap. Thus, important risk factors are ignored. Prominent examples include: (i) acts of malevolence or insanity; and (ii) gross errors in design, construction, and operation of facilities. Risk assessments for nuclear facilities routinely ignore these and other factors that may be major determinants of risk.[20]

A nuclear facility – such as a reactor, or a spent-fuel storage installation – typically has the potential to experience unplanned releases of radioactive material across a spectrum ranging from small releases to large releases. Risk analysts who subscribe to the arithmetic definition often conclude that small releases are more probable. With their arithmetic approach, it then appears that large releases with low probability are equivalent to small releases with high probability. Often, these analysts leap to the assumption that the apparent equivalence is "scientific". Thus, they argue, equal levels of the numerically-estimated risk should be equally acceptable to citizens.

In fact, the assumption of equivalence lacks a scientific basis. It is a subjective statement that reflects the values and interests of this group of analysts. From the perspective of a citizen, the potential for a large release may be much less acceptable than the potential for a small release, regardless of probability. That perspective could have a solid, rational basis, because a large release could have effects that are qualitatively different from the

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uncertainty, which can be used to identify risk-significant scenarios." (See: http://www.nrc.gov/reading-rm/basic-ref/glossary/risk.html, accessed on 16 February 2012.)

[19] Often, the arithmetic product will be calculated for each of a range of impact scenarios, and these products will be summed across the scenarios.

[20] For example, there is evidence that a major risk factor underlying the 1986 Chernobyl reactor accident was endemic secrecy in the USSR. (See: Shlyakhter and Wilson, 1992.) Also, there is evidence that a major risk factor underlying the 2011 Fukushima accident was collusion among government, the regulators, and the licensee (TEPCO). (See: Diet, 2012, page 16.) Radiological-risk studies performed by the nuclear industry and its regulators do not consider secrecy or collusion as risk factors.

effects of a small release. Moreover, a prudent citizen will be skeptical of the probability findings generated by arithmetic risk analysts, given the propensity of these analysts to ignore important risk factors.

Probabilistic risk assessment

The preceding paragraphs provide a basis for critical examination of an analytic art known as probabilistic risk assessment (PRA). This art can be useful in radiological risk assessment, provided that its limitations are kept firmly in mind.

PRA techniques have been developed to estimate the probabilities and impacts of potential unplanned releases of radioactive material from nuclear facilities. Similar techniques can be used to examine other types of risk, such as the potential for harm due to unplanned releases from chemical plants.

In the nuclear-facility context, most PRAs have been done for nuclear power plants. The first PRA for an NPP was known as the Reactor Safety Study, and was published by NRC in 1975.[21] A PRA for a nuclear power plant considers a range of scenarios (event sequences) that involve damage to the reactor core. The initiating events are categorized as “internal” events (human error, equipment failure, etc.) or “external” events (earthquakes, fires, strong winds, etc.). The core-damage scenarios that arise from these events are termed “accidents”.

PRAs typically do not consider initiating events that involve intentional, malevolent acts, although PRA techniques can be adapted to estimate the outcomes of such acts. For example, NRC adapted PRA techniques in developing its 1994 rule requiring protection of a nuclear power plant against attack using a vehicle bomb.[22]

PRAs for NPPs are conducted at Levels 1, 2 and 3, in increasing order of completeness, as discussed below. A thorough, full-scope PRA would be conducted at Level 3, and would consider internal and external initiating events. The findings of such a PRA would be expressed in terms of the magnitudes and probabilities of a set of adverse impacts, and the uncertainty and variability of those indicators. Typically, PRAs focus on atmospheric releases originating in the reactor core.[23] The adverse impacts of such releases at downwind locations would include:

> (i) “early” human fatalities or morbidities (illnesses) that arise during the first weeks and months after the release;
> (ii) “latent” fatalities or morbidities (e.g., cancers) that arise years after the release;

[21] NRC, 1975.
[22] NRC, 1994.
[23] A release could also occur to ground water or surface water (e.g., river, lake, or ocean). For a given size and composition of release, human exposure to radiation would typically be much larger for an atmospheric release than for a water release.

(iii) short- or long-term abandonment of land, buildings, etc.;
(iv) short- or long-term interruption of agriculture, water supplies, etc.; and
(v) social and economic impacts of the above-listed consequences.

The magnitudes and probabilities of such adverse impacts would be estimated in three steps. First, a Level 1 PRA analysis would be performed. In that analysis, a set of event sequences (accident scenarios) leading to damage to the reactor core would be identified, and the probability (frequency) of each member of the set would be estimated. The sum of those probabilities across the set would be the total estimated core-damage probability. That indicator is often known as core-damage frequency (CDF), expressed as a number per reactor-year (RY) of reactor operation.

Second, a Level 2 PRA analysis would be performed. In that analysis, the potential for release of radioactive material to the atmosphere would be examined across the set of core-damage sequences. The findings would be expressed in terms of a group of release categories characterized by magnitude, probability, timing, isotopic composition, and other characteristics.

Third, a Level 3 PRA analysis would be performed, to yield the findings described above. In that analysis, the atmospheric dispersion, deposition, and subsequent movement of the released radioactive material would be modeled for each of the release groups determined by the Level 2 analysis. The dispersion modeling would account for meteorological variation over the course of a year. Then, the adverse impacts of the released material would be estimated, accounting for the material's distribution in the biosphere. As mentioned above, the impacts would include adverse health effects and socio-economic impacts.

If done thoroughly, this three-step estimation process would account for uncertainty and variability at each stage of the process. A thorough, full-scope, Level 3 PRA is expensive and time-consuming. It yields estimated impacts expressed as statistical distributions of magnitude and probability, not as single numbers. Even after such a thorough effort, there are substantial, irreducible uncertainties in the findings.[24] PRA findings rely on numerous assumptions and judgments. There is no certainty that all of the relevant factors are captured. Findings of very low probability cannot be validated by direct experience. Moreover, a PRA cannot estimate the probabilities of malevolent acts, because there is no statistical basis for doing so. A PRA that considered malevolent acts would have to postulate the occurrence of a set of such acts and then estimate their impacts, accounting for variable factors such as wind speed and direction.

[24] Hirsch et al, 1989.

NUREG-1150

The high point of PRA practice worldwide was reached in 1990 with publication by NRC of its NUREG-1150 study, which examined five different US nuclear power plants using a common methodology.[25] The study was well funded, involved many experts, was conducted in an open and transparent manner, was done at Level 3, considered internal and external initiating events, explicitly propagated uncertainty through its chain of analysis, was subjected to peer review, and left behind a large body of published documentation. Each of those features is necessary if the findings of a PRA are to be credible. There are deficiencies in the NUREG-1150 findings, which can be corrected by fresh analysis and the use of new information. The process of correction is possible because the NUREG-1150 study was conducted openly and left a documentary record.

PRA practice in the USA has degenerated since the NUREG-1150 study. Now, PRAs are conducted almost entirely by the nuclear industry, and the only published documentation is a summary statement of findings. NRC formerly sponsored independent reviews of industry PRAs, but no longer does so. Thus, contemporary PRA findings have limited credibility.

Figures 4-1 through 4-3 show some findings from the NUREG-1150 study. The findings are for a pressurized-water reactor (PWR) plant at the Surry site, and a boiling-water reactor (BWR) plant at the Peach Bottom site. Those plants typify many of the Generation II plants in the present worldwide fleet of NPPs. In viewing the CDF findings in Figures 4-1 and 4-2, it should be noted that NUREG-1150 itself warns that estimated core-damage probabilities lower than 1 per 100,000 RY should be viewed with caution because of limitations in PRA. NRC has published for comment a draft report from its SOARCA program, describing new analysis of some core-damage sequences at the Surry and Peach Bottom plants.[26] The merit of that analysis, and its implications regarding the NUREG-1150 findings, are unclear at present.

Estimating core-damage probability from direct experience

Severe fuel damage at an NPP is often thought of as a rare event. Yet, a 2011 inventory lists twelve events involving severe damage to fuel in the reactor core of an NPP.[27] That inventory excludes similar events at non-power reactors. For example, it excludes the core fire and radioactive release experienced in 1957 by a reactor at the Windscale site in the UK. That reactor was used to produce plutonium and other materials for nuclear weapons.

Of the twelve core-damage events at NPPs, five have both: (i) occurred at a Generation II plant; and (ii) involved substantial fuel melting. These five events were at Three Mile Island (TMI) Unit 2 (a PWR plant in the USA) in 1979, Chernobyl Unit 4 (an RBMK

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[25] NRC, 1990.
[26] NRC, 2012.
[27] Cochran, 2011.

plant in the USSR) in 1986, and Fukushima #1 Units 1 through 3 (BWR plants in Japan) in 2011.

These five events occurred in a worldwide fleet of commercial NPPs, of which about 440 plants are currently operable. These plants and previous plants in the fleet had accrued 14,760 RY of operating experience as of 17 February 2012.[28] The five events provide a data set that is comparatively sparse and therefore does not provide a statistical basis for a high-confidence estimate of CDF. Nevertheless, this data set does provide a reality check for PRA estimates of CDF. From this data set – five core-damage events over a worldwide experience base of about 15,000 RY – one observes a CDF of 3.3E-04 per RY (1 event per 3,000 RY).[29]

Confidence in this reality check is enhanced by noting that the five events occurred in three different countries at three different types of NPP, involved differing initiating events, and happened on three distinct occasions over a period of 32 calendar years. This spread of accident characteristics is consistent with the diversity of circumstances that PRA analysis seeks to address.

Application of PRA techniques to SNF

This author is unaware of any study, in any country, that has systematically applied PRA techniques to examine the radiological risk posed by SNF. Credible studies related to that risk have been performed, but none has the systematic scope of a thorough PRA. The comparative lack of attention to SNF risk is notable because a spent-fuel pool containing SNF is located near every commercial reactor. That proximity, and current practice for storing SNF in pools, creates a linkage between SNF risk and reactor risk. (See Section 6, below.)

5. Public Attention to SNF Radiological Risk

The radiological risk posed by SNF has continued growing over the past several decades, due to the factors discussed in Section 6, below. During most of that period, public awareness of the risk was low. This situation was altered by the 2011 accident at the Fukushima #1 nuclear site. From the publicity accompanying the accident, citizens learned that SNF was stored in pools adjacent to the affected reactors, and that a large amount of radioactive material could have been released to atmosphere if a pool lost water and SNF became exposed to air. Table 5-1 shows the inventory of SNF at the site, as of March 2010.

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[28] World Nuclear Association website, http://www.world-nuclear.org/, accessed on 17 February 2012.

[29] This simple estimate of CDF might be criticized because the three core-damage events at Fukushima #1 had a common cause. However, there are some design differences between the three affected NPPs at Fukushima #1, and it appears that there were differences in the accident sequences at these plants. Also, multiple core-damage events with a common cause could occur in the future, potentially involving plants at single-unit sites.

Figure 5-1, which shows Unit 4 at the Fukushima #1 site during the 2011 accident, exemplifies the information that has become available to citizens. The Unit 4 reactor building exhibits severe damage from a hydrogen explosion. A concrete-pumping truck next to the building is spraying water, through the damaged roof of the building, into the Unit 4 spent-fuel pool. Before concrete-pumping trucks arrived at the site, unsuccessful attempts to add water to the spent-fuel pools at Units 1-4 involved the use of fire trucks and riot control vehicles to spray water, and the dropping of seawater from bags carried by helicopters. Television and press coverage of these activities gave citizens around the world an introduction to the risk posed by SNF.

The explosion in the Unit 4 reactor building involved the combustion of hydrogen in air. The only plausible source of this hydrogen was a reaction between steam and the zirconium alloy (zircaloy) cladding of overheated nuclear fuel.[30] This reaction could not have occurred in the Unit 4 reactor core, because the reactor had been defueled prior to the accident. Thus, when the explosion occurred, many analysts theorized that water had been lost from the Unit 4 spent-fuel pool, leading to overheating of SNF in the pool, culminating in steam-zircaloy reaction. A more recent, alternative theory is that the hydrogen traveled from Unit 3 to Unit 4 through a ventilation system.[31] This alternative theory seems to be a better fit with the facts known to date.[32] From the perspective of public awareness of SNF risk, what may be most significant about this experience is the visual demonstration – through violent hydrogen explosions – of the latent chemical energy in the zircaloy cladding of nuclear fuel.

Figure 5-2 represents another demonstration of SNF risk. This figure shows the contamination of land in Japan by radioactive Cesium released to atmosphere during the Fukushima accident. Various effects of the contamination – such as limits on the use of land for agriculture – will be evident to Japanese citizens for decades to come. Japanese officials have conceded that the release of Cesium would have been substantially greater if water had been lost from spent-fuel pools, causing SNF to burn (i.e., react exothermically with steam or air). In a February 2012 interview, Japan Atomic Energy Commission chair Shunsuke Kondo described a "worst-case" release scenario that he delivered to the Japanese government on 25 March 2011. The scenario envisioned an atmospheric release from burning SNF that would be "the radiation equivalent of two reactor cores".[33]

In this report, the isotope Cesium-137 is used to represent a radioactive release from SNF. The rationale for that representation is presented at the close of Section 6, below.

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[30] The steam-zirconium reaction is exothermic and proceeds as follows: Zr + 2H20 -> ZrO2 + 2H2
[31] Unit 3 also experienced a hydrogen explosion, the hydrogen in that case being created by steam-zircaloy reaction in overheated fuel in the Unit 3 reactor core.
[32] INPO, 2011.
[33] Associated Press, 2012.

6. Technical Understanding of SNF Radiological Risk in the LWR Context

Human-constructed fission reactors first began operating in the 1940s. The radiological risk posed by SNF has existed since that time. Over the intervening decades, the risk has increased due to: (i) growth in SNF inventories; (ii) changed properties of nuclear fuel; and (iii) design choices regarding modes of SNF storage. These factors are discussed here, with a focus on SNF from LWRs (which are either PWRs or BWRs). As shown in Table 6-1, LWRs dominate the world's inventory of NPPs.

Growth in SNF inventories

Table 6-2 shows the inventory and broad characteristics of SNF discharged from commercial reactors in the USA through 2010.[34] About three-quarters of that inventory is stored in spent-fuel pools adjacent to operating reactors, the remainder being stored in dry casks.[35] Other countries have accumulated smaller inventories of SNF, determined in each instance by the size, type, and history of operation of the country's fleet of NPPs.[36] The International Panel on Fissile Materials has published a useful review of worldwide experience in managing SNF.[37]

The units shown in Table 6-2 deserve an explanation. The mass of fuel is expressed in Mg (metric tons) of total initial uranium (Mg U), where "initial" refers to uranium in the fresh fuel inserted into a reactor. For uranium fuel, this mass is identical to the indicator "metric tons of heavy metal" (MTHM). However, MTHM is a more general indicator, because it encompasses situations in which uranium, plutonium, and other heavy metals are present in fresh fuel. The indicator Mg HM, which is equivalent to MTHM, is used at points in this report. Note that the indicators Mg U, Mg HM, and MTHM all refer to elemental mass in fresh fuel.

Table 6-2 shows the "burnup" of a spent-fuel assembly. This indicator is the cumulative thermal energy – in GWt-days per Mg U – released by fissions while the assembly is present in a reactor. The power unit GWt contrasts with GWe, which refers to electricity output from the NPP.

The growth in SNF inventories around the world reflects a long-term trend away from the reprocessing of spent fuel. When the nuclear fission industry was launched in the 1950s and 1960s, the industry's managers typically assumed that SNF would be reprocessed. One outcome of that assumption is that the spent-fuel pools at NPPs were originally designed to hold only a few years' discharge of spent fuel from the reactors. Over time,

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[34] For an overview of practices and regulations regarding SNF storage in the USA, see: EPRI, 2010.
[35] The NRC states that, as of the end of 2009, pools in the USA contained 48,818 Mg of commercial SNF while dry casks contained 13,856 Mg. See: http://www.nrc.gov/waste/spent-fuel-storage/faqs.html, accessed on 22 February 2012. Almost all of the SNF in pools is in pools adjacent to operating reactors.
[36] Choi, 2010.
[37] IPFM, 2011.

however, countries have turned away from reprocessing. For example, commercial SNF in the USA has not been reprocessed since 1972.

Growth in SNF inventories would, other factors remaining equal, have yielded a proportional increase in SNF radiological risk. The risk has actually grown at a faster, disproportionate rate, as a result of design decisions by the nuclear industry. One set of these decisions relates to the properties of nuclear fuel, and the other to choices regarding modes of SNF storage.

Properties of nuclear fuel

Figures 6-1 and 6-2 show schematic views of PWR and BWR fuel assemblies. Supporting data are shown in Table 6-3. The active portion of the assemblies consists of uranium oxide pellets – or, in some instances, mixed plutonium and uranium oxide (MOX) pellets – inside thin-walled metal tubes. When the fuel is fresh, the uranium is low-enriched (up to 5% U-235).[38] The tubes are typically known as "cladding". In contemporary NPPs the cladding is made of zircaloy, whose primary ingredient is zirconium.

Zircaloy is not the only material that can be used for fuel cladding. Stainless steel is an alternative cladding material, and was used in a number of water-cooled reactors during the early years of development of LWR technology. As of mid-1979, about 7% (about 1,500 fuel assemblies) of the commercial SNF inventory in the USA was fuel with stainless steel cladding.[39] Generally, this fuel performed well. In illustration, a thorough examination was made of a stainless-steel-clad PWR fuel assembly that was driven to a burnup of 32 GWt-days per Mg U in the Connecticut Yankee reactor and then stored for 5 years in a spent-fuel pool.[40] No degradation was observed.

Zircaloy and stainless steel performed about equally well as a cladding material, in terms of durability under the conditions experienced in a water-cooled reactor.[41] However, zircaloy was superior in terms of its lower absorption of neutrons, which improved the economics of NPP operation. Thus:[42] "By 1966 economic considerations had led to the selection of zirconium alloy fuel cladding for all water-cooled reactors." This outcome had been anticipated in a 1958 study that stated:[43]

> "In most of the nuclear reactors being designed today for commercial power production, it is technically feasible to use either stainless steel or zirconium or one of its alloys as structural material, fuel cladding or fuel diluent. When used within the neutron flux of the reactor the low neutron-absorption cross section of

[38] In a CANDU reactor, the fresh fuel contains natural uranium (0.7% U-235).
[39] Langstaff et al, 1982, page v.
[40] Langstaff et al, 1982.
[41] Gurinsky and Isserow, 1973.
[42] Gurinsky and Isserow, 1973, page 63.
[43] Benedict, 1958, page 1.

zirconium gives that material an important economic advantage over stainless steel. Use of zirconium instead of stainless steel makes possible savings through the use of uranium of lower enrichment, through reduction in the critical mass of uranium, or through some combination of these cost-saving features."

Exothermic reaction of zircaloy cladding

Although the economic advantage of zircaloy cladding during routine operation of an NPP is clear, there is a price to be paid in terms of radiological risk. Zircaloy, like zirconium, is a chemically reactive material that will react vigorously and exothermically with either air or steam if its temperature reaches the ignition point – about 1,000 deg. C. This temperature is well above the operating temperature of a water-cooled reactor, where zircaloy exhibits good corrosion resistance.[44]

The potential for ignition of zircaloy is well known in the field of reactor risk, and has been observed in practice on a number of occasions. For example, during the TMI reactor accident of 1979, steam-zirconium reaction occurred in the reactor vessel, generating a substantial amount of hydrogen. Some of that hydrogen escaped into the reactor containment, mixed with air, and exploded. Fortunately, the resulting pressure pulse did not rupture the containment. Similar explosions during the Fukushima #1 accident of 2011 caused severe damage to the reactor buildings of Units 1, 3, and 4.

Table 6-4 illustrates the significance of zircaloy's chemical reactivity in the context of SNF radiological risk. The calculation presented in this table assumes that a PWR fuel assembly surrounded by air experiences a rise in temperature to the point where the zircaloy cladding ignites and burns. Then, it is assumed, 50% of the heat from complete combustion of the cladding enters the adjacent fuel pellets. This amount of heat would raise the pellet temperature to well above the boiling point of Cesium. Thus, a substantial fraction of the pellet's inventory of Cesium would be released. A similar result is obtained if the fuel assembly is surrounded by steam, even though the heat of reaction of zirconium with steam (6.53 MJ per kg Zr) is smaller than the heat of reaction with air (11.9 MJ per kg Zr). These findings provide useful insight into the behavior of SNF in risk-relevant circumstances, despite the simplicity of the calculation.

Replacing zircaloy with alternative cladding materials

As mentioned above, stainless steel could substitute for zircaloy as a cladding material. The nuclear industry would undoubtedly resist this substitution, which would adversely affect the economics of NPP operation and would disrupt long-established practices in

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[44] Formation of a thin film of oxide on the water-facing surface of the zircaloy enhances corrosion resistance. This film becomes less effective in suppressing oxidation as the zircaloy temperature approaches the ignition point of about 1,000 deg. C. Moreover, as the temperature of zircaloy-clad fuel rises toward that point, the cladding will swell and burst from internal pressure, thus exposing un-oxidized surfaces to air or steam.

the industry. Also, stainless steel can react exothermically with air or steam, although with a lower heat of reaction than is exhibited by zircaloy.[45]

During the past two decades, there have been efforts to develop ceramic cladding as a replacement for zircaloy. Two major objectives drive these efforts. First, ceramic cladding may allow higher burnup of fuel, which would reduce NPP operating cost. Second, ceramic cladding may behave better in accident conditions, in part by avoiding the heat production and hydrogen generation that are unleashed in the steam-zircaloy reaction.

Currently, efforts to develop ceramic cladding appear to be focused on a "triplex" silicon carbide cladding. The developers hope to begin a prototype test program – in which complete fuel assemblies made with the triplex cladding are placed in commercial reactors – by about 2020.[46] If they keep to this schedule and the tests are successful, then reactors might be routinely fueled with ceramic-clad fuel by about 2030. In that event, ceramic-clad spent fuel would begin adding to SNF inventories in significant quantity by about 2040. Thus, for at least the next three decades, worldwide inventories of SNF will be dominated by fuel using zircaloy cladding.

Re-racking of spent-fuel pools, and its risk implications

At every LWR, a spent-fuel pool is located adjacent to the reactor. Fresh fuel enters the reactor via the pool, and spent fuel is discharged into the pool. As mentioned above, the pools were originally designed to hold only a few years' discharge of spent fuel from the reactors. As part of that design, the pools were equipped with low-density, open-frame racks into which fuel assemblies were placed. Figure 6-3 shows a PWR fuel rack of this type. Similar, open-frame racks were used for BWR fuel.

If water were lost from a pool equipped with low-density racks, there would be vigorous, natural convection of air and steam throughout the racks, providing cooling to the SNF.[47] Thus, in most situations, the temperature of the zircaloy cladding of SNF in the racks would not rise to the ignition point. Exceptional circumstances that could lead to ignition include the presence of SNF very recently discharged from a reactor, and deformation of the racks. Even then, propagation of combustion to other fuel assemblies would be comparatively ineffective, and the total release of radioactive material would be limited to the comparatively small inventory in the pool.

Faced with the problem of growing inventories of SNF, the nuclear industry could have continued using low-density racks in the pools while placing excess fuel in dry casks. That approach would have limited SNF radiological risk. Instead, the industry adopted a

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[45] The heat of reaction of stainless steel with air is 5.98 MJ per kg SS, and the heat of reaction with water is 1.06 MJ per kg SS. (See: Baker and Liimatainen, 1973, Table 3-1.)
[46] Yueh et al, 2010.
[47] Convective cooling of BWR fuel would be improved by separating the channel boxes from the fuel assemblies.

cheaper option. Beginning in the 1970s, the industry re-equipped its pools with higher-density racks. In the high-density racks that are now routinely used around the world, the center-center spacing of fuel assemblies approaches the spacing in a reactor. (See Table 6-3 for the reactor spacing.) To suppress criticality, the assemblies are separated by plates containing neutron-absorbing material such as boral (boron carbide particles in an aluminum matrix). Figure 6-4 illustrates the use of high-density racks, in this instance at Unit 4 at the Fukushima #1 site.

The neutron-absorbing plates divide the racks into long, narrow, vertical cells, open only at the top and bottom. If water were lost from a pool, this arrangement would suppress heat transfer by convection and radiation. The presence of residual water in the lower portion of the pool, which would occur in many water-loss situations, would limit heat transfer to only one effective mechanism – convective cooling by steam rising from the residual water. Over a range of water-loss scenarios, radioactive decay heating in the SNF would cause cladding temperature to rise toward the ignition point.[48]

Table 6-5 sets forth a simple calculation that illustrates the timeframe for cladding temperature to reach the ignition point (about 1,000 deg. C). The calculation assumes adiabatic conditions, which would be approached in the situation where a pool contains residual water. It will be seen that the fuel temperature rises at a rate of 9R deg. C per hour, where R is the fuel assembly's output of radioactive decay heat in kW per Mg HM. Various values of R are shown in Table 6-6. Consider, for example PWR-U fuel with a burnup of 50 GWt-days per Mg HM, aged 100 days after reactor shutdown. In that case, R = 28. Thus, under adiabatic conditions, fuel temperature would rise at a rate of 252 deg. C per hour.

The preceding discussion sets the scene for considering the attributes of a "pool fire". This incident would involve the following sequence of events:

> (i) loss of water from a spent-fuel pool due to leakage, boiling away, siphoning, or other mechanism;
> (ii) failure to provide water makeup or cooling;
> (iii) uncovering of SNF assemblies;
> (iv) heat-up of some SNF assemblies to the ignition point of zircaloy, followed by combustion of these assemblies in steam and/or air;
> (v) a hydrogen explosion (not inevitable, but likely) that damages the building surrounding the pool;
> (vi) release of radioactive material from affected SNF assemblies to the atmosphere; and
> (vii) propagation of combustion to other SNF assemblies.

A pool-fire event sequence would unfold over a timeframe ranging from a few hours to a number of days. During this timeframe, there would be opportunities for personnel to

[48] For supporting information, see: Alvarez et al, 2003.

halt or mitigate the event sequence through actions such as plugging holes in a pool, or adding water. However, addition of water after zircaloy ignites could be counter-productive, because the water could feed combustion. Circumstances accompanying the pool-fire event sequence, such as a core-damage event sequence at an adjacent reactor, could preclude mitigating actions.

Recognition of the pool-fire risk

Two studies completed in March 1979 independently identified the potential for a pool fire. One study was by members of a scientific panel assembled by the state government of Lower Saxony, Germany, to review a proposal for a nuclear fuel cycle center at Gorleben.[49] After a public hearing where the study was presented, the Lower Saxony government ruled in May 1979, as part of a broader decision, that high-density pool storage of spent fuel would not be acceptable at Gorleben.[50] Subsequently, new facilities built in Germany to store SNF used dry casks exclusively.

The second study was done by Sandia Laboratories for NRC.[51] In light of knowledge that has accumulated since 1979, the Sandia report generally stands up well, provided that one reads the report in its entirety. However, the report's introduction contains an erroneous statement that complete drainage of the pool is the most severe situation. The body of the report clearly shows that partial drainage can be a more severe case, as was recognized in the Gorleben study.

After receiving the Sandia report, NRC conducted and sponsored a number of studies related to pool-fire risk, which were published over a period of two decades. Unfortunately, those studies employed the erroneous assumption that complete drainage is the most severe case, until NRC partially corrected this error in October 2000. After September 2001, NRC ceased publishing analysis on pool-fire risk, but claims to have done some classified (secret) studies. Overall, NRC's work to assess pool-fire risk has useful elements but is deficient in several important respects.[52]

Nevertheless, NRC's published findings support the analysis presented here. NRC concedes that a fire could spontaneously break out in a spent-fuel pool following a loss of water, and that radioactive material released to the atmosphere during the fire would have significant, adverse impacts on the environment. To offset those concessions, NRC argues that the probability of a pool fire is low. NRC has attributed the alleged low probability, in part, to secret security measures and damage-control preparations that were implemented at NPPs in the USA after September 2001.[53] After the Fukushima accident of 2011, NRC released some information about the secret damage-control

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[49] Beyea et al, 1979.
[50] Albrecht, 1979.
[51] Benjamin et al, 1979.
[52] NRC studies on pool-fire risk have been identified, summarized, and critiqued in: Thompson, 2009.
[53] Thompson, 2009.

preparations. This author's review and NRC's own analysis revealed major deficiencies in those preparations.[54]

Independent studies on pool-fire risk have been performed. In 2003, eight authors published a paper on pool-fire risk and the options for reducing that risk.[55] That paper aroused vigorous comment, and its findings were disputed by NRC officials and others. In an effort to resolve this controversy, the US Congress requested the National Research Council (an affiliate of the National Academy of Sciences) to conduct a study on the safety and security of SNF storage. The Council submitted a classified (secret) report to Congress in 2004, and in 2005 released an unclassified version that was formally published in 2006.[56] Press reports described considerable tension between the Council and NRC regarding the inclusion of material in the unclassified report.[57] That report and the eight-author paper described above are mutually consistent, and both support the analysis in this report.

Linkage between pool-fire risk and reactor core-damage risk

At LWR stations, a spent-fuel pool is located adjacent to each reactor. Figure 6-5 shows the respective locations of the reactor and pool in the case of a BWR reactor with a Mark I containment. At PWR plants, the pool is typically located in a separate building that is outside the reactor containment but immediately adjacent to it. The pool shown in Figure 6-5 is elevated above ground level. At PWR plants, the floor of the pool is typically at ground level or a few meters below it. There may be open spaces (rooms, corridors) below the pool floor.

Systems to cool the water in the pool, and to provide makeup water, are integrated with similar systems that support reactor operation. Thus, cooling and water makeup to the pool would be interrupted during many of the potential event sequences that could lead to reactor core damage. This interruption could initiate – or contribute to – a sequence of events that lead to a pool fire. As mentioned above, that sequence would unfold over a timeframe ranging from a few hours to a number of days.

There would be opportunities during this period for personnel to halt or mitigate the event sequence. In some cases, simply adding water to the pool would be sufficient to prevent a pool fire. However, accompanying circumstances could prevent personnel from taking the necessary actions. For example, the site could be contaminated by radioactive material released from one or more reactors, and structures and equipment could be damaged by hydrogen explosion and/or the influence (e.g., an earthquake) that initiated the event sequence. Indeed, these circumstances arose during the Fukushima #1 accident, and substantially impeded mitigating actions by onsite personnel.[58]

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[54] NRC, 2011; Thompson, 2011.
[55] Alvarez et al, 2003.
[56] National Research Council, 2006.
[57] Wald, 2005.
[58] INPO, 2011.

A reactor and its adjacent pool (if filled with SNF at high density) can be thought of as a coupled risk system. The reactor and the pool can affect each other in ways that increase the total risk posed by the system. To illustrate, consider the following hypothetical sequence of events. First, a reactor experiences core damage and a breach of containment. These events lead to severe contamination of the site by short-lived radio-isotopes that are released from the reactor. Intense radiation fields from this contamination, together with damage from a hydrogen explosion, preclude onsite mitigating actions by personnel. The pool then boils dry, or drains due to a related influence. That outcome initiates a pool fire that leads to another hydrogen explosion and a large release of longer-lived radio-isotopes (especially Cesium-137) from the pool. Those phenomena further preclude onsite mitigating actions by personnel, thus prolonging the reactor release and, potentially, initiating releases from other reactors and pools on the site.

This hypothetical sequence of events is not far-fetched. The Fukushima accident could have followed a similar course, given a few changes in site preconditions, in the initiating earthquake/tsunami, and/or in site management during the accident.[59] In that case, the accident would have involved a much larger release of radioactive material than was actually experienced.

The potential for malevolent action

The prospect of a linked sequence of reactor and pool events is especially ominous when one considers the possibility that a malevolent group of people would deliberately trigger the sequence. A technically knowledgeable and operationally capable group could focus and time an attack in such a manner that both a reactor release and a pool fire would be likely outcomes.[60] The group's investment of resources would be small by comparison with the damage inflicted on the attacked country. Thus, from a military-strategic perspective, a reactor and an adjacent pool filled with SNF at high density are, taken together, a large, pre-emplaced radiological weapon awaiting activation by an enemy.

Detailed discussion of attack scenarios is not appropriate in a document intended for general publication, as is this report. Instead, some general observations are provided here. Relevant literature is publicly available.[61]

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[59] Funabashi and Kitazawa, 2012.

[60] This report is intended for general publication. Thus, the optimal foci and timing of an attack are not discussed here. However, technically knowledgeable attackers could readily determine these factors without external advice.

[61] There is a body of publicly-available technical literature about attacks on commercial nuclear facilities. See, for example: Ramberg, 1984; Ramberg, 1980; Rotblat, 1981; Fetter, 1982; Fetter and Tsipis, 1980; Knox, 1983; Thompson, 2005; Thompson, 1996; Sdouz, 2007; Morris et al, 2006; Honnellio and Rydell, 2007; POST, 2004.

Table 6-7 shows some potential modes and instruments of attack on an NPP, and the present defenses at US plants. One sees that the defenses are limited in scope. In other countries, NPP defenses are typically no more robust than in the USA. Also, SNF systems that are not co-located with NPPs typically have less robust defenses than do NPPs.

One of the instruments of attack that could be used against a nuclear facility is a shaped charge. Table 6-8 summarizes the properties of this instrument. Table 6-9, Figure 6-6, and Figure 6-7 provide supporting information. Expertise in the design and use of shaped charges is widely available around the world. Arms manufacturers are actively developing tandem warheads that employ shaped charges. For example, in January 2008 Raytheon successfully tested the shaped-charge penetrating stage for its Tandem Warhead System.[62] The shaped charge penetrated 5.9 m into steel-reinforced concrete with a compressive strength of 870 bar.

Table 6-10 shows some characteristics of the containments of selected NPPs. That table gives particular attention to the materials, configurations, and thicknesses of the containment walls, which are indicators of a containment's ability to resist external attack. Clearly, these containments vary in their ability to resist attack, but each of them could be penetrated by instruments that are available to well-resourced attackers. Most spent-fuel pools are similarly vulnerable. For example, at the Pilgrim NPP in the USA, the outward-facing (reinforced concrete) walls of the spent-fuel pool have thicknesses ranging from 1.2 m to 1.9 m, and the pool floor (also reinforced concrete) has a thickness of 1.7 m.[63]

A successful attack on a spent-fuel pool would not necessarily involve physical damage to structures by the attackers. For example, attackers might be able to take control of a nuclear site, or a portion of the site where a pool is located. Then, they could siphon or pump water from the pool. Uncovering of the SNF would lead to production of hydrogen, which would explode in the upper part of the pool building, and to release of Cesium from fuel pellets. The hydrogen explosion would create a pathway for Cesium to travel directly from damaged fuel pellets to the atmosphere. Also, the explosion would hinder efforts by site personnel to regain control of the pool from the attackers.

Indirect effects of violence and disorder

The preceding discussion assumes a deliberate attack on a nuclear facility.[64] There may also be situations in which a nuclear facility could be indirectly threatened by war or other forms of political violence, and/or by societal disorder. Events of this type could,

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[62] Warwick, 2008; Raytheon, 2008.

[63] Thompson, 2006, Table 3-2. The inward-facing wall of the pool is integrated with the reactor shield wall.

[64] A facility might be attacked inadvertently or contrary to the wishes of high commanders, as a result of a communication failure or other factor. For the purposes of this report, such an attack can be regarded as deliberate.

for example: (i) interrupt the provision of electricity, water, and other services to a facility; and/or (ii) prevent personnel from performing their duties at the facility. Those influences could, in turn, initiate an event sequence that leads to an outcome such as a pool fire. The potential for such event sequences could be examined using the same analytic approach as would be used to examine accident-initiated event sequences.

Release of radioactive material from a dry cask

Dry casks are widely used for storing and transporting SNF discharged from LWRs. Figure 6-8 shows a type of cask (the Holtec HI-STORM 100 cask system) that is popular in the USA. The SNF is housed in a sealed, multi-purpose canister (MPC) made of stainless steel and filled with helium. During storage, the MPC is located inside a concrete-and-steel storage overpack as shown in Figure 6-8. During transportation, the MPC is located inside a transportation overpack.

The MPC-plus-overpack concept is one approach to the design of a dry cask. Another approach is the "monolithic" cask that consists of a single structure. Some monolithic casks are designed solely for storage use, some are designed solely for transportation use, and some are dual-purpose.

The nuclear industry and regulators around the world have given some attention to the radiological risk posed by a dry cask. With a few exceptions, the attention has focused on the potential for humans to be exposed by inhalation of radioactive gases and small particles.

Calculations summarized in Table 6-11 illustrate the potential for inhalation exposure. These calculations postulate an event that creates a small hole (equivalent diameter of 2.3 to 36 mm) in a multi-purpose canister, and also involves severe shaking of the canister. The canister would experience "blowdown" through the hole, driven by the pressure of helium in the canister plus gases released from SNF rods as a result of damage to their cladding. This event would be slightly more severe than a "design basis" accident. It could, for example, represent the accidental crash of a fighter aircraft on a HI-STORM 100 cask system.

One sees from Table 6-11 that the fractional release of Cesium-137 would be small. The Cesium-137 release would be somewhat greater if the cask were engulfed by a fire, during and/or after blowdown. If the event were an aircraft crash, a fire could arise from combustion of jet fuel.

There has been some regulatory consideration of scenarios involving an attack on a dry cask. Various analyses and experiments have been done to estimate the characteristics and radiological consequences of a radioactive release from a dry cask if a shaped-charge warhead were to penetrate the cask.[65] In a typical attack scenario considered in these

[65] Luna et al, 2001.

studies, some SNF rods would experience cladding rupture, and some fuel pellets would be pulverized, creating a radioactive "dust". The warhead would create a pressure pulse inside the cask, helping to drive the radioactive dust into the external atmosphere. The resulting inhalation dose to a nearby, downwind person could exceed the levels shown in Table 6-11.

These industry and regulatory studies have typically not considered the initiation of a zirconium-air reaction inside the cask. Thus, they do not predict a significant fractional release of Cesium-137. Clearly, these studies have not addressed a full spectrum of potential attacks. The rationale for this incomplete investigation is unclear. A few studies have gone against the general trend and considered the potential for cladding ignition during an attack. Unsurprisingly, they have identified a potential for a substantial fractional release of Cesium-137.[66]

Table 6-4 shows that a zircaloy-air reaction, once initiated, could generate a substantial release of Cesium-137 from SNF rods. Thus, the basic mechanisms of a "cask fire" – analogous to a pool fire – are in place. In order for a cask fire to occur in an actual situation, three conditions must be satisfied. First, a circulating pathway between SNF and the atmosphere must exist, so that air can reach the SNF, and combustion products and Cesium-137 can reach the atmosphere. Second, circulation of fluid through this pathway must be driven by natural convection. Third, the temperature of the cladding of a portion of the SNF in the cask must be raised to the ignition point, so that a self-sustaining reaction can begin.

These conditions are unlikely to be satisfied in an accident situation. They could be satisfied, however, during an attack by a knowledgeable, well-resourced group. A successful attack would probably involve the use of incendiary instruments, together with breaching of the cask in a manner that encourages a "chimney" effect, whereby air flows through the cask interior and feeds a zircaloy-air reaction.

Use of Cesium-137 to represent a radioactive release

SNF contains a variety of radioactive isotopes. In this report, attention is focused on a single isotope – the fission product Cesium-137. Other studies of SNF radiological risk have also focused on Cesium-137, for five reasons.[67] First, Cesium is a comparatively volatile material that is readily released from overheated nuclear fuel, as is evident from its release to atmosphere during the Fukushima accident. Second, when released to atmosphere, Cesium forms small particles that travel downwind and are deposited on the ground and other surfaces, from which they can be difficult to remove.[68] Third, the radioactive decay of Cesium-137 creates penetrating gamma radiation.[69] Fourth, Cesium-

[66] See, for example: Mannan, 2007.
[67] See, for example: Alvarez et al, 2003.
[68] Radioactive Cesium can also contaminate food and water supplies.
[69] Most (95%) of Cesium-137 decays are to an excited state of Barium-137 that decays with a half-life of about 150 seconds, yielding a gamma ray with an energy of 0.66 MeV.

137 has a 30-year half-life, so its radiological impact is of concern over a typical human lifetime and beyond. Fifth, because of the four preceding reasons, Cesium-137 accounts for most of the offsite radiation exposure that is attributable to the 1986 Chernobyl accident.[70]

Table 6-12 shows the inventories of Cesium-137 in the reactor cores of three types of NPP. Also shown are the core inventories of Iodine-131, which can represent the shorter-lived isotopes in an operating reactor. Table 6-13 shows amounts of Cesium-137 that are related to the Chernobyl and Fukushima accidents.

7. Options for Risk Reduction in the LWR Context

The present level of radiological risk posed by commercial nuclear facilities is not inevitable. Instead, this level of risk reflects choices made by the nuclear industry and accepted by regulatory organizations. The most significant choices relate to facility design, and the designs are strongly influenced by two factors. First, cost minimization is a major driver of the initial design decisions. Second, the nuclear industry is reluctant to revisit those decisions at a later time, even if evidence accumulates that the initial designs were deficient.

Table 7-1 describes some options to reduce the risk of a fire in a spent-fuel pool at a PWR or BWR plant. One can see that the option of re-equipping the pool with low-density, open-frame racks would be the most effective and reliable method of reducing risk. This would be a design option that requires no alteration in reactor operation. Excess spent fuel would be transferred to dry casks located at the plant site or elsewhere.

The cost of introducing this option would be comparatively modest.[71] The dominant component of the cost would be the expense of deploying additional dry casks. Moreover, the same expense could be incurred some years later even if risk reduction were not a concern. That would be the case if SNF remained at the site of an NPP after the plant is shut down, which is an increasingly likely outcome at many plants. Given that outcome, the SNF in the plant's pool would typically be transferred to dry storage soon after plant shut-down. Thus, the true incremental cost of transferring SNF to dry storage now, rather than after plant shut-down, would be the time value of the transfer expense.

NRC established a task force of staff members to study the Fukushima accident and make recommendations about incorporating lessons from the accident into NRC regulation. The task force reported in July 2011. Some of its recommendations were intended to reduce the risk of a pool fire. For example, the task force recommended that each NPP owner be required to install fixed pipes that could spray water into each reactor-adjacent

[70] DOE, 1987, page x.
[71] Alvarez et al, 2003.

pool, with a ground-level connection so that a portable pump could feed water to the pipes.[72] Table 7-1 mentions this option.

Dry casks pose a much lower radiological risk than do spent-fuel pools, especially if the pools are equipped with high-density racks. Nevertheless, dry casks could be attacked, and attackers could initiate a cask fire as discussed in Section 6, above. In recognition of the potential for attack, analysts have proposed that dry casks be given additional protection. For example, a researcher at Tokyo University has discussed options for underground placement of dry casks.[73]

Holtec has developed a design for a vertical-axis, dry-cask system in which, for most of its height, the cask would be below ground. The system is known as the HI-STORM 100U, and is a variant of the system shown in Figure 6-8. Holtec has described the robustness of the 100U system as follows:[74]

> "Release of radioactivity from the HI-STORM 100U by any mechanical means (crashing aircraft, missile, etc.) is virtually impossible. The only access path into the cavity for a missile is vertically downward, which is guarded by an arched, concrete-fortified steel lid weighing in excess of 10 tons. The lid design, at present configured to easily thwart a crashing aircraft, can be further buttressed to withstand more severe battlefield weapons, if required in the future for homeland security considerations. The lid is engineered to be conveniently replaceable by a later model, if the potency of threat is deemed to escalate to levels that are considered non-credible today."

Options for reducing the risk posed by nuclear facilities may be significant in terms of national strategy. That issue is addressed in summary form in Table 7-2.

8. Developing a Technical Understanding of SNF Radiological Risk and Risk-Reduction Options in the CANDU Context

Section 6 examines the present technical understanding of SNF radiological risk in the LWR context, and Section 7 discusses the present understanding of risk-reduction options in the LWR context. The same level of understanding on these matters, or a higher level, could be achieved in the CANDU context if CNSC and the Canadian nuclear industry sponsored an appropriate set of studies.

The Draft Screening Report has already identified the locations of potential events that could be major contributors to SNF radiological risk at a station such as DNGS. Those locations are the IFBs and the DSCs, where the SNF is stored. For each of these locations, studies should be conducted to identify and characterize a range of scenarios

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[72] NRC, 2011, Appendix A.
[73] Choi, 2010.
[74] Holtec, 2007. Also, see: Holtec, 2012.

that could involve a release of radioactive material.[75] Then, additional studies should be conducted to identify and characterize a set of risk-reduction options that respond to the release scenarios.

The studies should be conducted by independent institutions and investigators, should be openly published, and should be subjected to peer review and public review. (Caveats apply in regard to consideration of malevolent acts, as discussed below.) Investigators could draw upon related analyses in the LWR context (see Sections 6 and 7, above), and upon Canadian expertise in PRA and associated disciplines.[76]

The Draft Screening Report does not consider malevolent acts, and seeks to justify that omission with the argument that "security issues are being appropriately managed". (See the quote at the beginning of Section 3, above.) Thus, the Draft Screening Report assumes a probability of zero for an entire class of events that are technically feasible, and that could generate outcomes that serve the interests of potential attackers. That assumption is imprudent, and may lead to substantial under-estimation of SNF radiological risk.

Studies about radiological risk and risk reduction should generally be open and transparent. Clearly, however, these studies should not disclose detailed information that would assist potential attackers. Fortunately, experience shows that these interests can be balanced, so that general openness is maintained but certain details are withheld from publication. Many investigators of radiological risk are familiar with striking such a balance.

[75] Relevant characteristics of a release scenario would include the magnitude, composition, timing, and pathway of the release.
[76] For a recent example of Canadian work in the PRA field, see: OPG, 2012.

9. Conclusions and Recommendations

Conclusions

C1. A number of credible studies show that management and storage of SNF discharged from commercial LWRs can create substantial radiological risk, and that options for reducing the risk are available. Experience with the Fukushima accident has highlighted the relevance of these studies to the regulation of nuclear generating stations.

C2. The major contributor to SNF radiological risk at LWR stations is the potential for SNF to be uncovered (exposed to air) due to loss of water from a spent-fuel pool. In that event, the zircaloy cladding of the SNF could undergo an exothermic reaction with steam and/or air, leading to a substantial release of radioactive material to the atmosphere. Also, a zircaloy-steam reaction would generate hydrogen gas, which could explode violently when mixed with air.

C3. While SNF radiological risk has been extensively studied in an LWR context, comparable studies have not been done for SNF discharged from CANDU reactors such as those used at DNGS. Nevertheless, the CNSC's Fukushima Task Force has acknowledged that a substantial radiological risk arises from storage of SNF under water in IFBs at stations such as DNGS. The Task Force has acknowledged that uncovering of the SNF could cause the fuel to overheat, leading to a release of radioactive material and hydrogen gas.

C4. The Fukushima Task Force has implicitly recognized the lack of studies of SNF radiological risk at CANDU stations. The Task Force has called upon Canadian licensees to enhance their modeling capabilities in this area, and to conduct systematic analyses of beyond-design-basis accidents at IFBs. The Task Force has said that these analyses should include the estimation of releases, into the atmosphere and water, of radioactive material and hydrogen gas.

C5. The SENES Report shows that OPG is aware that uncovering of SNF is an event to be feared. Also, one could reasonably expect that OPG would be fully cognizant of the findings of the Fukushima Task Force.

C6. The Draft Screening Report cites the SENES Report and the Fukushima Task Force Report. Yet, the Draft Screening Report fails to acknowledge the risk associated with uncovering of SNF in an IFB. Instead, the Draft Screening Report focuses its discussion of SNF radiological risk on two comparatively minor events – drop of a DSC, and drop of an SNF storage module. In those cases, it seems that the Draft Screening Report has simply adopted the position of OPG.

C7. The Draft Screening Report explicitly excludes consideration of malevolent acts as contributors to radiological risk. That exclusion may lead to substantial under-estimation of risk.

C8. Technical understanding of SNF radiological risk and risk-reduction options in a CANDU context could be brought up to or beyond the present level of understanding of SNF radiological risk and risk-reduction options in an LWR context. Achieving that outcome would require the conduct of a number of independent, CANDU-focused studies that are openly published and subjected to peer review and public review.

C9. Completion of a credible EA process for refurbishment and continued operation of DNGS would require, among other ingredients, that OPG and CNSC demonstrate a thorough technical understanding of SNF radiological risk and risk-reduction options associated with DNGS. The studies outlined in Conclusion C8 could provide that understanding, if conducted appropriately.

Recommendations

R1. Completion of the EA process for refurbishment and continued operation of DNGS should be deferred until OPG and CNSC demonstrate a thorough technical understanding of SNF radiological risk and risk-reduction options associated with DNGS, and this understanding is clearly communicated to the public in relevant EA documents. (See Conclusions C8 and C9.)

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Table 5-1
SNF Inventory at Fukushima #1 Nuclear Site in Japan, as of March 2010

Storage Method	Storage Capacity (number of fuel assemblies)	Inventory (number of fuel assemblies)
Spent-fuel pools at six reactors	8,310	3,450
Common spent-fuel pool	6,840	6,291
Dry casks	408	408
Total	15,558	10,149

Notes:
(a) These data are from: Kumano, 2010.
(b) Six reactors were operational at the Fukushima #1 site prior to the accident of March 2011. These reactors discharged about 700 spent fuel assemblies each year. The site's total spent-fuel storage capacity of 15,558 assemblies was approximately 450% of the total core capacity of the six reactors.
(c) The six reactors entered commercial service between March 1971 (Unit 1) and October 1979 (Unit 6).

Table 6-1
Number of Commercial Nuclear Reactors Worldwide, by Type

Type Code	Description	Number of Reactors as of 31 December 2010	
		Operational	**In Construction**
PWR	Pressurized Light-Water-Moderated and Cooled Reactor	269	56
BWR	Boiling Light-Water-Moderated and Cooled Reactor	92	4
PHWR	Pressurized Heavy-Water-Moderated and Cooled Reactor	46	4
GCR	Gas-Cooled, Graphite-Moderated Reactor	18	
LWGR	Light-Water-Cooled, Graphite-Moderated Reactor	15	1
FBR	Fast Breeder Reactor	1	2
TOTAL		441	67

Notes:
(a) This table is adapted from: IAEA, 2011, Table 23.
(b) PHWR reactors are in Argentina, Canada, China, India, South Korea, Pakistan, and Romania. The PHWR reactors built by the Canadian nuclear industry are known as CANDU reactors.
(c) All GCR reactors are in the UK.
(d) LWGR reactors were constructed only in the former USSR, where they were known as RBMK reactors.
(e) The fast breeder reactors listed in this table are cooled by sodium.

Table 6-2
Inventory and Characteristics of Spent Fuel Discharged from US Commercial Reactors through 2010

Reactor Type	Total Number of Spent Fuel Assemblies	Total Initial Uranium (Mg U)	Average Enrichment when Fresh (% U-235)	Average Burnup (GWt-days per Mg U)	Average Age After Discharge (yr)
PWR	97,400	42,300	3.74	39.6	14.9
BWR	128,600	23,000	3.12	33.3	15.4
Total	226,000	65,200	N/A	N/A	N/A

Notes:
(a) Data are from: Carter et al, 2011, Sections 2.1 and 2.2.
(b) Almost all fuel currently being discharged from US reactors has a burnup exceeding 45 GWt-days per Mg U, and some fuel approaches 60 GWt-days per Mg U. Burnup is currently limited in the USA by the reactor licensing basis of 62.5 GWt-days per Mg U, and by the 5% U-235 licensing basis for enrichment and fuel fabrication plants.

Table 6-3
Selected Characteristics of Representative PWR and BWR Reactors

Characteristic	Value	
	PWR	**BWR**
Rated thermal power	3,411 MWt	3,579 MWt
Rated electrical output	1,100 MWe	1,220 MWe
Core (or fuel rod) active length	3.7 m	3.8 m
Number of fuel assemblies	193 (15x15 assembly array)	748 (8x8 assembly array)
Av. thermal power per assembly	17.7 MWt	4.78 MWt
Total number of fuel rods	39,372	46,376
Fuel cladding material	Zircaloy-4	Zircaloy-2
Cladding diameter (OD)	1.07 cm	1.23 cm
Cladding thickness	0.06 cm	0.08 cm
Fuel material	UO_2	UO_2
Pellet diameter	0.9 cm	1.04 cm
Pellet height	1.5 cm	1.04 cm
Total mass of fuel (UO_2)	98.4 Mg	155 Mg
Total mass of fuel (U)	86.7 Mg	137 Mg
Av. mass of fuel (U) per assembly	449 kg	183 kg
Core diameter	3.4 m	4.9 m
Av. area density of fuel mass (U) over core footprint	9.55 Mg per m^2	7.27 Mg per m^2
Av. center-center spacing of fuel assemblies	21.7 cm	15.9 cm
Design fuel burnup	32 GWt-days per Mg U	28.4 GWt-days per Mg U
Fresh fuel assay	3.2% U-235	2.8% U-235
Spent fuel assay (design)	0.9% U-235, 0.6% Pu-239 & 241	0.8% U-235, 0.6% Pu-239 & 241

Notes:
(a) Data are from: Nero, 1979, Tables 5-1 and 6-1.
(b) The PWR is a Westinghouse plant, and the BWR is a General Electric plant.
(c) The values shown are correct only for the specific, representative reactors. Other reactors have somewhat different values.
(d) Typical fuel burnup has increased substantially since these data were compiled. Almost all fuel currently being discharged from US reactors has a burnup exceeding 45 GWt-days per Mg U, and some fuel approaches 60 GWt-days per Mg U. (See: Carter et al, 2011, Section 2.2.)

Table 6-4
Illustrative Calculation of Heat-Up of a Fuel Rod in a PWR Fuel Assembly Due to Combustion in Air

Calculation Step	Properties and Behavior of Rod Components	
	Zircaloy Cladding	**UO_2 Pellets**
Solid volume, per m length	1.90E-05 m^3 (OD = 1.07 cm; thickness = 0.06 cm)	6.36E-05 m^3 (OD = 0.9 cm)
Mass, per m length	0.124 kg (@ 6.55 Mg per m^3)	0.700 kg (@ 11.0 Mg per m^3)
Heat output from complete combustion of material in air, per m length	1.48 MJ (@ 2,850 cal per g Zr, where 1 cal = 4.184 J)	Neglected (Pellet combustion would be incomplete, and a minor contributor to heat output)
Heat input if material receives 50% of heat output from adjacent combustion, and if heat loss from material is neglected	Neglected (Cladding and its combustion products have comparatively low thermal mass)	1.48x0.5 = 0.74 MJ (i.e., 1.06 MJ per kg UO_2)
Equilibrium temperature rise due to heat input	Neglected (Cladding and its combustion products have comparatively low thermal mass)	approx. 2,700 deg. C (The enthalpy rise if UO_2 temp. rises from 300 K to 3,000 K = 1.05 MJ per kg UO_2)

Notes:
(a) This table is adapted from Table 6-2 of: Thompson, 2009.
(b) Melting point of UO_2 is 2,850 deg. C (3,123 K), and boiling point of elemental Cesium is 685 deg. C.
(c) Boiling point of CsI is 1,280 deg. C, and boiling point of CsOH is 990 deg. C. (See: Silberberg et al, 1986, Table 3.2.)
(d) Average enthalpy rise per deg. C as UO_2 temperature rises from 300 K to 3,000 K: $(1.05x10^3)/2,700$ = 0.39 kJ per kg UO_2 per deg. C. (See also: Popov et al, 2000.)
(e) An analogous table could be prepared for combustion of the zircaloy cladding in steam. In that case the heat of reaction would be 1,560 cal per g Zr = 6.53 MJ per kg Zr. (See: Baker and Liimatainen, 1973, Table 3-1.) As shown above, the heat of reaction in air would be 2,850 cal per g Zr = 11.9 MJ per kg Zr. Both values are approximate.
(f) Oxidized Zr will form a liquefied two-phase mixture with UO_2 at about 1,900 deg. C. (See: Silberberg et al, 1986, Table 3.2.)

Table 6-5
Illustrative Calculation of Adiabatic Heat-Up of a Fuel Rod in a PWR Spent Fuel Assembly

Calculation Step	Properties and Behavior of Rod Components	
	Zircaloy Cladding	**UO_2 Pellets**
Solid volume, per m length	1.90E-05 m^3 (OD = 1.07 cm; thickness = 0.06 cm)	6.36E-05 m^3 (OD = 0.9 cm)
Mass, per m length	0.124 kg (@ 6.55 Mg per m^3)	0.700 kg (@ 11.0 Mg per m^3)
Specific heat (approx.)	300 J/kg/K	300 J/kg/K
Heat output from radioactive decay (assembly)	R = decay heat in kW per Mg U	
Heat output from radioactive decay (rod)	0 (W per kg Zr)	(238/270)R = (0.88)R (W per kg UO_2)
Rate of temperature rise from decay heat, if pellets and cladding are a tightly coupled adiabatic system	(0.88)R(0.7/(0.7 + 0.124))/300 = (2.5E-03)R (K per second) or (9.0)R (K per hr)	

Notes:
(a) Data are from: Thompson, 2009, Table 6-2; Popov et al, 2000; CRC, 1986.
(b) As an example, consider PWR fuel with a burnup of 50 GWt-days per Mg U, aged 100 days after reactor shutdown. In this case, R = 28 kW per Mg U. Thus, the adiabatic rate of temperature rise would be 9x28 = 252 K per hr (deg. C per hr).

Table 6-6
Radioactive Decay Heat in Spent Fuel at Selected Times After Reactor Shutdown, with a Fuel Burnup of 50 GWt-days per Mg HM

Type of Fuel	Decay Heat (kW per Mg HM) at Selected Times After Reactor Shutdown				
	1 day	**10 days**	**100 days**	**1,000 days**	**10,000 days**
PWR-U	182	78	28	5.1	1.3
PWR-MOX	187	93	41	7.7	2.9
BWR-U	180	77	27	4.9	1.2
BWR-MOX	180	91	40	7.3	2.7

Notes:
(a) Data are from: Ade and Gauld, 2011. These data were estimated using the SCALE code system. Decay heat was estimated for burnups of 35, 40, 45 and 50 GWt-days per Mg HM, and for times from 0.01 to 19,300 days after reactor shutdown.
(b) PWR-U and BWR-U fuel pellets contain only uranium oxide when fresh. PWR-MOX and BWR-MOX fuel pellets contain a mixture of uranium oxide and plutonium oxide when fresh. ("MOX" refers to mixed-oxide fuel.) The decay heats shown for MOX fuel are for fuel made from reactor-grade plutonium.
(c) "HM" refers to heavy metal (uranium and plutonium) in fresh fuel.

Table 6-7
Some Potential Modes and Instruments of Attack on a Nuclear Power Plant

Attack Mode/Instrument	Characteristics	Present Defenses at US Plants
Commando-style attack	• Could involve heavy weapons and sophisticated tactics • Successful attack would require substantial planning and resources	Alarms, fences and lightly-armed guards, with offsite backup
Land-vehicle bomb	• Readily obtainable • Highly destructive if detonated at target	Vehicle barriers at entry points to Protected Area
Small guided missile (anti-tank, etc.)	• Readily obtainable • Highly destructive at point of impact	None if missile launched from offsite
Commercial aircraft	• More difficult to obtain than pre-9/11 • Can destroy larger, softer targets	None
Explosive-laden smaller aircraft	• Readily obtainable • Can destroy smaller, harder targets	None
10-kilotonne nuclear weapon	• Difficult to obtain • Assured destruction if detonated at target	None

Notes:
(a) This table is adapted from: Thompson, 2007, Table 7-4. Further citations are provided in that table and its supporting narrative. For additional, supporting information of more recent vintage, see: Ahearne et al, 2012, Chapter 5.
(b) Defenses at nuclear power plants around the world are typically no more robust than at US plants.

Table 6-8
The Shaped Charge as a Potential Instrument of Attack

Category of Information	Selected Information in Category
General information	• Shaped charges have many civilian and military applications, and have been used for decades • Applications include human-carried demolition charges or warheads for anti-tank missiles • Construction and use does not require assistance from a government or access to classified information
Use in World War II	• The German MISTEL, designed to be carried in the nose of an un-manned bomber aircraft, is the largest known shaped charge • Japan used a smaller version of this device, the SAKURA bomb, for kamikaze attacks against US warships
A large, contemporary device	• Developed by a US government laboratory for mounting in the nose of a cruise missile • Described in detail in an unclassified, published report (citation is voluntarily withheld here) • Purpose is to penetrate large thicknesses of rock or concrete as the first stage of a “tandem” warhead • Configuration is a cylinder with a diameter of 71 cm and a length of 72 cm • When tested in November 2002, created a hole of 25 cm diameter in tuff rock to a depth of 5.9 m • Device has a mass of 410 kg; would be within the payload capacity of many general-aviation aircraft
A potential delivery vehicle	• A Beechcraft King Air 90 general-aviation aircraft can carry a payload of up to 990 kg at a speed of up to 460 km/hr • The price of a used King Air 90 in the USA can be as low as $0.4 million

Source:
This table is adapted from Table 7-6 of: Thompson, 2009.

Table 6-9
Performance of US Army Shaped Charges, M3 and M2A3

Target Material	**Indicator**	**Value for Stated Type of Shaped Charge**	
		Type: M3	**Type: M2A3**
Reinforced concrete	Maximum wall thickness that can be perforated	150 cm	90 cm
	Depth of penetration in thick walls	150 cm	75 cm
	Diameter of hole	• 13 cm at entrance • 5 cm minimum	• 9 cm at entrance • 5 cm minimum
	Depth of hole with second charge placed over first hole	210 cm	110 cm
Armor plate	Perforation	At least 50 cm	30 cm
	Average diameter of hole	6 cm	4 cm

Notes:
(a) This table is adapted from Table 7-7 of: Thompson, 2009. The data are from US Army Field Manual FM 5-25, published May 1967.
(b) The M2A3 charge has a mass of 5 kg, a maximum diameter of 18 cm, and a total length of 38 cm including the standoff ring.
(c) The M3 charge has a mass of 14 kg, a maximum diameter of 23 cm, a charge length of 39 cm, and a standoff pedestal 38 cm long.

Table 6-10
Some Characteristics of Containments of Selected NPPs in the Generation II and Generation III Categories

Plant Name or Type	Containment Characteristics
Indian Point Units 2 and 3	• The containment is a reinforced concrete vertical cylinder topped by a hemispherical dome made of the same material. The cylinder walls are 1.4 m thick with a 1.0 cm thick steel liner, and the dome is 1.1 m thick with a 1.3 cm thick steel liner. • There is no shield building.
ACR-1000	• The containment is a vertical cylinder with a domed top, made of pre-stressed (cable-tensioned) concrete and equipped with a steel liner. The wall thickness of the cylinder is 1.8 m. According to Bruce Power: "The containment structure is designed for tornado conditions, including tornado missiles, and aircraft crashes." • There is no shield building.
US-EPR	• The containment is a vertical cylinder with a domed top, made of pre-stressed (cable-tensioned) concrete and equipped with a steel liner. The wall of the cylinder is 1.3 m thick, and the dome is 1.0 m thick. • Surrounding the containment is a shield building (with a configuration similar to that of the containment) made of reinforced concrete. This building's wall and dome are each 1.8 m thick.
AP1000	• The containment is a vertical, steel cylinder with a wall thickness of 4.4 cm. • Surrounding the containment is a cylindrical shield building made of reinforced concrete, with a wall thickness of 0.9 m.

Notes:
(a) Data are from: Thompson, 2007, Section 7.5; Thompson, 2008, Section 5.
(b) Indian Point Units 2 and 3 are Generation II PWR plants operating in New York State, USA, and are located on the Hudson River upstream of New York City.
(c) The other three plants are generic, proposed, Generation III plants. The ACR-1000 is an “advanced CANDU” plant. The US-EPR and AP1000 are PWR plants. Data for specific plants that are built may differ from the values shown here.
(d) These characteristics provide an indication of each containment’s ability to resist external attack. Other characteristics would also be relevant to a full-scope assessment of the radiological risk posed by each plant.

Table 6-11
Estimated Atmospheric Release of Radioactive Material and Downwind Inhalation Dose for Blowdown of the Multi-Purpose Canister in a Spent-Fuel-Storage Module

Indicator		**Release Characteristics for Selected Values of MPC Leakage Area**		
		4 sq. mm (equiv. dia. = 2.3 mm)	**100 sq. mm (equiv. dia. = 11 mm)**	**1,000 sq. mm (equiv. dia. = 36 mm)**
Fuel Release Fraction	Gases	3.0E-01	3.0E-01	3.0E-01
	Crud	1.0E+00	1.0E+00	1.0E+00
	Volatiles	2.0E-04	2.0E-04	2.0E-04
	Fines	3.0E-05	3.0E-05	3.0E-05
MPC Blowdown Fraction		9.0E-01	9.0E-01	9.0E-01
MPC Escape Fraction	Gases	1.0E+00	1.0E+00	1.0E+00
	Crud	7.0E-02	5.0E-01	8.0E-01
	Volatiles	4.0E-03	3.0E-01	6.0E-01
	Fines	7.0E-02	5.0E-01	8.0E-01
Inhalation Dose (CEDE) to a Person at a Distance of 900 m		0.063 Sv	0.48 Sv	0.79 Sv

Notes:
(a) This table is adapted from Table 6-1 of: Thompson, 2009.
(b) The assumed multi-purpose canister (MPC) contains 24 PWR spent fuel assemblies with a burnup of 40 MWt-days per kgU, aged 10 years after discharge.
(c) The following radioisotopes were considered: Gases (H-3, I-129, Kr-85); Crud (Co-60); Volatiles (Sr-90, Ru-106, Cs-134, Cs-137); Fines (Y-90 and 22 other isotopes).
(d) The calculation followed NRC guidance for calculating radiation dose from a design-basis accident, except that the MPC Escape Fraction was drawn from a study by Sandia National Laboratories that used the MELCOR code package.
(e) CEDE = committed effective dose equivalent. In this scenario, CEDE makes up most of the total dose (TEDE) and is a sufficient approximation to it.
(f) The overall fractional release of a radioisotope from fuel to atmosphere is the product of Fuel Release Fraction, MPC Blowdown Fraction, and MPC Escape Fraction.
(g) For a leakage area of 4 square mm, the overall fractional release is: Gases (0.27); Crud (0.063); Volatiles (7.2E-07); Fines (1.9E-06). Fines account for 95 percent of CEDE, and Crud accounts for 4 percent.

Table 6-12
Estimated Core Inventories of Iodine-131 and Cesium-137 at Three Types of NPP in the Generation III Category

Plant Type	Core Inventory (PBq)		Normalized Core Inventory (PBq per GWe)	
	Iodine-131	Cesium-137	Iodine-131	Cesium-137
ACR-1000	3,640	172	3,640	172
US-EPR	5,140	914	3,210	571
AP1000	3,560	418	3,560	418

Notes:
(a) This table is adapted from Table 3-2 of: Thompson, 2008. Core inventories are estimates by Bruce Power, which operates NPPs in Ontario, Canada. It can be presumed that the core inventories were estimated for full-power, steady-state operation.
(b) According to Bruce Power, the nominal electricity-generating capacities of the three plant types are:

- ACR-1000: 1,000 MWe
- US-EPR: 1,600 MWe
- AP1000: 1,000 MWe

(c) These plants are generic, proposed, Generation III plants. The ACR-1000 is an "advanced CANDU" plant. The US-EPR and AP1000 are PWR plants. Data for specific plants that are built may differ from the values shown here.
(d) The half-lives of Iodine-131 and Cesium-137 are 8 days and 30 years, respectively.

Table 6-13
Amounts of Cesium-137 Related to the Chernobyl and Fukushima Accidents

Category	Amount of Cesium-137 (PBq)
Chernobyl release to atmosphere (1986)	85
Fukushima release to atmosphere (2011)	36
Deposition on Japan due to the Fukushima atmospheric release	6.4
Pre-release inventory in reactor cores of Fukushima #1, Units 1-3 (total for 3 cores)	940
Pre-release inventory in spent-fuel pools of Fukushima #1, Units 1-4 (total for 4 pools)	2,200

Notes:
(a) This table shows estimated amounts of Cesium-137 from: Stohl et al, 2011. The estimates for release from Fukushima #1 and deposition on Japan may change as new information becomes available.
(b) Stohl et al, 2011, provide the following data and estimates for Fukushima #1, Units 1-4, just prior to the March 2011 accident:

Indicator	Unit 1	Unit 2	Unit 3	Unit 4
Number of fuel assemblies in reactor core	400	548	548	0
Number of fuel assemblies in reactor spent-fuel pool	392	615	566	1,535
Cesium-137 inventory in reactor core (Bq)	2.40E+17	3.49E+17	3.49E+17	0
Cesium-137 inventory in reactor pool (Bq)	2.21E+17	4.49E+17	3.96E+17	1.11E+18

(The core capacity of Unit 4 was 548 assemblies. The core of Unit 3 contained some MOX fuel assemblies at the time of the accident.)

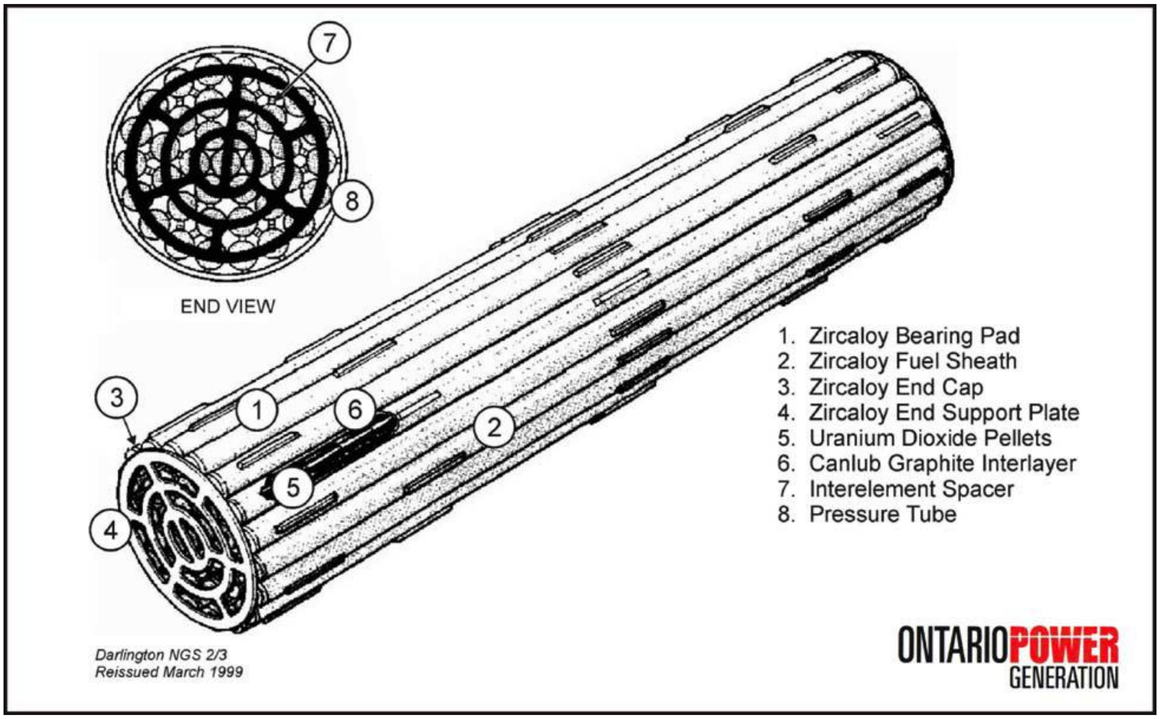
Table 7-1
Selected Options to Reduce the Risk of a Pool Fire at a PWR or BWR Plant

Option	Passive or Active?	Does Option Address Fire Scenarios Arising From: Attack?	Does Option Address Fire Scenarios Arising From: Other Events?	Comments
Re-equip pool with low-density, open-frame racks	Passive	Yes	Yes	• Would substantially reduce pool inventory of radioactive material • Would prevent auto-ignition of fuel in almost all cases
Install emergency water sprays above pool	Active	Yes	Yes	• Spray system must be highly robust • Spraying water on overheated fuel could feed Zr-steam reaction
Mix hotter (younger) and colder (older) fuel in pool	Passive	Yes	Yes	• Could delay or prevent auto-ignition in some cases • Would be ineffective if debris or residual water blocks air flow • Could promote fire propagation to older fuel
Minimize movement of spent-fuel cask over pool	Active	No (Most cases)	Yes	• Could conflict with adoption of low-density, open-frame racks
Deploy air-defense system (e.g., Sentinel and Phalanx) at site	Active	Yes	No	• Implementation would require presence of military personnel at site
Develop enhanced onsite capability for damage control	Active	Yes	Yes	• Would require new equipment, staff and training • Personnel must function in extreme environments

Table 7-2
Selected Approaches to Protecting a Country's Critical Infrastructure From Attack by Sub-National Groups, and Some Strengths and Weaknesses of these Approaches

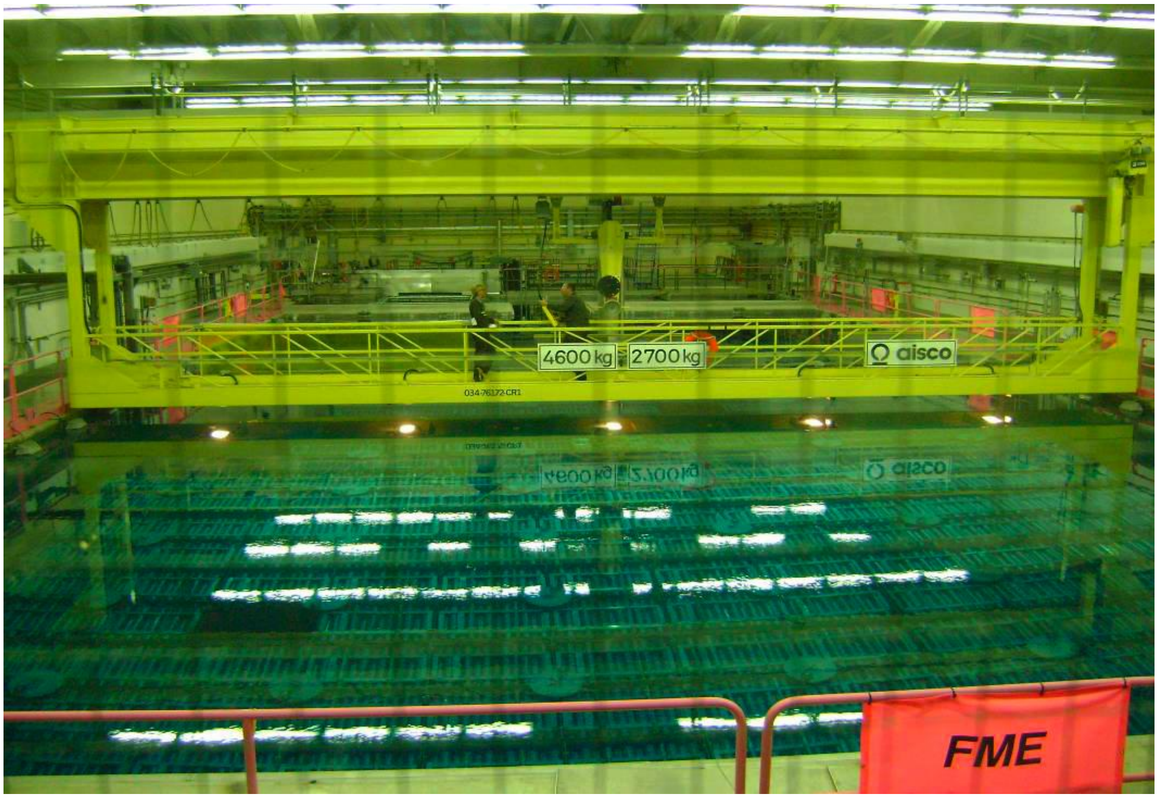
Approach	Strengths	Weaknesses
Offensive military operations internationally	• Could deter or prevent governments from supporting sub-national groups hostile to the Country	• Could promote growth of sub-national groups hostile to the Country, and build sympathy for these groups in foreign populations • Could be costly in terms of lives, money, etc.
International police cooperation within a legal framework	• Could identify and intercept potential attackers	• Implementation could be slow and/or incomplete • Requires ongoing international cooperation
Surveillance and control of the domestic population	• Could identify and intercept potential attackers	• Could destroy civil liberties, leading to political, social and economic decline
Secrecy about design and operation of infrastructure facilities	• Could prevent attackers from identifying points of vulnerability	• Could suppress a true understanding of risk • Could contribute to political, social and economic decline
Active defense of infrastructure facilities (by use of guards, guns, gates, etc.)	• Could stop attackers before they reach the target	• Requires ongoing expenditure & vigilance • May require military involvement
Robust and inherently-safe design of infrastructure facilities	• Could allow target to survive attack without damage, thereby enhancing protective deterrence • Could substitute for other protective approaches, avoiding their costs and adverse impacts • Could reduce risks from accidents & natural hazards	• Could involve higher capital costs

Figure 2-1
DNGS Fuel Bundle



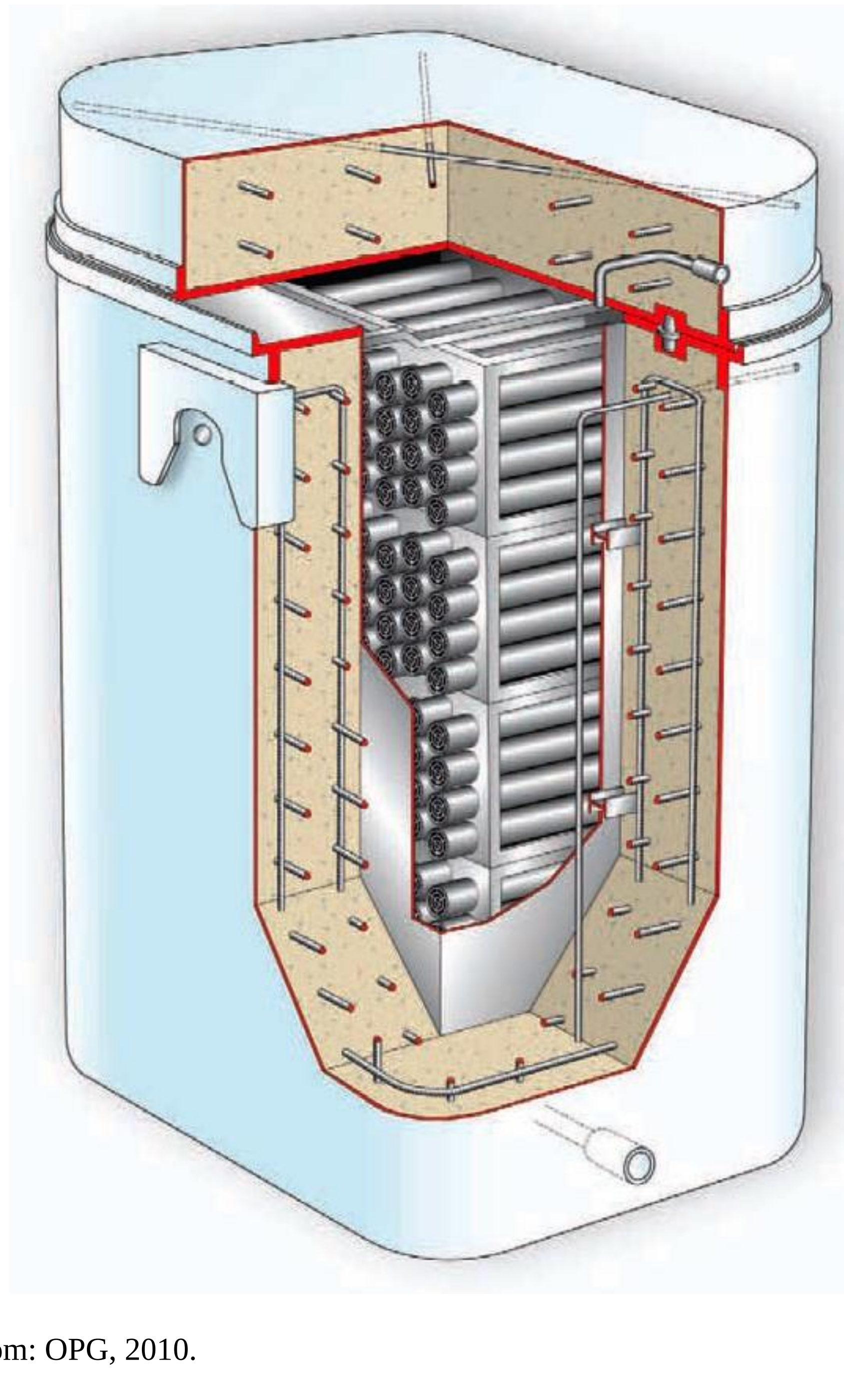
Source:
Adapted from Figure 2.5-3 of: OPG, 2011.

Figure 2-2
Typical Irradiated Fuel Bay at a CANDU Station



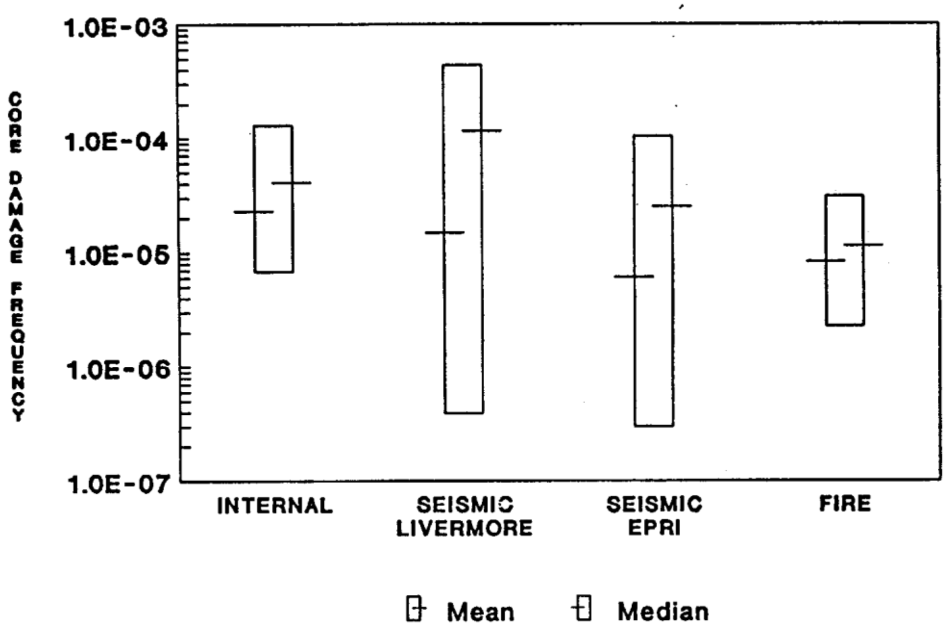
Source:
Adapted from Figure A.9 of: CNSC-FTF, 2011.

Figure 2-3
Dry Storage Container for DNGS Spent Fuel



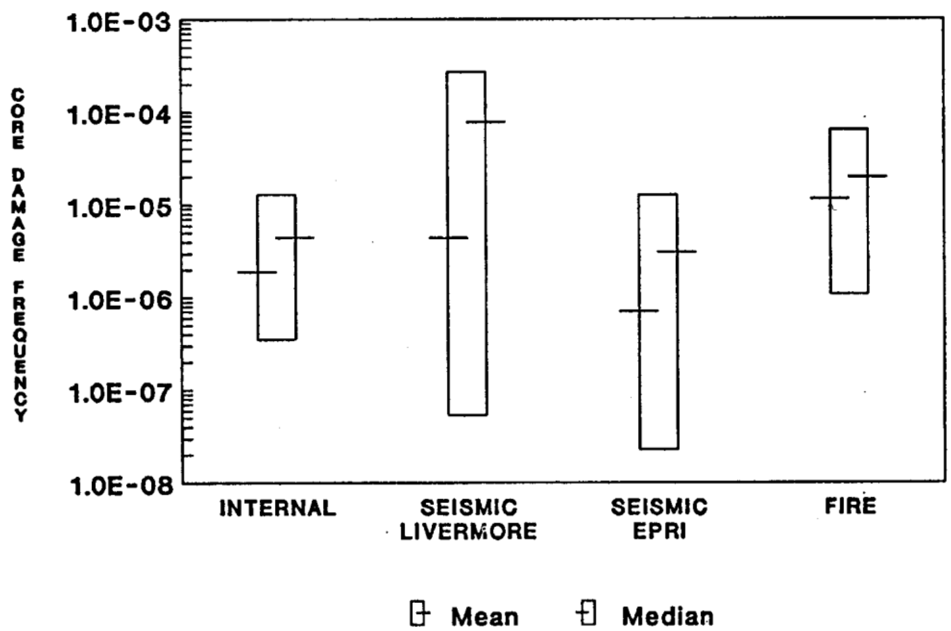
Source:
Adapted from: OPG, 2010.

Figure 4-1
Core Damage Frequency for Accidents at a Surry PWR Nuclear Power Plant, as Estimated in the NRC Study NUREG-1150



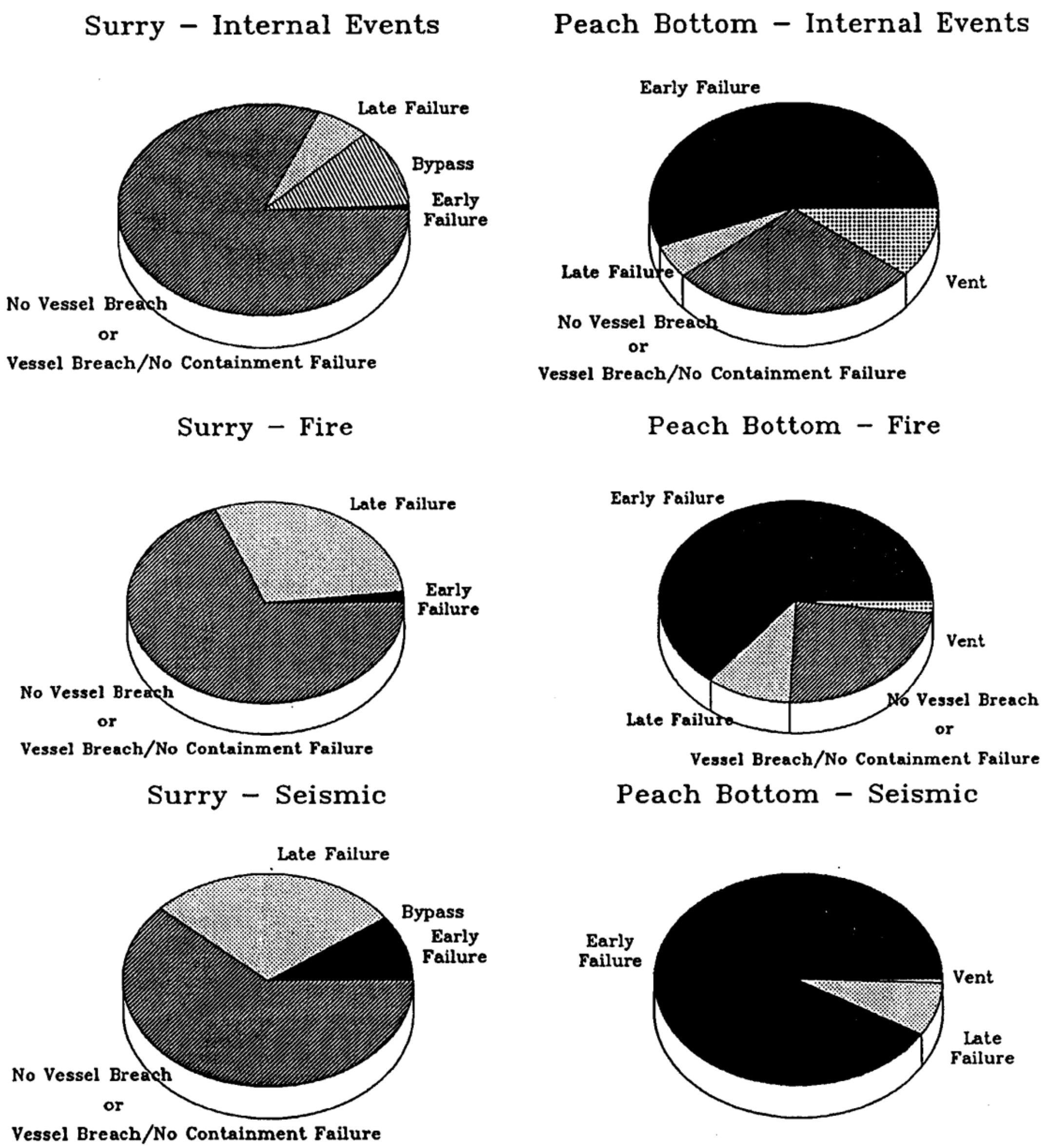
Notes:
(a) This figure is adapted from Figure 8.7 of: NRC, 1990.
(b) The bars range from the 5th percentile (lower bound) to the 95th percentile (upper bound) of the estimated core-damage frequency (CDF). CDF values shown are per reactor-year (RY).
(c) Two estimates are shown for the CDF from earthquakes (seismic effects). One estimate derives from seismic predictions done at Lawrence Livermore National Laboratory (Livermore), the other from predictions done at the Electric Power Research Institute (EPRI).
(d) CDFs are not estimated for external initiating events other than earthquakes and fires.
(e) Malevolent acts and gross errors in design, construction, or operation are not considered.

Figure 4-2
Core Damage Frequency for Accidents at a Peach Bottom BWR Nuclear Power Plant, as Estimated in the NRC Study NUREG-1150



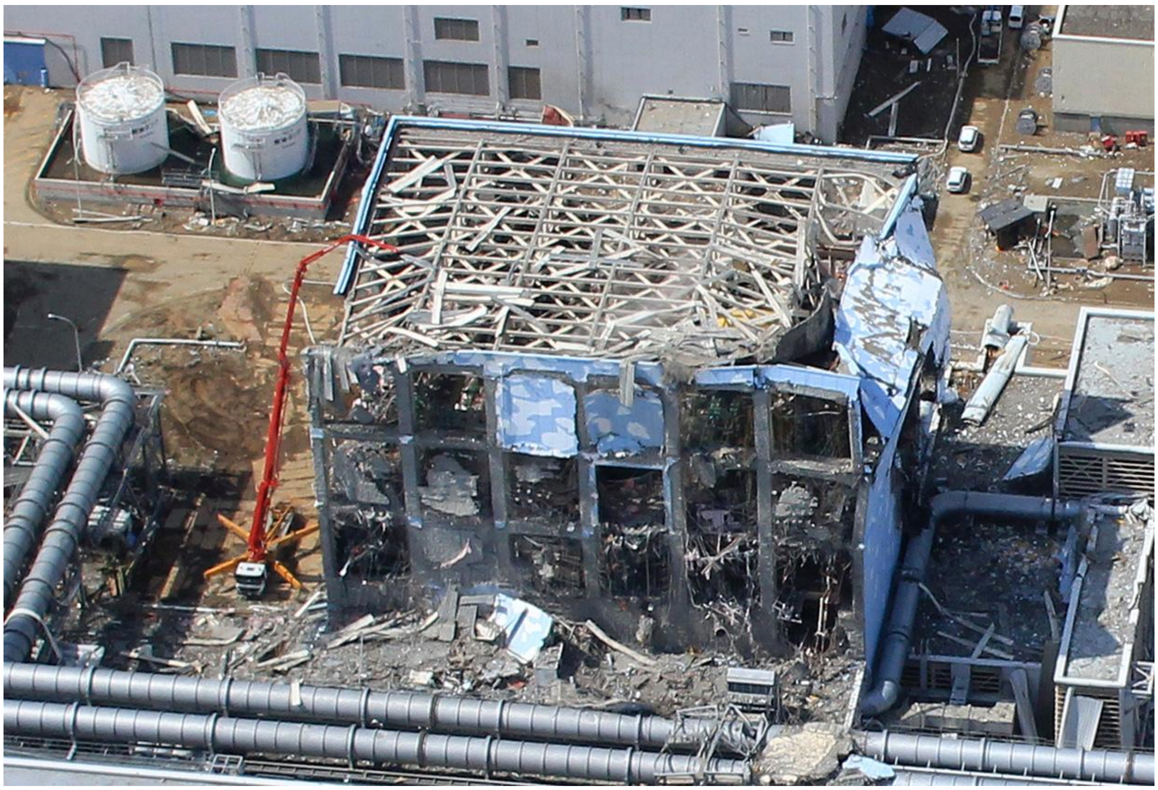
Notes:
(a) This figure is adapted from Figure 8.8 of: NRC, 1990.
(b) The bars range from the 5th percentile (lower bound) to the 95th percentile (upper bound) of the estimated core-damage frequency (CDF). CDF values shown are per reactor-year (RY).
(c) Two estimates are shown for the CDF from earthquakes (seismic effects). One estimate derives from seismic predictions done at Lawrence Livermore National Laboratory (Livermore), the other from predictions done at the Electric Power Research Institute (EPRI).
(d) CDFs are not estimated for external initiating events other than earthquakes and fires.
(e) Malevolent acts and gross errors in design, construction, or operation are not considered.

Figure 4-3
Conditional Probability of Containment Failure Following a Core-Damage Accident at a Surry PWR or Peach Bottom BWR Nuclear Power Plant, as Estimated in the NRC Study NUREG-1150



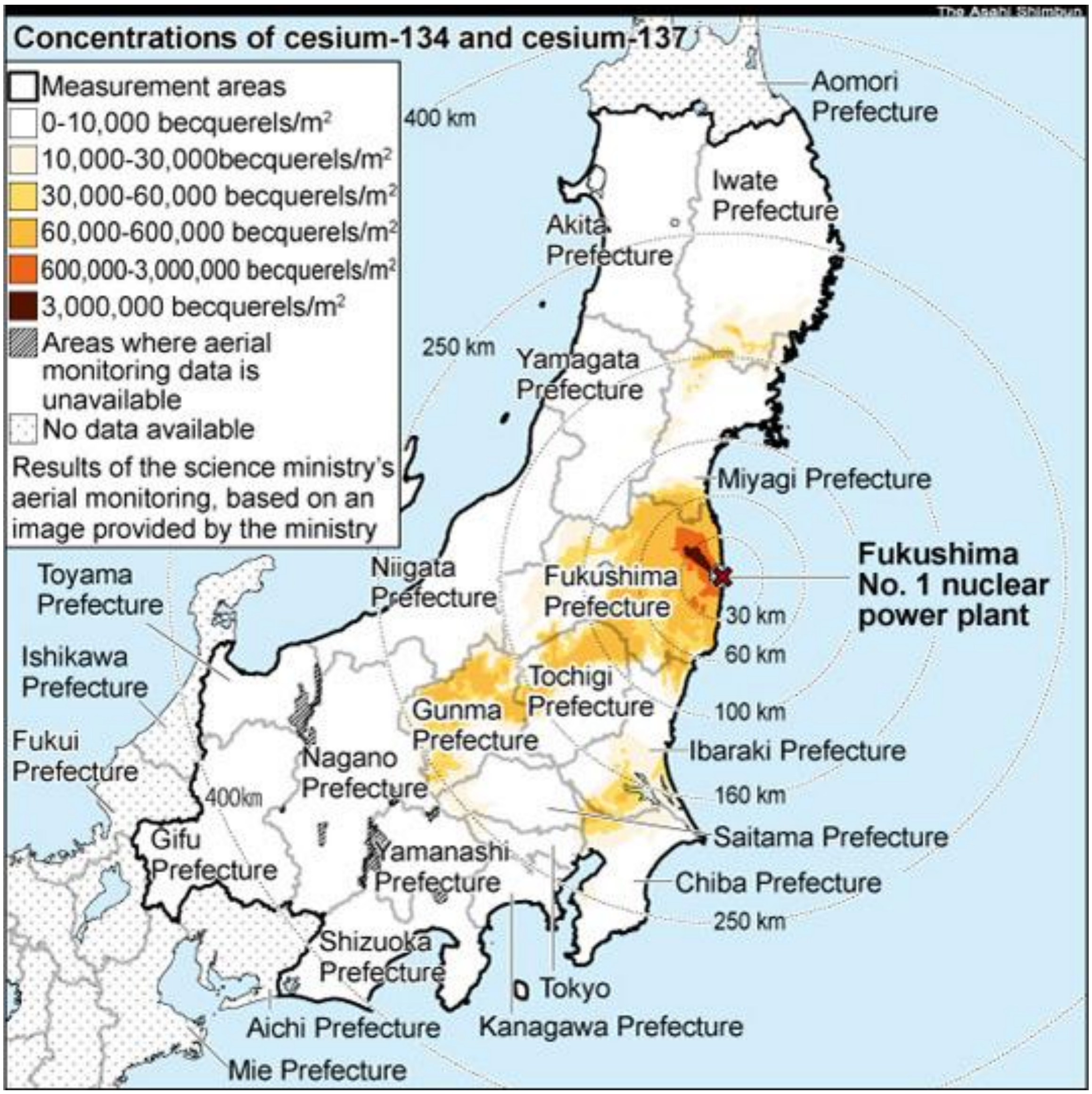
Source:
Adapted from Figure 9.5 of: NRC, 1990.

Figure 5-1
Unit 4 at the Fukushima #1 Site During the 2011 Accident



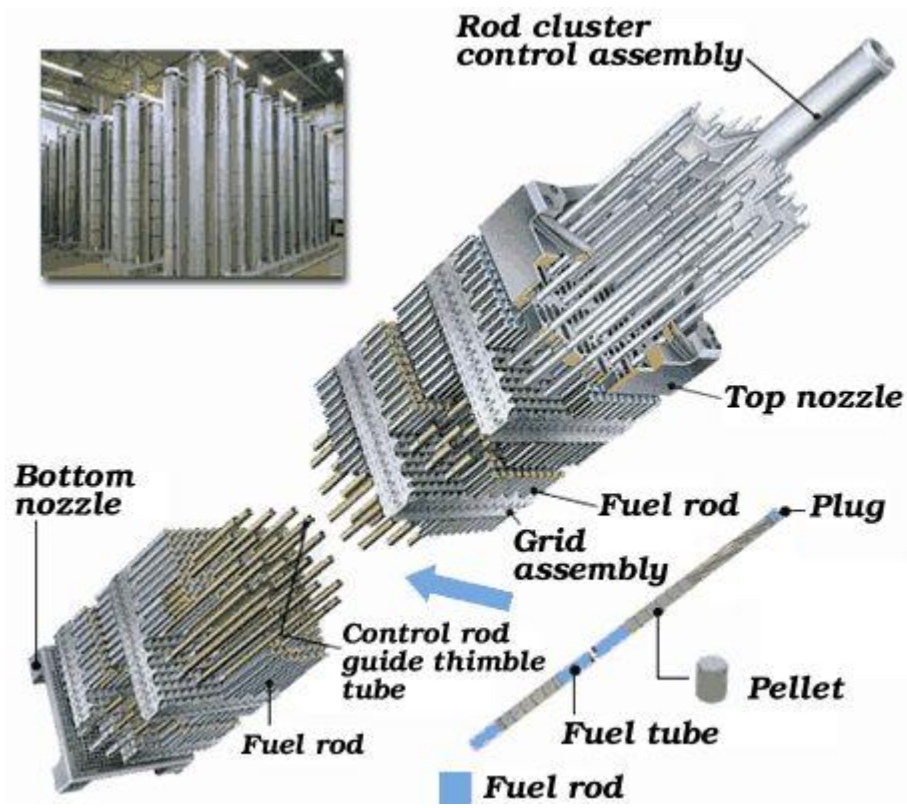
Source:
Accessed on 20 February 2012 from Ria Novosti at:
http://en.rian.ru/analysis/20110426/163701909.html; image by Reuters Air Photo Service.

Figure 5-2
Contamination of Land in Japan by Radioactive Cesium Released to Atmosphere During the Fukushima Accident of 2011



Source:
Asahi Shimbun, 2011.

Figure 6-1
Schematic View of a PWR Fuel Assembly (Mitsubishi Nuclear Fuel)

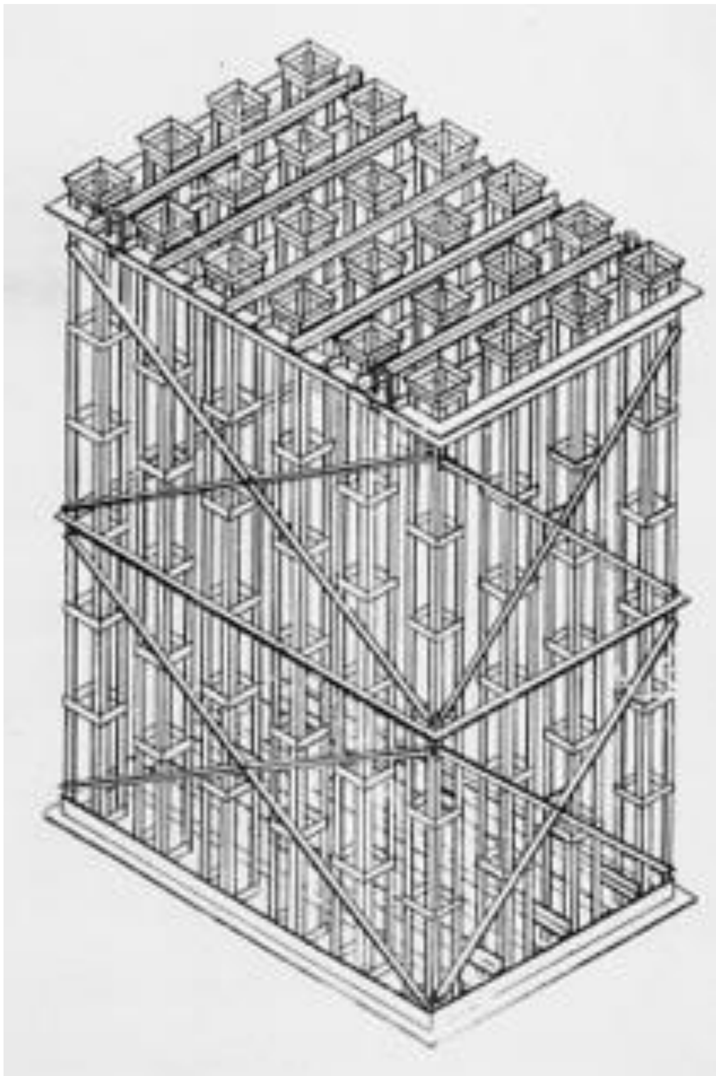


Source:
Accessed on 22 February 2012 from: http://www.world-nuclear.org/info/nuclear_fuel_fabrication-inf127.html

Figure 6-2
Schematic View of BWR Fuel Assemblies (General Electric)

Source:
Accessed on 22 February 2012 from: http://www.world-nuclear.org/info/nuclear_fuel_fabrication-inf127.html

Figure 6-3
Typical Low-Density, Open-Frame Rack for Pool Storage of PWR Spent Fuel

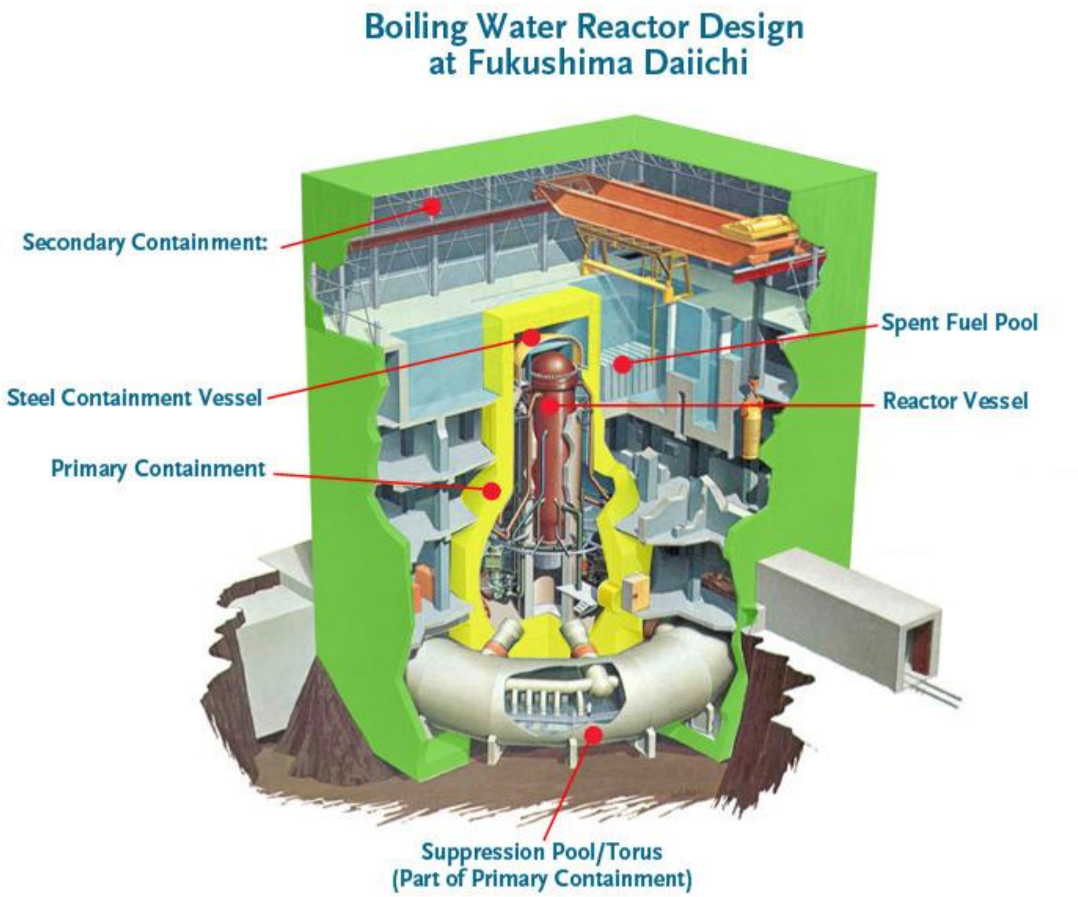


Source:
Adapted from Figure B.2 of: NRC, 1979.

Figure 6-4
February 2012 View of Spent Fuel in the Unit 4 Pool at Fukushima #1

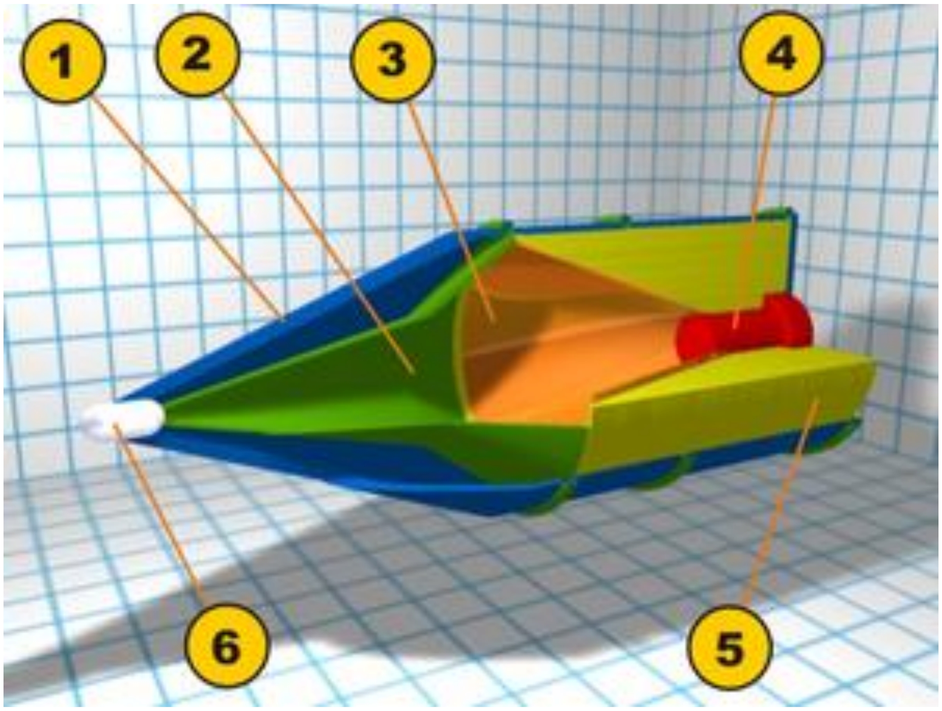
Notes:
(a) This figure is from: Asahi Shimbun, 2012.
(b) The figure is from video footage taken by TEPCO on 9 February 2012
(c) The storage configuration shown here is a high-density, closed-frame rack.
(d) A variety of debris, such as that shown in the figure, is distributed across the pool.

Figure 6-5
Schematic View of a BWR Reactor with a Mark I Containment, as Used at the Fukushima #1 Site and Elsewhere



Notes:
(a) This figure accessed on 24 February 2012 from:
http://safetyfirst.nei.org/japan/background-on-fukushima-situation/
(b) All BWR reactors with Mark I containments have the same basic configuration. Details vary for specific reactors.

Figure 6-6
Schematic View of a Generic Shaped-Charge Warhead



Notes:
(a) Figure accessed on 4 March 2012 from: http://en.wikipedia.org/wiki/Shaped_charge
(b) Key:

Item 1: Aerodynamic cover
Item 2: Empty cavity
Item 3: Conical liner (typically made of ductile metal)
Item 4: Detonator
Item 5: Explosive
Item 6: Piezo-electric trigger

(c) Upon detonation, a portion of the conical liner would be formed into a high-velocity jet directed toward the target. The remainder of the liner would form a slower-moving slug of material.

Figure 6-7
MISTEL System for Aircraft Delivery of a Shaped Charge, World War II

Notes:
(a) Photo accessed on 5 March 2012 from:
http://www.historyofwar.org/Pictures/pictures_Ju_88_mistel.html
(b) A shaped-charge warhead can be seen at the nose of the lower (converted bomber) aircraft, replacing the cockpit. The aerodynamic cover in front of the warhead would have a contact fuse at its tip, to detonate the shaped charge at the appropriate standoff distance.
(c) A human pilot in the upper (fighter) aircraft would control the entire rig, and would point it toward the target. Then, the upper aircraft would separate and move away, and the lower aircraft would be guided to the target by an autopilot.

Figure 6-8
Schematic View of Dry Cask for Storing PWR or BWR Spent Fuel (Holtec HI-STORM 100 Cask System)

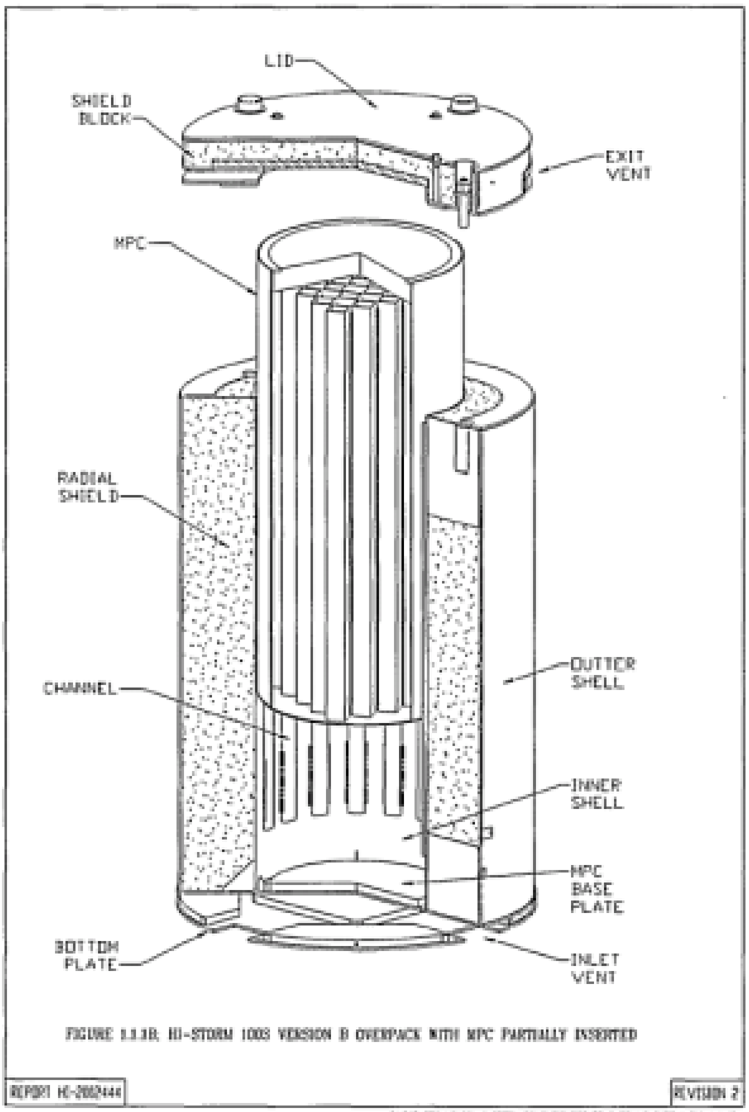


FIGURE 1.1.3B HI-STORM 100S VERSION B OVERPACK WITH MPC PARTIALLY INSERTED

Source:
Accessed on 28 February 2012 from: http://www.nrc.gov/reading-rm/sensitive-info/faq.html

APPENDIX 2

Non-Compliance Events at Darlington Nuclear Generating Station, 2015-2024

As found online at https://www.opg.com/reporting/regulatory-reporting/event-reports/

Sourced on May 2, 2025

Year	Event as Listed
2015	D-2015-20023 Degradation - Breach of Containment
2015	D-2015-21273 Licence Non-Compliance: Prior Notification Not Provided to CNSC
2015	D-2015-21504 Degradation - Breach of Containment
2015	D-2015-22326 Licence Non-Compliance: Radioactive Contamination Not Properly Assessed
2015	D-2015-22412 Safeguards: Unit 1 Core Discharge Monitor Lost Power
2015	D-2015-22423 Degradation: Construction Boiler House Instrument Air
2015	D-2015-22964 Equipment Misuse: Damage to Whole Body Monitor
2015	D-2015-23497 Degradation: Level 2 Impairment of Shutdown System 2 (SDS2)
2015	D-2015-23644 Licence Non-Compliance: Non-Permissable Material Installed on Pressure Boundary System
2015	D-2015-24021 Missed Test: Licensing Preventive Maintenance Not Executed
2015	D-2015-24132 Licence Non-Compliance: Pressure Boundary - Missed Authorized Nuclear Inspector Witness Point
2015	D-2015-24331 Degradation - Breach of Containment
2015	D-2015-25802 Licence Non-Compliance - Unqualified Worker Performing Radioactive Work
2015	D-2015-25340 Licence non-Compliance: Pressure Boundary - Missing Authorised Nuclear Inspector Approval of Inspection Test Plan
2015	D-2015-26161 Degradation - Breach of Containment
2015	D-2015-26990 Licence non-Compliance: Pressure Boundary - Non-Conformance
2015	D-2015-26994 Licence non-Compliance: Out of Calibration Gamma Meter Found in Rubber Area
2015	D-2015-28541 Shutdown System Actuation: Primary Heat Transport Pump Motor
2015	D-2015-27411 Degradation: Relief Valve Stuck in Closed Position Darlington Nuclear Generating Station 2015 R
2015	D-3.1.1 Reporting (2015) Report Number Event Title Page 2 of 4
2015	D-2015-27383 Licence Non-Compliance: Pressure Boundary – Inspection Test Plan Incomplete
2015	D-2015-28962 Degradation: Relief Valve Lifted Above Associated Hydrostatic Test Pressure
2015	D-2015-29095 Degradation: Breach of Containment Unit 3 Airlock 2
2015	D-2015-29907 Degradation: Pressurizer Heater Leak to Collection Q3

2015 D-2015-14000 Degradation: Steam Protection Impairment Caused By Refrigeration Units

2015 D-2015-16077 Degradation: Relief Valve Lifted Above Set Pressure

2015 D-2015-16295 Licence Non-Compliance: Environmental Gamma Meter Used Past Calibration Due Date

2015 D-2015-16365 Licence Non-Compliance: Late Notification to CNSC of Certified Staff Employment Status Change

2015 D-2015-15425 Licence Non-Compliance: Emergency Lights Not Maintained Per National Fire Code

2015 D-2015-16773 Equipment Misuse: PA Speaker Volume Reduced Inappropriately

2015 D-2015-18338 Equipment Misuse: Hand and Foot Monitor Damaged

2015 D-2015-18731 Critical Injury: Worker Sustained Fractured Shoulder

2015 D-2015-18184 Licence Non-Compliance: Annual Testing of Smoke Detectors Not Conducted

2015 D-2015-17991 Licence Non-Compliance: Missing or Deficient Smoke Seals

2015 D-2015-17914 Licence Non-Compliance: Over-Pressurizing of Low Pressure Service Water

2015 D-2015-18869 Licence Non-Compliance: Fuel Handling Below Minimum

2015 D-2015-20275 Degradation: Impairment of Negative Pressure Containment

2015 D-2015-21880 Licence Non-Compliance: Portable Area Gamma Monitor Used Past Calibration Due Date

2015 D-2015-21039 Equipment Misuse: Damage to Whole Body Monitor Darlington Nuclear Generating Station 2015 R

2015 D-2015-07557 Licence Non-Compliance: Environmental Manual Not Provided to

2015 D-2015-08597 Reactor Shutdown: Unit 2 Transient Due to Heat Transport System Leakage Outside Containment

2015 D-2015-07270 Licence Non-Compliance: Annual Fire Panel Inspection Not

2015 D-2015-08450 Degradation: Emergency Service Water Side Nozzles Below Critical Thickness

2015 D-2015-08873 Degradation: Dual Fan Trips Leads to Steam Protection Impairment

2015 D-2015-09440 Degradation: Breach of Containment at Airlock

2015 D-2015-09229 Licence Non-Compliance: Pressure Boundary Witness Hold Point Bypassed

2015 D-2015-09499 Licence Non-Compliance: Fire Hose Cabinet Blocked

2015 D-2015-12825 Licence Non-Compliance: Pressure Vessels Found Without Certification Q1

2015 D-2014-35257 Licence Non-Compliance: Standby Generator Fuel Storage Tank Inspections Not Completed

2015 D-2015-00343 Safety System Degradation: Emergency Power Generators

2015 D-2015-00373 Pressure Boundary Degradation: Relief Valve Above Given Set Pressure Range

2015 D-2015-01738 Unplanned Power Change: Unit 2 Turbine Trip

2015 D-2015-02586 Equipment Misuse: Damage to Whole Body Monitor

2015 D-2015-03151 Licence Non-Compliance: Pressure Vessels Certification Required

2015 D-2015-03852 Licence Non-Compliance: Fire Zone Removed From Service Without Compensatory Actions

2015 D-2015-04751 Licence Non-Compliance: Nuclear Operators Below Minimum Complement

2015 D-2015-04455 Licence Non-Compliance: Non-permissible Material Installed on Pressure Boundary System Darlington Nuclear Generating Station 2015 R

2015 D-2015-05191 Suspect Item: Informed of Substandard Material from Valve

2015 D-2015-06374 Licence Non-Compliance: Fabricated Tool Does Not Meet Pressure Boundary Material Traceability

2015 D-2015-06463 Licence Non-Compliance: Emergency Response Team Access Affected by SATM Non-Compliance

2016 D-2016-22406 Licence Non-Compliance: Radiation Hazard Board Removed

2016 D-2016-24649 Licence Non-Compliance: Radiation Barriers Moved – Un-posted

2016 D-2016-24581 Licence Non-Compliance: Notification Not Provided to CNSC Relating to Governance

2016 D-2016-22731 Licence Non-Compliance: Missed Authorized Nuclear Inspector Review of Pressure Boundary Inspection and Test Plan

2016 D-2016-24459 Degradation: Loss of Both Refrigeration Units on Unit 2

2016 D-2016-24812 Matter of Regulatory Interest: Error in Documentation Relating to Shim Operation

2016 D-2016-24994 Licence Non-Compliance: Missed Authorized Nuclear Inspector Review of Pressure Boundary Inspection and Test Plan

2016 D-2016-26543 Degradation: Steam Door Left Unlatched and Alarming

2016 D-2016-26475 Licence Non-Compliance: Missed Inspection Required by the Periodic Inspection Program

2016 D-2016-28125 Safety System Degradation: Level 2 Impairment of the Heat Transport System

2016 D-2016-28171 Unplanned Power Change: Shut-Off Rod Dropped Into Core

2016 D-2016-29857 Critical Injury: Worker Sustained Fractured Leg

2016 D-2016-30256 Licence Non-Compliance: Pressure Boundary Non-Conformance

2016 D-2016-31097 Degradation: Steam Door Found Open Due to Defective Latch

2016 D-2016-30803 Safety System Degradation: Emergency Power System Unavailable

2016 D-2016-18508 Licence Non-Compliance: Minimum Complement Violation

2016 D-2016-20203 Unplanned Power Change: Transient Occurred

2016 D-2016-21388 Degradation: Defective Steam Door Latch

2016 D-2016-21576 Shutdown System Actuation: Primary Heat Transport Pump Motor
2016 D-2016-21828 Licence Non-Compliance: Missing Valve Registration Number Inspection Test Plan
2016 D-2016-22108 Licence Non-Compliance: Fire Extinguisher Blocked
2016 D-2016-22538 Degradation: Breach of Containment - Improper Operation of Airlock Door
2016 D-2016-22549 Licence Non-Compliance: Minimum Complement Violation
2016 D-2016-22894 Counterfeit CSA Certification on Welding Receptacle
2016 D-2016-07549 Licence Non-Compliance: Access to Firefighting Equipment
2016 D-2016-07816 Licence Non-Compliance: Storage of Transient Combustibles
2016 D-2016-08194 Licence Non-Compliance: Pressure Boundary Welding Record Anomalies
2016 D-2016-08366 Safety System Degradation: Potential Impact to Group 1 Safety Equipment
2016 D-2016-08553 Licence Non-Compliance: Missed Periodic Inspection
2016 D-2016-08460 Licence Non-Compliance: Design Procedural Non-Compliances for Valve Replacements
2016 D-2016-11034 Safety System Degradation: Potential Damage to Pressurizer Temperature Element
2016 D-2016-12262 Degradation: Breach of Containment (Faulty Transfer Chamber
2016 D-2016-14030 Matter of Regulatory Interest: Emergency Response Staff Fitness and Medical Certification Requalification Issues
2016 D-2016-12142 Licence Non-Compliance: Pressure Boundary (Missed Authorized Nuclear Inspector Hold Point)
2016 D-2016-12160 Degradation: Breach of Containment (Improper Operation of Airlock Door)
2016 D-2016-13850 Licence Non-Compliance: Out-of-Plant Co-ordinator Role Below Minimum Complement
2016 D-2016-13918 Degradation: Breach of Containment (Improper Operation of Airlock Door)
2016 D-2016-15164 Critical Injury: Worker Sustained Fractured Wrist
2016 D-2016-14875 Degradation: Breach of Containment (Improper Operation of Airlock Door)
2016 D-2016-16755 Degradation: Breach of Containment (Improper Operation of Airlock Door)
2016 D-2015-29213 Degradation: Relief Valve Lifted Above Associated Hydrostatic Test Pressure
2016 D-2016-01210 Safety System Degradation: Steam Generator Emergency Cooling System (SGECS) Unavailable Due to Programmable Controller Failure
2016 D-2016-01946 Licence Non-Compliance: Fire Access Route Blocked

2016 D-2016-02044 Licence Non-Compliance: Notification Not Provided to CNSC Relating to Testing Records

2016 D-2016-02166 Missed Test: Licensing Preventive Maintenance Not Executed

2016 D-2016-03260 Degradation: Relief Valve Lifted Above Associated Hydrostatic Test Pressure

2016 D-2016-03464 Licence Non Compliance: Access to Fire Cabinet Blocked

2016 D-2016-05085 Degradation: Steam Door Found Open Due to Defective Latch

2016 D-2016-05037 Licence Non-Compliance: Missed ANI Witness Point

2016 D-2016-03256 Licence Non-Compliance: Unassessed Dose Rates in Work Area

2016 D-2016-06424 Licence Non-Compliance: Missed ANI Witness Point

2016 D-2016-06933 Licence Non-Compliance: Nuclear Operators Below Minimum Complement

2016 D-2016-06607 Licence Non-Compliance: Access to Firefighting Equipment

2016 D-2016-07460 Licence Non-Compliance: Stockkeeper Work Group Below Minimum Complement

2016 D-2016-30971 Degradation: Environmentally Qualified Deficiencies in Transmitter Housing Covers

2016 D-2016-31401 Licence Non-Compliance: Fixed Area Alarming Gamma Monitors Out of Calibration

2017 D-2017-01194 Licence Non-compliance: Relief Valve Failed to Stroke Fully During

2017 D-2017-02025 Critical Injury: Worker Sustained Broken Bone in Hand

2017 D-2017-01475 Licence Non-compliance: Inaugural Periodic Inspection Performed

2017 D-2017-02123 Licence Non-Compliance: Pressure Boundary Non-Conformance

2017 D-2017-03623 Unplanned Power Change: Unit 1 Transient Due to Sustained High Flux Tilt

2017 D-2017-03587 Licence Non-Compliance: Transfer of Tritiated Motors to Unlicensed Vendor

2017 D-2017-03957 Equipment Misuse: Smoke Detectors Found Impaired by Rubber

2017 D-2017-04071 Licence Non-Compliance: Heavy Water Management Building Emergency Fire Door Blocked

2017 D-2017-04006 Licence Non-Compliance: Pressure Boundary Non-Conformance

2017 D-2017-04757 Missed Test: Preventive Maintenance Not Executed

2017 D-2017-05265 Employee Injury: Elbow Fractured While Moving Drums

2017 D-2017-05970 Licence Non-Compliance: Missing Radiation Hazard Labels

2017 D-2017-07573 Employee Death On Site: Non-Work Related

2017 D-2017-07298 Employee Injury: Worker Sustained Broken Shoulder

2017 D-2017-06237 Licence Non-Compliance: Pressure Boundary Non-Conformance

2017 D-2017-14421 Shutdown System Actuation: Shutdown System 2 Trip (Unit 1)

2017 D-2017-13746 Licence Non-Compliance: Drums Missing Radiation Hazard Labels

2017 D-2017-13131 Degradation: Breach of Containment Alarm (Unit 1)

2017 D-2017-12704 Degradation: Breach of Containment Alarm (Unit 1)

2017 D-2017-11640 Licence Non-Compliance: Non-Compliance Radiation Protection Regulations (S.7)

2017 D-2017-10970 Unplanned Power Change: Unit 4 Shutdown After Spurious Drop of Shutoff Rod

2017 D-2017-09874 Employee Injury: Worker Sustained Broken Foot

2017 D-2017-09117 Licence Non-Compliance: Minimum Complement (Emergency Response)

2017 D-2017-08894 Degradation: Breach of Containment Alarm (Unit 1)

2017 D-2017-21807 Licence Non-Compliance: Radiation Hazard Sign Not Visible

2017 D-2017-21635 Notification Non-Compliance: Removal of Certified Personnel

2017 D-2017-21506 Licence Non-Compliance: Minimum Complement Violation (Unit 0 Operator)

2017 D-2017-20599 Equipment Misuse: Damage to Hand and Foot Monitor

2017 D-2017-20419 Licence Non-Compliance: Active Waste Bags Missing Radiation Hazard Labels

2017 D-2017-20055 Unplanned Power Change: Unit 1 Turbine Trip

2017 D-2017-18079 Degradation: Level 2 Impairment of Shutdown System #1 (Unit 4)

2017 D-2017-18027 Critical Injury: Worker Lost Consciousness Due to Heat Stress

2017 D-2017-16021 Licence Non-Compliance: Radiation Hazard Sign Containing Incorrect Information

2017 D-2017-29491 Licence Noncompliance - Radiation Hazard Sign Not Visible

2017 D-2017-29309 Licence Noncompliance - Tritium Removal Facility (TRF) Tritium Inventory Exceeded Design Limit

2017 D-2017-28287 Discovery Issue Resolution Process: Potential Reduction in Critical Heat Flux (CHF)

2017 D-2017-26548 Contingency Plan: Air Conditioning Unit Electrical Fault Required Emergency Response

2017 D-2017-26157 Degradation: Potential Extent of Condition of Adjuster Absorber Unit Operability

2017 D-2017-25548 Licence Non-Compliance: Unposted Hazardous Waste Bag

2017 D-2017-23755 Licence Non-Compliance: Improperly Posted Hazard Board

2018 D-2018-06962 Licence Non-Compliance: Improperly Posted Radiation Hazard in West Fuelling Facilities Auxiliary Area

2018 D-2018-05407 Licence Non-Compliance: Possible Unposted Radioactive Hazard in Tritium Removal Facility Loading Bay

2018 D-2018-04927 Licence Non-Compliance: Trefoil Symbols Not Visible on Transportation Package

2018 D-2018-02157 Packaging and Transport: Legacy Multi-Purpose Transportation Package Certificates and Authorized Radioactive Contents Issue

2018 D-2018-01591 Degradation: Steam Generator Emergency Cooling System

2018 D-2018-00503 Unplanned Power Change: Unit 1 Setback on Adjusters Driving Out

2018 D-2018-08138 Licence Non-Compliance: Boiler Blow Down Flow Rate Measurements Greater Than Current Feedwater Operational Safety Requirements

2018 D-2018-09216 Licence Non-Compliance: Technical Info sent to Original Equipment Manufacturer (OEM) not in accordance with Nuclear Non-Proliferation Import and Export Control Regulations

2018 D-2018-09633 Licence Non-Compliance: D1831 Improperly Posted Radiation Hazard in Rubber Area

2018 D-2018-10359 Licence Non-Compliance: Unlabelled Radiation Hazard in U3 Operations Drying Cabinet

2018 D-2018-11080 Licence Non-Compliance: D1831 wetting in plastic suit

2018 D-2018-12428 Research Finding: Darlington Axial Delayed Hydride Cracking (DHC) Growth Rate Results Above CSA N285.8 Upper Bound

2018 D-2018-14274 Licence Non-Compliance: Inadequate Posting of Radiological

2018 D-2018-15018 Licence Non-Compliance: Station Minimum Complement

2018 D-2018-15249 Degradation: System Test Performed on Wrong Unit

2018 D-2018-16839 Licence Non-Compliance: Unposted Radioactive Hazard in Tritium Removal Facility (TRF)

2018 D-2018-17388 Unplanned Power Change: Unit 4 Transient due to Suspected

2018 Control Computer (DCC) Power Supply Issue

2018 D-2018-18158 Licence Non-Compliance: Delay to Submission of Inventory Change Document (ICD) to Canadian Nuclear Safety Commission (CNSC) / International Atomic Energy Agency (IAEA)

2018 D-2018-18399 Degradation: Loss of Steam Protection due to Unavailability of 4-73910- RFU1 and 4-73910-RFU2

2018 D-2018-18961 Licence Non-Compliance: Dose rate exceedance (above 2.5 mrem/hr) at Radioactive Material Storage Area (RMSA) Cage Boundary

2019 D-2019-00332 Degradation: Steam Protection Unavailable, Unit 4 Room R207

2019 D-2019-00361 Environmental Release Monitoring: Unit 4 Calibration of Monitoring Equipment Non-Compliance

2019 D-2019-00959 Licence Noncompliance: Fixed Area Alarming Gamma Monitors Past Calibration Date

2019 D-2019-01190 Unplanned Power Change: Unit 1 Thermal Power > 101%

2019 D-2019-01669 Degradation: Unit 1 Steam Door Alarming and not Latching

2019 D-2019-01750 Licence Non-Compliance: Heavy Water Drums in Unit 4 Room R4-001 Missing D-FORM-10613 "Darlington Heavy Water Drum Content"

2019 D-2019-01984 Licence Non-Compliance: Labeling of Shutdown Cooling Heat Exchangers Not to Regulatory Expectations

2019 D-2019-04442 Degradation: Unit 3 Loss of Annulus Gas System Pressure

2019 D-2019-04999 Licence Non-compliance: Delay in Preparing and Submitting Inventory Change Document for Dry Storage Container Transfer due to Local Area Network Outage at Darlington Site

2019 D-2019-05292 Misuse of Safety Equipment: Fire Door Latching Mechanism

2019 D-2019-05533 Environmental Release: Hydrocarbon Spill on Soil

2019 D-2019-08102 Licence Non-Compliance: Unposted Radiological Hazard found at Rubber Area Boundary

2019 D-2019-08865 Degradation: Unit 4 Steam Doors Closing and not Latching

2019 D-2019-09827 Late Licensing Predefined: Safety-Related System Test not completed prior to Late Date

2019 D-2019-10907 Contingency Plan: Unit 1 Electrical Bus Tripped on Differential

2019 D-2019-12348 Missed Regulatory Predefine: Main Steam Line Break Logic Test on Even Emergency Power System Ventilation

2019 D-2019-12704 Degradation: Unit 4, Standby Class 3 Power Unavailable

2019 D-2019-12793 cence Non-Compliance: Program Document Issued without Canadian Nuclear Safety Commission Notification

2019 D-2019-12872 Degradation: Unit 1 Air Conditioning Units Unavailable

2019 D-2019-13190 Unplanned Change in Reactor Power: Unit 4 Setback

2019 D-2019-13245 Missed Regulatory Predefine: Unit 2 Contaminated Exhaust Filter

2019 D-2019-13954 Licence Non-Compliance: Flood Relief Non-Compliances Found for Units 1, 3, and 4

2019 D-2019-14314 Licence Non-Compliance: Station Minimum Complement Violation

2019 D-2019-15444 Licence Non-Compliance: Elevated Dose Rate Particle found in used Radiation Personal Protective Equipment Laundry Bag

2019 D-2019-16453 Offsite Training Injury: Fractured Wrist

2019 D-2019-16927 Environmental Release Control: Unit 0 Refrigerant Leak on Refrigeration Unit

2019 D-2019-18484 Missed Regulatory Predefine: Contaminated Exhaust Filter Testing for East Fuelling Facilities Auxiliary Area

2019 D-2019-18966 Missed Regulatory Predefine: Unit 1/3/4 Late Mandated Vault Vapour Recovery System Filter Testing Preventive Maintenance

2019 D-2019-19143 Degradation: Unit 4 Steam Door Failed to Latch Closed

2019 D-2019-19525 Licence Non-Compliance: Worker Frequencies not in Compliance with N-PROC-RA-0012 "Dosimetry and Dose Reporting"

2019 D-2019-19595 Degradation: Unit 3, Standby Class 3 Power Unavailable

2019 D-2019-19753 Degradation: Unit 1, Standby Class 3 Power Unavailable

2019 D-2019-19794 Degradation: Unit 4, Standby Class 3 Power Unavailable

2019 D-2019-20345 Environmental Release: Potential Discharge Directly from Inactive Drainage to Circulating Cooling Water Duct

2019 D-2019-20508 Licence Non-Compliance: Inadvertent and Short-Term EFFAA South Truck Bay Overhead Light Blackout rendered IAEA Surveillance Cameras Non-Functional

2019 D-2019-20538 Degradation: Unit 3 Low Pressure Service Water Booster Pump Unavailable due to passing check valve

2019 D-2019-20692 Discovery Issue Resolution Process: Steam Protection Condensation Criterion not met for Unit Emergency Power System EVEN Rooms

2019 D-2019-21206 Licence Non-Compliance: Unapproved Storage of Radioactive Material in Unit 1, Room R1-136

2019 D-2019-21411 Safety System Actuation: Switching to Solid Mode during Unit

2019 D-2019-21822 Licence Non-Compliance: Unit 4 Vault Fixed Area Alarming Gamma Monitors Past Calibration Date

2020 D-2020-00123 Degradation: Unit 1 Steam Door, Not Latched

2020 D-2020-01127 Missed Predefine: Unit 4 Safety-Related System Test Sign Off Incomplete Following Late Date

2020 D-2020-01479 Environmental Release Control: Refrigerant Leak on Refrigeration Unit in Heavy Water Management Building

2020 D-2020-01672 Unplanned Power Change: Unit 4 Stepback

2020 D-2020-01710 Unplanned Power Change: Unit 3 Setback

2020 D-2020-01806 Licence Non-Compliance: Rubber Area Waste Unposted, not

2020 D-2020-02912 Degradation: Unit 1 Steam Door, Not Latched

2020 D-2020-03036 Degradation: Unit 1 Standby Class 3 Power Unavailable

2020 D-2020-04188 Regulatory Interest: Ministry of Labour Notification, Worker Experienced Non-Occupational Illness

2020 D-2020-04563 Licence Non-Compliance: Fixed Area Alarming Gamma Monitor Past Calibration Date

2020 D-2020-04865 Regulatory Interest: Adverse Trend of Access Control Area Fixed Area Alarming Gamma Monitors Out of Calibration

2020 D-2020-05083 Regulatory Interest: Access Control Barriers Inadequate During Trolley Traverse With Irradiated Fuel

2020 D-2020-05136 Research Findings: Darlington Pressure Tube Inlet Rolled Joint Hydrogen Equivalent Concentration Results Above CSA N285.4 Acceptance

2020 D-2020-05209 Degradation: Unit 1 Steam Door, Not Latched

2020 D-2020-05376 Licence Non-compliance: Radioactive Material Discovered Abandoned in Unit 2

2020 D-2020-05546 Licence Non-compliance: Missed Unit 3 Steam Generator Periodic Inspection Program Interval for Tube Metallurgical Examination

2020 D-2020-05969 Licence Noncompliance: Worker Found Contaminated at Bridge Whole Body Monitor

2020 D-2020-06187 Degradation: Unit 2 Standby Class 3 Power Unavailable

2020 D-2020-06457 Regulatory Interest: Updated Coupling Design Installed on Unit 2, Primary Heat Transport Pump 3, Without Item Equivalency Evaluation

2020 D-2020-06690 Regulatory Interest: Follow-Up Bioassay Sample from Personal Contamination Event

2020 D-2020-06788 Unplanned Power Change: Unit 2 Hydrogen Leak Leading to Manual Turbine Trip

2020 D-2020-06885 Licence Non-compliance: Open Container with Tritiated Water found in Unit 2, Moderator Purification Room

2020 D-2020-07693 Revised Safety Analysis: Continued Operation of Inspected Pressure Tube Based on Predicted Hydrogen Equivalent Concentration Level Exceeding Terminal Solid Solubility for Hydrogen Dissolution

2020 D-2020-07926 Regulatory Interest: Ministry of Environment, Conservation and Parks Notified, Small Oil Leak on Unit 2 Main Output Transformer Red Phase

2020 D-2020-08117 Regulatory Interest: Ministry of Labour Notified, Employee Fainted and Hit Head in Cafeteria, Not Work Related

2020 D-2020-08421 Unplanned Power Change: Unit 1 Power Reduced to 59% Full Power Due to Sustained Elevated Turbine Bearing 7 Vibration

2020 D-2020-08963 Regulatory Interest: Unit 2 Transient, Turbine Generator Spurious Load Reduction

2020 D-2020-99999 Regulatory Interest: Darlington Employees Tested Positive for COVID-19, Not Work Related

2020 N-2020-04266 Regulatory Interest: Ontario Power Generation Corporate Crisis Management and Communications Centre Activation

2020 D-2020-09118 Regulatory Interest: Main Security Building Loss of Power, No System Risks and/or Breach

2020 D-2020-10107 Regulatory Interest: Discrepancy Found in Reportable Deferral Numbers for

2020 D-2020-10128 Unplanned Power Change: Unit 3 Setback Due To Flux Tilt

2020 D-2020-10471 Operations Support Building Fire Alarm Activation: Battery-Powered Vacuum Fire in Janitor Closet, No Injuries

2020 D-2020-10481 Unplanned Power Change: Unit 4 Shutoff Rod Stuck During Testing, No Reactivity Impact

2020 D-2020-10656 Licence Non-Compliance: Unit 3 Fixed Area Alarming Gamma Monitors (FAAGMs) Out of Calibration

2020 D-2020-12002 Environmental Release Control: Refrigerant Leak on Refrigeration

2020 D-2020-12220 Regulatory Interest: Ministry of Labour Notified, Cable Damaged During Concrete Key Removal, No Injuries

2020 D-2020-13010 Unplanned Power Change: Unit 1 Adjuster Rod Drove Out of Core, No Reactivity Impact

2020 D-2020-13515 Unplanned Power Change: Unit 1 Setback Due To Flux Tilt

2020 D-2020-13776 Regulatory Interest: Roadrunner Transportation Package Shield Plug Missing Bearing Pad, No Safety Impact

2020 D-2020-99998 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2020 D-2020-14917 Environmental Release Control: Refrigerant Leak on Refrigeration

2020 D-2020-14925 Degradation: Unit 4 Standby Class 3 Power Unavailable

2020 D-2020-16523 Regulatory Interest: Pressure Boundary Noncompliance, Unit 2 Carbon Steel to Stainless Steel Adaptors, No Operability Impact

2020 D-2020-16746 Emergency Power Generator 2 Building Fire Alarm Activation: Bearing Oil Leak, No Injuries

2020 D-2020-16833 Unplanned Power Change: Unit 2 Stepback on Turbine Load

2020 D-2020-18461 Regulatory Interest: Ministry of Labour Notified of Critical Injury, Fractured Ankle When Descending Stairs

2020 D-2020-18472 Degradation: Unit 3, Grid Disturbance Leads to Unavailability of Unit Secondary Control Area Air Conditioning Units

2020 D-2020-18955 Unplanned Power Change: Unit 2, Brief Power Reduction to 88% Full Power due to Unexpected Change in Channel Outlet Temperature

2020 D-2020-18978 Regulatory Interest: Confirmatory Bioassay Results

2020 D-2020-19382 Degradation: Unit 1, Shutdown Cooling Unavailable due to Programmable Controller Fault

2020 D-2020-19549 Regulatory Interest: Incorrect Fuse in Operating Documentation for Rod-Based Guaranteed Shutdown State

2020 D-2020-99997 Regulatory Interest: Contract Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-01493 Environmental Release Control on Refrigeration Unit

2021 D-2021-02568 Regulatory Interest: Ministry of Labour Notified of Injury, Fractured Wrist, Slip and Fall on Approved Walkway

2021 D-2021-02911 Regulatory Interest: Darlington Contract Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-02998 Regulatory Interest: Ministry of Labour Notified of Injury, Fractured Wrist, Slip on Stairwell

2021 D-2021-03011 Licence Non-Compliance: Amended Radiation Protection Regulations SOR/2020-237

2021 D-2021-04248 Regulatory Interest: Darlington Employees Tested Positive for COVID-19, Not Work Related

2021 D-2021-04856 Regulatory Interest: Darlington Contract Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-05393 Missed Predefine: Unit 1 Safety-Related System Test Completed After Late Date

2021 D-2021-05485 System Degradation: Unit 2 Steam Generator Emergency Cooling System Potential Unavailability, due to Environmentally-Qualified Junction Boxes Found Without Drain Holes

2021 D-2021-05636 Regulatory Interest: Darlington Contract Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-06714 Research Findings: Darlington Pressure Tube Inlet Rolled Joint Hydrogen Equivalent Concentration Results

2021 D-2021-06730 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-07030 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-07083 Degradation: Loss of Steam Protection to Main Control Room resulted in brief Shutdown System 1 Impairment Equivalent

2021 D-2021-07517 Unplanned Power Change: Unit 1 Turbine Generator Trip

2021 D-2021-08207 Unplanned Power Change: Unit 4 Turbine Trip during Execution of Safety-Related System Test

2021 D-2021-08324 Research Finding: Analysis Gap for Emergency Coolant Injection Pipe Breaks

2021 D-2021-08699 Regulatory Interest: Darlington Employees Tested Positive for COVID-19, Not Work Related

2021 D-2021-08785 Regulatory Interest: Hydro Pole Fire in Upper Parking Lot, outside of Darlington Protected Area

2021 D-2021-09524 Operating Experience: Unit 2, Through Bolt Material Grade Designation Discrepancy between Installed Material and Design Documentation for Auxiliary Shutdown Cooling Pumps, no Operability Impact

2021 D-2021-09751 Nuclear Safety Analysis Finding: Updated Analysis Predicts Lower Containment Repressurization Times than in Darlington Safety Report, no impact to Safe Operating Envelope Limits

2021 D-2021-11300 Regulatory Interest: Confirmatory Bioassay Results

2021 D-2021-11848 Regulatory Interest: Moisture Separator Degradation Observed during Planned Steam Generator Inspection, No Safety Impact

2021 D-2021-12086 Research Findings: Darlington Pressure Tube Inlet Rolled Joint Hydrogen Equivalent Concentration Results

2021 D-2021-12174 Licence Non-Compliance: Orange Badge Qualified Workers Entered Radiation Area without Radiation Exposure Permits or Electronic Personal Dosimetry, No Significant Radiation Exposures Resulted

2021 D-2021-12227 Licence Non-Compliance: Station Minimum Complement

2021 D-2021-12470 Regulatory Interest: Ministry of Labour Notified of Injury, Fractured Ankle When Descending Stairs

2021 D-2021-12506 Research Findings: Unit 3, Channel S13, Darlington Axial Delayed Hydride Cracking Growth Rate Results

2021 D-2021-12971 Regulatory Interest: Ministry of Labour Notified of Accident, Tape Measure Contacts Prongs of Energized Ground-Fault Circuit Interrupter, No

2021 D-2021-13173 Regulatory Interest: Member of public observed speeding on-site, prohibited items discovered in vehicle, turned over to Durham Regional Police

2021 D-2021-13523 Regulatory Interest: Ministry of Environment, Conservation and Parks Notified, Missing Data from Lagoon Datalogger

2021 D-2021-13995 Regulatory Interest: Ministry of Labour Notified of Injury, Fractured Wrist due to Fall in Parking Lot, outside of Darlington Protected Area

2021 D-2021-14288 Regulatory Interest: Member of public observed speeding on-site, driving unsafely, suspected intoxicated, turned over to Durham Regional Police

2021 D-2021-15065 Safeguards: Inadvertently-Broken International Atomic Energy Agency Seal, East Fuelling Facility Auxiliary Area Bridge

2021 D-2021-15768 Environmental Release Control: Small Oil Sheen on Oil Contaminated Water Treatment System Pump, Discharge to Forebay, no Adverse Environmental Impact

2021 D-2021-16298 Licence Non-Compliance: Improperly Labelled Radiological Hazard, Waste Bag

2021 D-2021-17619 Regulatory Interest: Darlington Contract Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-17749 Regulatory Interest: Unit 4 Hydrazine Spill Found, resolved with no immediate health impacts

2021 D-2021-17939 Regulatory Interest: Three Shutdown System 2 Neutron Overpower Detectors Prompt Fractions Estimated Below 80%, no Operability Impact

2021 D-2021-18757 Regulatory Interest: Ministry of Labour Notified of Injury, Two Fractured Fingers, Pinched Between Hydraulic Ram Body and Cylinder Nut

2021 D-2021-19052 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-19117 Potential Programmatic Licence Non-compliance: Adverse Trend - Gaps in Implementation of Safe Operating Envelope, no Nuclear Safety Impact

2021 D-2021-19233 Regulatory Interest: Confirmatory Bioassay Results

2021 D-2021-19395 Licence Non-compliance: Heavy Water Management Building, West Annex, Fixed Area Alarming Gamma Monitors Out of Calibration

2021 D-2021-19465 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-99999 Regulatory Interest: Darlington Contract Employee Tested Positive for COVID-19, Not Work Related

2021 D-2021-19709 Licence Non-compliance: Radiation Hazard Warning Not Posted at Unit 2, Airlock 2 Access Control Gate

2021 D-2021-19938 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2022 D-2022-00341 Regulatory Interest: Ministry of Labour, Training and Skills Development (MLTSD) Critical Injury Notification, Employee Fractured Ankle

2022 D-2022-00429 Missed Predefine: Annual Refrigerant Leak Test for Air Conditioning Unit for Emergency Power System Room

2022 D-2022-00642 Regulatory Interest: Ministry of Environment, Conservation and Parks (MECP) Notified, Missed Weekly Municipal and Industrial Strategy for Abatement Sampling

2022 D-2022-00824 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2022 D-2022-00910 Degradation: Unit 2, Emergency Service Water System Supply to Moderator Unavailable

2022 D-2022-01842 Licence Non-Compliance: Unposted Hazard, Unsealed Carboy in Heavy Water Management Building

2022 D-2022-02690 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2022 D-2022-02906 Regulatory Interest: Darlington Employee Tested Positive for COVID-19, Not Work Related

2022 D-2022-04308 Regulatory Interest: MLTSD Notification, employee lost consciousness, Not Work Related

2022 D-2022-06567 Licence Non-Compliance: Delay to Submission of Inventory Change Document

2022 D-2022-07150 Suspect Counterfeit or Fraudulent: Potential Nonconforming

2022 D-2022-07509 Unplanned Power Change: Unit 4 Transient due to Unexpected Rapid Load Reduction

2022 D-2022-09684 Unplanned Power Change: Unit 2 Turbine Trip on Main Output Transformer Differential Protection

2022 D-2022-10326 Regulatory Interest: MLTSD Notification, Employee Fractured Wrist and Ribs, Descending a Ladder

2022 D-2022-10388 Regulatory Interest: MLTSD Notification, Employee Lost Consciousness, Not Work Related

2022 D-2022-10574 Research Findings: Impact of Aging of Shutdown System Neutron Overpower Pt-clad Inconel In-Core Flux Detectors Not Fully Accounted for In Design and Safety Analyses, No Operability Impact

2022 D-2022-13707 Suspect Counterfeit or Fraudulent: End Fitting Material

2022 D-2022-13844 Licence Non-Compliance: Station Minimum Complement

2022 D-2022-15397 Regulatory Interest: MECP Notified, Compromised Weekly Morpholine Sample Result

2022 D-2022-17042 Unplanned Power Change: Unit 2, Turbine Reheat Emergency Stop Valve Failed During Testing

2022 D-2022-17199 Contingency Plan: Tritium Removal Facility, Fire Event in Electrical Panel, no Operability Impact and Safely Resolved

2022 D-2022-17264 Environmental Release Control on Refrigeration Unit

2022 D-2022-18430 Regulatory Interest: MLTSD Notification, Employee Fractured Two Fingers Between Paver and Skid Steer Bucket, Outside Protected Area

2022 D-2022-18605 Licence Non-Compliance: Unposted Hazards, Unit 2 Rooms

2022 D-2022-18827 Licence Non-Compliance: Unlabelled Containers, In Station Flasks

2022 D-2022-19127 Unplanned Power Change: Unit 4 Heat Transport System Increased Leakage to Containment, Resolved and Unit Safely Returned to Service

2022 D-2022-19590 Degradation: Unit 4 Post-Accident Monitoring System (PAMS) Flow Indication Unavailable (FI31K#1 and FI31K#2), no Nuclear Safety Impact

2022 D-2022-19918 Degradation: Unit 4 PAMS Flow Indication Unavailable (FI34L#1 and FI34L#2), no Nuclear Safety Impact

2022 D-2022-20296 Missed Predefine: Unit 2 Safety-Related System Test Completed After Late Date

2022 D-2022-20320 Licence Non-Compliance: Station Minimum Complement

2023 D-2023-02361 Regulatory Interest: Missing Weld on Unit 3 Containment Bulkhead, no Operability Impact

2023 D-2023-02539 Regulatory Interest: Missed Condensate Tank Sampling, minimal Environmental Impact

2023 D-2023-03639 Equipment Misuse: Door Discovered Unsecure, no Threat to Operations, to Staff, or to the Public

2023 D-2023-03876 Degradation: Level 2 Impairment of Emergency Coolant Injection

2023 D-2023-05127 Licence Non-Compliance: Unposted Hazard in West Fuelling Facilities Auxiliary Area, Radiation Waste Bags

2023 D-2023-05295 Regulatory Interest: In Station Transfer Skid Hitch Failure During Pressure Tube/Calandria Tube Flask Transport, no Radiological Consequences and no Personnel Injuries

2023 D-2023-07842 Licence Condition Non-Compliance: Document Issued Without Written Notification to CNSC Staff

2023 D-2023-07852 Regulatory Interest: Coolant Leak from Crane, no Environmental

2023 D-2023-08538 Licence Non-Compliance: Station Minimum Complement

2023 D-2023-08924 Contingency Plan: Unit 1 Boiler Event, no Operability Impact and Safely Resolved

2023 D-2023-09062 Environmental Release Control: Visible Oil Sheen Observed During Oil Contaminated Water Treatment System Sump Discharge, no Environmental

2023 D-2023-09492 Licence Non-Compliance: Heavy Water Management Building, West Annex, Fixed Area Alarming Gamma Monitors Found in Service Beyond Calibration Due Date

2023 D-2023-09873 Licence Non-Compliance: Ion Chambers Import Licence Authorized Quantity Limit Exceeded

2023 D-2023-10433 Environmental Release Control: Unit 3 Boiler Morpholine Exceedance, minimal Environmental Impact

2023 D-2023-10449 Unplanned Power Change: Unit 3 Reactor Setback due to Turbine

2023 D-2023-11222 Licence Non-Compliance: Unposted Radiation Hazard in Active Liquid Waste, Room S-086, Safely Resolved

2023 D-2023-11825 Unplanned Power Change: Unit 3, Moderator Cover Gas High D2 Concentration, no Operability Impact

2023 D-2023-11884 Unplanned Power Change: Unit 2, Pressurizer Steam Loss, no Operability Impact

2023 D-2023-13679 Reactor Control Impairment: Unit 2, Stepback Unavailable, Heat Transport System Safety Function Unavailable, loss of power to 2-63310-PK0003-11, no Operability Impact

2023 D-2023-13773 Environmental Action Level Exceeded: Radiological Airborne

2023 D-2023-15183 Environmental Release Control: Sewage System Spill, outside of Protected Area, no Environmental Impact

2023 D-2023-16681 Regulatory Interest: On-Site Public Address System Audibility

2023 D-2023-17317 Regulatory Interest: Ministry of Labour, Immigration, Training and Skills Development (MLITSD) Notification, Fractured Leg When Descending Stairs

2023 D-2023-17432 Regulatory Interest: Missed Sample Analysis for Total Suspended Solids, Water Supply Plant Neutralization Sump Discharge, minimal

2023 D-2023-17704 Vendor Internal Training Record Quality Document Issue

2023 D-2023-18710 Licence Non-Compliance: Late Notification of Change to Authorized Delegates and Responsible Persons

2023 D-2023-19027 Regulatory Interest: MLITSD Notification, Fractured Ankle When Descending Stairs

2023 D-2023-19111 Reactor Control Impairment: Unit 3 Setback/Stepback Unavailable, Failure of Valve 3-34810-PV106, no Operability Impact

2023 D-2023-19210 Regulatory Interest: Fire Dampers Unavailability Due to Design Condition, no Safety Impact

2023 D-2023-19963 Unplanned Power Change: Temporary Loss of Unit 3 Electrical Bus, no Operability Impact

2024 D-2024-00062 Missed Test: As-Found Test of Pressure and Inventory Control System Bleed Condenser Relief Valve

2024 D-2024-00184 Degradation: Impairment of Negative Pressure Containment System, due to Inadvertent Operation of Circuit Breaker, no Safety or Operability

2024 D-2024-01131 Unplanned Power Change: Unit 3 Transient due to Boiler Feed Pump Trip, no Operability Impact

2024 D-2024-01140 Regulatory Interest: Tubing Penetration Insulation Assumptions at the Feeder Cabinet, no Safety or Operability Impacts

2024 D-2024-01399 Licence Non-Compliance: Heavy Water Management Building, West Annex, Fixed Area Alarming Gamma Monitors Found in Service Beyond Calibration Due Date

2024 D-2024-01731 Environmental Action Level Exceedance: Tritium Removal Facility, Elemental Tritium, Safely Resolved

2024 D-2024-03701 Licence Non-Compliance: Non-Dose Management System Active Worker Entered a Radiological Area, no Exposure Levels or Dose Limits Exceeded

2024 D-2024-06318 Licence Non-Compliance: Driver Left Unescorted in the Protected Area, Safely Resolved

2024 D-2024-06353 Component Degradation: Relief Valve Stuck Closed During As-Found Test

2024 D-2024-06646 Environmental Release Control: Unit 3 Fire Resistant Hydraulic Fluid Leaks, no Environmental Impact

2024 D-2024-06668 Environmental Release Control: Refrigerant Leak on Refrigeration Unit, no Environmental Impact

2024 D-2024-07005 Radiation Protection Action Level Exceedance: Tritium, Unit 2 Moderator Pump Room, Safely Resolved

2024 D-2024-07028 Degradation: Unit 3, Standby Class 3 Power System Unavailable

2024 D-2024-07080 Regulatory Interest: Missed Samples for Total Residual Chlorine, no Environmental Impact

2024 D-2024-07665 Licence Non-Compliance: Driver Left Unescorted in the Protected Area, Safely Resolved

2024 D-2024-08146 Licence Non-Compliance: Reports for Annulus Gas System Unavailability Events not filed per REGDOC-3.1.1

2024 D-2024-08189 Licence Non-Compliance: Deficiency with Radiation Hazard Signage, Unit 3 Gaseous Fission Product Monitoring Room, Safely Resolved

2024 D-2024-08463 Licence Non-Compliance: Notification of Changes to Notice of Regulatory Undertakings Not Issued to CNSC staff

2024 D-2024-09016 Regulatory Interest: Unit 3 Annulus Gas System Leak Detection Unavailable, Relief Valve Opened and Failed to Reseat, no Operability Impact

2024 D-2024-09096 Regulatory Interest: Unit 3 Annulus Gas System Leak Detection Unavailable, Relief Valve Opened and Failed to Reseat, no Operability Impact

2024 D-2024-09569 Regulatory Interest: Late Chlorine Analysis, no Environmental

2024 D-2024-09596 Regulatory Interest: Potential Unanticipated Neutron Radiation at Retube Waste Processing Building, Below Posting or Dosimetry Requirements

2024 D-2024-09607 Missed Predefine: Relief Valve Testing Date Missed

2024 D-2024-10350 Degradation: Unit 2, Standby Class 3 Power System Unavailable

2024 D-2024-10829 Missed Predefine: Unit 2 Emergency Coolant Injection Instrumentation Calibration

2024 D-2024-11297 Environmental Release Control: High Chlorine in Condenser Cooling Water Discharge, no Environmental Impact

2024 D-2024-11487 Licence Non-Compliance: Radioactive Drums without Visible Labeling, Safely Resolved

2024 D-2024-11508 Degradation: Unit 1, Standby Class 3 Power System Unavailable

2024 D-2024-12516 Unplanned Power Change: Unit 3, Condenser Cooling Water Pump Trips on High Travelling Screen Differential Pressure, no Operability Impact

2024 D-2024-13161 Component Degradation: Relief Valve As-Found Test Failed High

2024 D-2024-13433 Licence Non-Compliance: Unposted Radiation Hazard in Fuel Handling Maintenance Shop Rubber Area, Safely Resolved

2024 D-2024-13670 Missed Predefine: As-Found Test of Primary Heat Transport System Feed Circuit Relief Valve

2024 D-2024-13673 Degradation: Unit 1 Secondary Control Area Unavailable due to Air Conditioning Units Unavailability

2024 D-2024-13891 Degradation: Unit 2, Steam Generator Emergency Cooling System Unavailability, Valves Failed to Open, no Operability Impact

2024 D-2024-13918 Component Configuration: Unit 1, Moderator Cover Gas System Valve Handle Installed Incorrectly, no Operability Impact

2024 D-2024-14200 Contingency Plan: Welding Hot Work Event on Feeder Cabinet Catwalk, Safely Resolved

2024 D-2024-14205 Component Degradation: Relief Valve As-Found Test Failed High

2024 D-2024-14693 Licence Non-Compliance: Unlabeled Radioactive Waste, Safely Resolved

2024 D-2024-14701 Safeguards: Lost Power to IAEA Camera Control Cabinet, Unplanned Power Outage, Safely Resolved

2024 D-2024-14947 Programmatic Non-Compliance: Unresolved Gaps Related to OPG/Subsidiary Interface

2024 D-2024-15201 Misuse: Worker Covered Audio-Visual Telemetry System Camera, Safely Resolved

2024 D-2024-Q4 not available