Building InterimEnd-state Strategy Assessment for Pickering Storage-with-Surveillance

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Abstract

OPG's Pickering Nuclear Power Plant is due to cease commercial operations in 2024 OPG has decided on a deferred decommissioning approach and will implement a building endstate strategy to maintain the plant in storage with surveillance (SwS) for approximately 30 years. Candesco division of Kinectrics Inc. carried out a technical assessment of various hypothetical Endstate conditions to identify opportunities and challenges in reducing the operational footprint of the station while maintaining the facility out-of-servicebuildings and structures in a safe, stable condition until dismantling and demolition activities would be undertaken.

Important aspects of this assessment include:

- Using relevant codes and standards and reviewing OPEX to validate the building endstate strategy (Referred to henceforth as the "Strategy").
- Identifying the minimum inspection, monitoring and maintenance requirements for buildings during SwS.
- Understanding the lifecycle cost of the Strategy and identifying reasonably foreseeable complications that might arise during the SwS or subsequent phases.
- Minimizing any new hazards resulting from out-of-service buildings.

1. Introduction and Approach

OPG's Pickering Nuclear Power Plant is due to cease commercial operations in 2024. OPG has considered a deferred decommissioning approach with a building" Interim end-state" strategy to maintain the plant in "storage with surveillance" (SwS) for approximately 30 years. (SwS is equivalently referred to as "Safestore." or Safe Enclosure). Planning for implementation of this strategy included a technical assessment to identify opportunities and challenges for reducing the operationalfootprint of the station while maintaining the facility out-of-service buildings and structures in a safe, stable condition until dismantling and demolition takes place. That assessment is the subject of this paper.Hypothetical "Interim Endstates" (referred to throughout this paper as "Endstates") considered for the plant out-of-servicebuildings and structures during SwS are discussed in the following section.

The methodology involved identifying requirements governing SwS projects and associated activities, applying requirements to assess the potential strategy to achieve the SwS status, and developing conclusions and recommendations. The overall technical approach took into account the requirements in the guidelines, codes and standards, operating experience (OPEX) gathered from other decommissioning projects, good engineering practices, and sound business principles. The technical approach used the following steps:

- Grouping buildings/structures on the siteto take advantage of similarities amongst them. A few of these were expected to remain operational during the SWS period and were not included in the assessment. Those remaining, intended to be out-of-service, were grouped in eleven categories based on structure types and their prior operational function.
- Assessment of the proposed, hypothetical Endstates to identify shortcomings in meeting known requirements and providing recommendations to achieve compliance.
- Identification and consideration of the potential for creating new hazards on the site or complicating the future decommissioning activities. Factors such as the effects of weather damage (frost and severe storms), condensation or water ingress, mould growth, infestation by vermin (e.g.: rodents, insects or pigeons) and so forth are accounted need to be considered. Where potential hazards are identified, reasonable controls and mitigation strategies that might be implemented to manage the hazard are identified and presented.
- Proposing specific inspection and maintenance requirements for each of the eleven building groups. These were organized by first defining the end-state criteria for 14 categories of building systems, structures, and components. The proposed inspection and maintenance requirements were determined at a functional level for each of the building groups based on the hypothetical end-state conditions that would apply to the group. The resulting inspections also took into accountbuilding construction features. Types of inspections and corresponding frequencies are largely determined based on a review of available OPEX and best engineering judgment.

For each out-of-service building group, recommendations were developed based on the results of these steps. This includes suggestions/recommendations for actions to address issues that require further consideration.

The recommended inspection and maintenance regimens address building structural elements important from a safety perspective (e.g., columns, beams, foundations); building envelopes (e.g., roof, wall, doors and windows); and building services (e.g., electrical, Heating Ventilation Air Conditioning (HVAC), water and sewage). Consideration is also given to issues related to aging (e.g., corrosion and weather damage), minimizing new hazards resulting from building lay-up, housekeeping (e.g., dust buildup and condensation); and occupational health (e.g., mould growth, insect or rodent infestation and deteriorating air quality).

In carrying out the assessment, the authors met several times with staff of Ontario Power Generation to discuss the approach and seek their input in defining relevant hypothetical Endstates. The buildings and structures were also walked-down on two separate occasions to gain a better appreciation of the current and likely future evolution of their condition.

2. Hypothetical Endstates Considered

Endstate was defined as the hypotheticalphysical condition in which a building, structure or other fixed piece of equipment, would be maintained during the SwS phase.This was described for each out-of-servicebuilding group based on the level of detail available, and additional assumptions were made whererequired.

Grouping of like Systems and Structures for purpose of Building Endstate Assessment

The study took into account all Buildings and Structures within the Protected Area (the area enclosed by the x—x pattern in Figure 1).

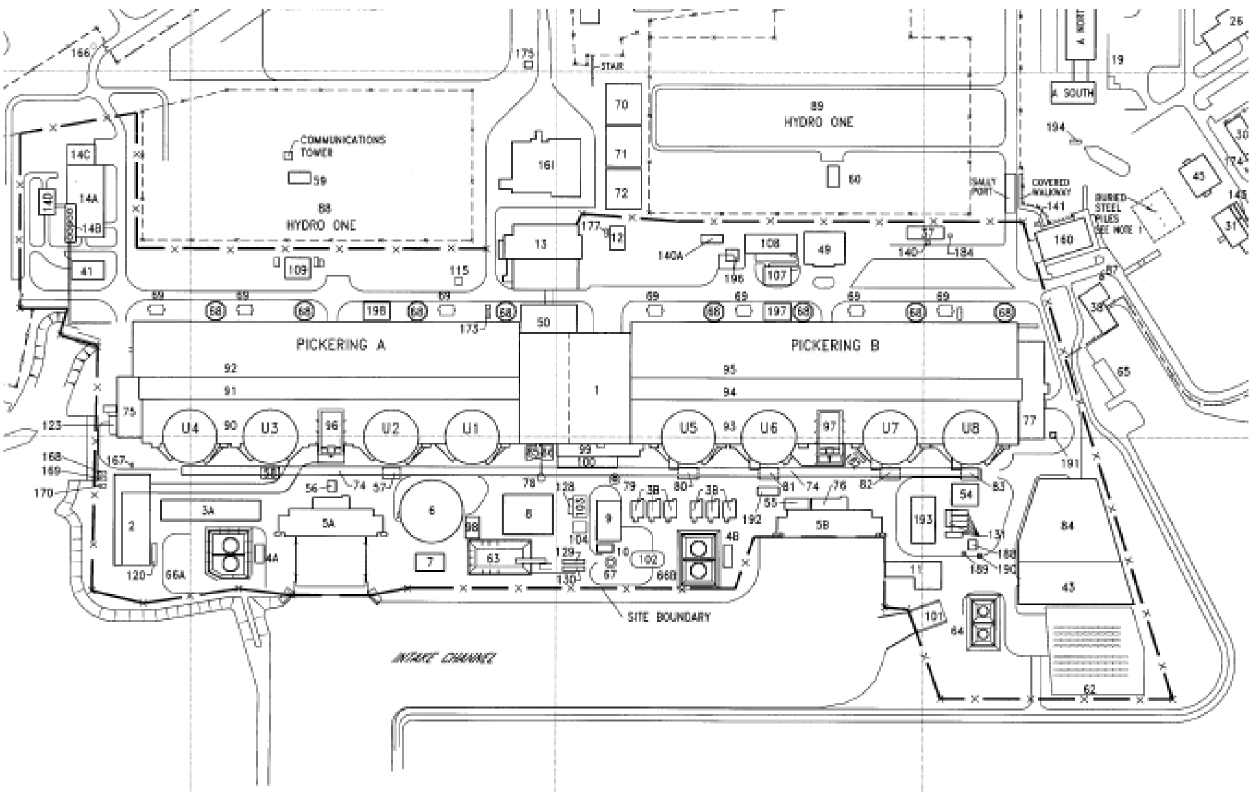

Figure 1: Site Plan – Buildings Inside Protected Area

Altogether a total of 100 building and other structures were considered in the study, broken down as 61 buildings, 3 structures, 3 towers, 26 tanks, 6 equipment enclosures and a settling basin.

Of this total, there were 8 reactor buildings, 2 powerhouses, Service Building and a Vacuum Building. These 12 buildings are the largest ones on the site.

3. National and International Guidelines and Codes of Practice.

3.1 Examples of National and International Guidelines

The guidelines issued by international and national authorities, which pertain to the storage with surveillance projects of nuclear facilities were identified and compared, with a focus on IAEA and Canadian documents. Internationally, these included IAEA WS-R-5 [1], which provides decommissioning requirements to which the CNSC subscribes, based on higher level IAEA Standards, and informs lower-tier documents such as IAEA SRS-26 [2] and IAEA SRS-36 [3]which provides greater detail regarding the implementation of the requirements.

Nationally, the CNSC does not provide explicit regulatory guidance for decommissioning. Guides are provided currently only for decommissioning planning [4]and funding [5]. Decommissioning practice is addressed by the industry standard CSA N-294[6], which was developed with the support and participation of the CNSC and other federal and provincial authorities; this standard provides general indications of good practice. It is noted that update No.1 of CSA N-294 (Annex K: Decommissioning Requirements for High-Energy Reactor Facilities) was published in August of 2014, after this assessment was completed, although a draft version of this publication was available to the authors during preparation of the assessment).

While nuclear sites in Canada are licensed under federal codes and standards, the CNSC has traditionally sought to consider the requirements of provincial and municipal authorities and other federal agencies by deferring to whichever formulation is the more encompassing.

3.2Applicable Codes of Practice

A review of applicable Canadian codes and standards was conducted with the aim of identifying requirements that will affect buildings or structures.

The codes and standards reviewed for applicability included the following:

- National Building Code of Canada (NBCC), 2010 [7]
- Ontario Building Code, 2012 [8]
- National Fire Code of Canada (NFCC), 2010 [9]
- Ontario Fire Code, 1997 [10]
- Occupational Health and Safety Act (OSHA), 1990 [11]
- City of Pickering Property Standard By-law, 2002 [12]
- Canadian Standards Association, Decommissioning of Facilities Containing Nuclear Substances, CSA Standard N294-09, July 2009.[6]

While no requirements in the above codes were identified that would pose major compliance issues,there is no body of public information in Canada related to the code issues and their resolution that may have occurred to date with layup and SwS of nuclear facilities. Consequently, analysis of the applicability of the various codes and standards is based on an understanding of how these *might* apply as opposed to how they would apply. This in turn depends on what is likely to be considered “best practice” based on experience (OPEX) in Canada and elsewhere.

3.3 Experience with Extended SwS in Canada.

In order to assess the hypotheticalSwS conditions for their applicability to Pickering, a review of related national and international experience was carried out.

Several Canadian reactors are either already in SwS or have been shut down for extended periods.The experience gained from these has contributed to the planning for extended SwS. Key areas of this OPEX include:

- incompletely drained process systems leading to leaks and contamination spread,
- problems with drainage collection and sump pumping,
- persistence of tritium in the reactor buildings indicating a need for vapour recovery drying,
- corrosion of components and structures,
- failure of foundation drains/drainage,
- problems due to equipment being removed from service that was subsequently needed, and
- housekeeping irregularities affecting repeat access.

Inspection and maintenance programs have demonstrated that maintaining a shutdown reactor is very similar to maintaining operational reactors. In particular:

I. Storage with Surveillance Plans had to be continuously upgraded to remain in compliance with nuclear regulations,
II. Extensive effort had to be devoted to configuration management and documentation of Safe Storage conditions to offset the loss of the potential for knowledge transfer.

The longest periods of SwS have been experienced by AECL's CANDU Prototypes at three sites: Douglas Point (1968-1984), Gentilly-I (1972-1979) and the Nuclear Power Demonstration-NPD (1962-1987).All three have been shut-down for more than 30 years. The most commonly encountered issues at these sites are summarized in the following paragraph.

Prolonged SwS has resulted in the need to provide temperature/humidity control within critical areas of the facilities to mitigate moisture condensing on surfaces leading to corrosion, peeling paint, the saturation and falling of asbestos insulation, and spread of radioactive and asbestos contamination. Canadian experience with closed, partially occupied and infrequently occupied - but wet or damp - plant utility buildings has also included a partial collapse of ceilings due to water damage, extensive mould growth, bird (pigeon and gull) occupancy, and animal droppings from raccoons and other wildlife leading to contamination both inside and outside the perimeter fence.A particular challenge for Canadian CANDU reactors is their harsh operating environment due to the climate. Furthermore, most Canadian CANDUs are directly cooled by river or lake-water.In general, increased erosion of plant lake fronts can be anticipated due to exposure to damage from ice movement, possible seismic activity, changes in lake water level, high winds, and "seiche" effects. Means to mitigate damage to the shoreline and buildings and structures communicating with the lake need to be considered when configuring these for SwS.Their proximity to these water sources particularly affects auxiliary buildings such as those associated with water treatment or pumpinghaving a very deep "basement" that communicates either directly or indirectly with the water body. Many of the issues listed in Table 1 are due to water entering buildings of which this case offers a specific example. All of the above "wet" conditions can lead to accelerated concrete degradation during SwS, exacerbated if coupled with those rare occasions when concrete supplied may not have been in compliance with the original design specification. The result may be expensive structural repairs during extended SwS.

4. OPEX from International Nuclear Plants in Extended SwS:

Review of International experience with extended SwS drew heavily on an IAEA consultant's report on this topic [13], prepared by experts who presented experience from France, Germany, Italy, Slovakia, UK, and the USA, in addition to Canada. Additional examples were sought from published papers and the personal experience of the authors and their colleagues. Tabulation and analysis of the complete list (comprising approximately 70 cases) to-date has provided the "short list" of issues presented in Table 1. As noted above, many of the issues listed in Table 1 are potentially due to water entering or otherwise accumulating in buildingsfromseepage, in-leakage, or condensation.

Of these, erosion and subsidence would not necessarily apply directly to the buildings, but to adjacent areas for example subsidence may be induced by the presence of the below grade water, leading to crumbling of buildings and infrastructure such as lamp-posts.

Table 1: Issues list from operating experience associated with transition to decommissioning

Issue #	Potential Issue	Typical Indications of degradation
1	Frost rupture of incompletely drained pipe	Water and/or rust staining on surfaces Excessive water accumulation in sumps
2	Hazards from falling objects or structural materials	Loose hangers or other items attached to walls. Dislodged concrete pieces or other debris on floor
3	Mould Growth	Evidence of green/black mold growth
4	Structural failure of miscellaneous infrastructure elements	Observed during periodic external walkdowns, e.g. lamp posts, fencing, pavement
5	Freeze thaw (temperature cycling) structural and envelope damage	Floor heaving, cracking of wall to floor joint, loosened structural connection
6	Failure of (sometimes undocumented) live electrical system	Scorch marks, dangling wires
7	Water accumulation through ingress via failed building envelope, condensation, pipe burst, etc.	Water and/or rust staining on surfaces. Excessive water accumulation in sumps
8	Human Intrusion, unauthorized equipment removal or storage of materials/equipment	Entranceways forced, panels removed, objects not as shown on the plans

Issue #	Potential Issue	Typical Indications of degradation
9	Animal Intrusion	Openings in envelope, tunneling evidence, droppings, carcasses, dirt
10	Erosion, Subsidence	Distortion of floors and foundations, cracks in the walls, "sticky" doors
11	Detection of airborne radioactive contamination and spread of surface radioactive contamination. Deterioration of fixatives.	Loose contamination is not expected at the beginning of SwS. However, deterioration of fixatives may lead to subsequent loose contamination.
12	Detection of airborne contamination or asbestos hazard and spread of non-radioactive surface contamination or other source of degradation of air quality.	Airborne contamination and spread of non-radioactive surface contamination or other degradation of air-quality. Not likely visible, so may requires swipes for analysis. Asbestos is the main potential hazard. Closed/sealed areas may build up contaminants, have low oxygen.
13	Loss of strength of structural elements or fixtures	Obvious defects (cracks, leaks, holes, etc), thickness loss, support attachment integrity, defective welds, defective bolted connections, fatigue, corrosion, galvanic corrosion, shape changes deflection, alignment/warping. Abrasion/erosion
14	Failure of equipment installed to support safe storage	Changes to normal lighting levels, alarms status, datacom, temperature, humidity due to changes in ventilation, heating dehumidification, sumps and sump pumps, etc. (See also 16)
15	Degradation of isolation safety tags	Tags difficult to read, evidence of tears or discoloration, missing tags visible in previous photos
16	Unintended blockage (and/or isolation) of venting of areas and equipment	Evidence of equipment movement or unexpected ambient temperature, moisture condensation, water accumulation and freeze up

Issue #	Potential Issue	Typical Indications of degradation
17	Inadequate "Housekeeping" and general degradation	General conditions e.g. unattached materials, systems & equip left in obviously non-standard conditions, loose trash, scattered items, obstructions, hazards, snow accumulation etc.
18	Groundwater contamination	Results differing from baseline measurements, showing up in routine sampling of drainage collection

5. Review Of Proposed Hypothetical Endstates

In the course of review of the proposedhypothetical Endstate conditions, a number of issues emerged that required discussion and further consideration of these hypothetical Endstate conditions. These included observations on both the end-states themselves, and the ways that these should be achieved.

During SwS, auxiliary systems will likely be required for some buildings and building groups. These may include lighting, heating, ventilation, drainage, communication and annunciation, continuous air sampling of exhaust, portal and/or portable monitors.

Based largely on Canadian and International OPEX, as discussed above. some buildings may need to include provision for partial heating, drying and ventilation. To permit requirements for this and specifications for equipment needed, the monitoring of the temperature and humidity conditions in the areas most likely to experience elevated humidity (such as the lower portions of the Reactor Buildings) was identified as an appropriate next step.

Increased measures to control moisture levels and condensation would likely require steps to manage the liquid wastes produced:

- condensate and drainage collection, preferably at a central collection, sampling, and transfer point
- central location of readouts and annunciation for monitoring conditions inside containment to reduce the frequency of active area entry during SwS

Plans for managing solid wastes, including secondary wastes (which may include materials and equipment used in placing the facility in SwS) and mixed wastes,also require consideration in preparing for SwS. For example asbestos and asbestos-contaminated radioactive waste represent a significant portion of decommissioning wastes. Systematic asbestos removal during transition to SwS can help reduce this by preventing asbestos contamination spread throughout the plant due to insulation degradation.

For the management of both solid and liquid wastes arising from transition to SwS, the approaches should be well-enough defined to permit appropriate space allocation for storage and processing of these wastes.

Because of its lakeside location, a number of structures (such as the pumphouse) located near the waterfront communicate with the lakewater. Means to isolate these from the lake need to be considered.During normal operation, some of these structures are partially protected by frazzle ice protection which is unlikely to be available after shut-down. One option that can be considered would involve the use of “stop logs”. However, reliable isolation for the long SwS periods envisaged may warrant isolation of the below-grade internals of structures from the lake usinga double walled barrier, that is, by providing an inner space between the isolating barriers that can be inspected. In the absence of such isolation, a means of water agitation and partial heating (to avoid damage due to freeze/thaw) should be considered. Such partial heating and water agitation systems operation will require corresponding inspection procedures to be put in place for these systems.

6. Inspections Proposed for the SwS Period

A table was prepared for each building group to address the proposed building structure and envelope inspections associated with the structural integrity for a building group. A simplified example is provided as Table 2. By structural integrity, it is implied primarily that systems would not present a safety hazard e.g., by collapse, debris falling or degradation of floors and safety barriers which could result in personnel injury.The inspections discussed here are visual, although more specialized inspections, such as those involving ultrasonic thickness measurements are frequently used to complement visual inspection where components are accessible.Visual inspections consist of external visual inspection, internal visual inspection and remote visual inspection. These inspections and interpretation of their results are inter-related:

- Building external visual inspection needs to address all surfaces exposed to weather (roof, walls, floor, openings, concrete components, metal components, joints, etc.), including inspection of the sealing between foundation and asphalt, which requires access for inspection to eachroof.
- Internal visual inspection should address all accessible areas and surfaces in the interior (roof, walls, floor, openings, concrete components, metal components, joints, etc.

In addition to structural aspects, envelope integrity is important to keeping out water, and pests (vermin). Internal visual inspection can also provide evidence of such infestation, mould growth, or other signs of degradation.

If there is evidence of blockage or backup of internal or external drainage, remote visual inspection of the underdrainage should be carried out using a tethered televisioncamera to view the perimeter of the footing and the connection to the main drain. Assessment of the images would help identify next steps such as removal of any blockage, and whether piping repairs and/or replacements need to be carried out.

During SwS, the frequency of internal and external inspections for structural integrity should be continuously revised based on nature of the hazards and condition of the facilities. The general approach is to set a (conservative) higher frequency of inspection and gradually extend the intervals between inspection, based on the absence of issues.

In addition to the more formalized inspections referred to above, periodic “walkthrough” routines are recommended, especially for areas where changes in SwS conditions are most anticipated. This periodic visual surveillance plays an important part in identifying any changing field conditions on an on-going basis. Similarly, “walkdowns” of the grounds surrounding the structures (but not necessarily including building entry) should be carried out at least weekly and following major storms to identify any obvious change of condition. These should involve the visible (accessible) exterior of all buildings as well.

Table 2: An Example of a Checklist for Building Structure and Envelope Inspections Associated with Group A – Reactor Building

Inspection #	Material/Location	Some Typical Inspection Methods
1.	Concrete (External and Internal)	Visual(see note 1), impact hammer, crack measurement, non-destructive test (e.g. ultrasonic testing –UT), coring
2.	Brick (External) (see Note 2)	Visual
3.	Steel/Metal (External and Internal)	Visual, thickness measurement, torque wrench and/orfinger tightness check
4.	Roof (External) (see Note 2)	Visual, physical check (i.e. walking the roof feeling for soft spots that indicate water accumulating between the roof deck and roof membrane).
5.	Piping (Internal to Buildings)	TV camera – interior piping, non-destructive test (e.g. UT)
6.	Joints – Caulking and Sealants (Internal and External)	Visual, thickness gauge (loss of coating thickness), knife and tape (method for adhesion of metallic coating), testing for blistering of paints, testing for rust on painted surfaces
7.	Insulation (Internal)	Visual
8.	Coatings (Internal and External)	Visual, thickness gauge, knife and tape method for metallic coating, test method for blistering

Notes:

1. Field notes should be attached for all inspections. Photographs should be taken and captions applied as part of all visual inspections.
2. Applies to steel frame buildings with metal/brick/block cladding. May not apply to reactor building.

For internal inspections, a similar checklist for internal inspections can be created to take into account the typical indications of degradation illustrated in Table 1.

7. Lifecycle Considerations

The evolving experience with SwS in Canada and elsewhere has provided input to important questions concerning the safety and cost-effectiveness of keeping abandoned structures - especially those of light construction and with little or no radioactivity - in an acceptable state throughout a protracted SwS period. In general, international experience reflects a growing preference for prompt dismantlement of un-needed, non-contaminated systems and structures on the site. The rationale in each case appears to involve a combination of cost, safety, and environmental factors.

International OPEX illustrates that every extended safe enclosure situation is unique[13]. For example, are there potential other uses of portions of the larger, more permanent structures, their equipment or the space occupied by them? Would removing the turbine generators and surrounding equipment provide a cost-recovery opportunity? What would be the value to be assigned to making the turbine hall available for temporary storage, laying down during dismantlement, and eventually providing a unique hall for disassembly or assembly of large equipment? Uncertainties in the timing, location, design, and regulatory requirements for waste and used fuel further complicate the planning for such initiatives and limit the opportunities to implement cost-saving measures based on the answers to these questions. Without definitive waste routes, early dismantlement of contaminated structures would result in multiple-handling of waste packages and pose a compliance risk with respect to generally yet-to-be-approved waste acceptance criteria for the waste and used fuel disposal facilities.

Nevertheless, it should be possible to release most site buildings without a history of contamination for conventional demolition (i.e., by a demolition contractor operating within a “construction island”). Selective use of such contractors brings important experience for the detailed planning of these (and subsequent) dismantlement activities. In addition, typical activities for cost-effective use of external contractors during preparing for SwS could include:

- the decontamination and dismantlement of large components such as the main-circuits - which is a specialized and well-developed industrial technology,
- location of buried services which should be carried out during the transition to safe storage while experienced operations and maintenance staff are available. This information would contribute to updating of configuration documentation which is very important for planning and executing extended safe storage.

8. Conclusions and Recommendations

In general, effective approaches for SwS are well defined in IAEA and other documents incorporating lessons learned over many projects. Applying these lessons to the SwS of CANDU reactors requires these to be tailored to suit multi-unit reactor blocks on freshwater bodies, in cold climate, and taking into account some of the unique design features of CANDU reactors. Experience with CNLprototype CANDU reactors is a primary source of such lessons. Based on this experience,the following should be considered when establishing SwS on multi-unit CANDU sites:

1. As far as possible un-needed, uncontaminated structures including tanks, towers, electrical transformers, standby generators and outbuildings should be removed from the site during the preparation for SwS. This reduces surveillance and maintenance costs during extended SwS. Those which may be required to remain partially or fully in service, or whose removal is problematic will require case-by-case decisions regarding their removal.
2. Once the un-needed structures are demolished and fuel and waste removed, it may be possible to shrink the site footprint, reduce security costs and free land for other uses. In practice, this can be expected to be determined by the availability of suitable waste characterization, processing and disposal facilities and the time required to complete spent fuel transfer to dry storage.
3. Measures to assess and manage aging of structures on site will be needed. Of particular importance in this regard would be the reactor domes, wall to slab joints and those structures whose lower portions are in direct or indirect contact with the lake.
4. Degradation of plant internal conditions would be inevitable due to the aggressive Canadian continental climate and siting near water bodies. In SwS, Canadian reactors are

particularly susceptible to effects such as freeze-thaw damage, wave erosion, water ingress, water accumulation from condensation, and inadequate drainage.

5. Control of moisture in reactor buildings requires their temperature and humidity to be monitored and controlled, and may require heating and ventilation to prevent condensation, mould-growth or local freezing. Ventilation exhaust on a unit by unit basis should be considered to avoid cross contamination between the units.
6. The presence of potentially contaminated water in reactor buildings, and the ongoing need for decontamination of equipment (including salvage) requires planning for continued availability of systems for dehumidification, collection, monitoring, treatment, transfer, and disposal. Operating reactors frequently take advantage of their Component Cooling Water (CCW) outflows for dispersal of low activity waste-water, a facility which may not be available on-site once CCW flow ceases.
7. Potential sources of occupational hazards such as asbestos, mercury and PCBs should be systematically addressed during preparation for SwS in order to prevent contamination spread throughout the plant – a phenomenon promoted by weather-induced degradation.

In general, aging effects during SwS can be managed through a combination of inspection and maintenance. Periodic inspections would be needed, whose frequency and focus address the most vulnerable systems and structures. Inspection frequencies can be expected to vary from weekly rounds for areas subject to rapid change in condition, to years where slow physical changes may be occurring. Initial frequencies can be reduced as SwS conditions are confirmed to be stable over longer periods. Out-of-servicebuildings and structures with common features and needs for surveillance and maintenance should be considered together in defining periodic inspections.

9. References

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