Compilation and analysis of national and international OPEX for Safe Enclosure prior to decommissioning

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ABSTRACT

Around the world, a large number of aging nuclear plants are approaching final shutdown. While this is largely driven by plants reaching the end of their design life, economic factors such as low gas prices (in North America) and the smaller unit size of early commercial reactors are important contributors to this trend. In several instances, economic pressures have resulted in a need for a more rapid transition to Safe Enclosure than originally anticipated. Thus plans for this transition taking into account experience with Safe Enclosure periods of varying lengths are being actively prepared in many jurisdictions.

The IAEA as well as other national and international authorities have long recognized the importance of the topic of Safe Enclosure and provided guidance [1-7], and the IAEA has recently undertaken a study of "Lessons Learned from Deferred Decommissioning of Nuclear Facilities" [8].

Beginning with preliminary experience from Canadian CANDU reactors in extended shutdown or safe enclosure, this paper aims to compare this experience with the larger pool of experience from the international community to:

- *classify the main issues or themes,*
- *examine means to mitigate these, and*
- *formulate general measures of "good practice".*

Compilation of this experience represents the first steps towards a comprehensive, searchable database potentially of use to many in the decommissioning community. Tabulation and analysis of the complete list (comprising approximately 70 cases) has provided the "short list" of issues presented in Table 1. Examples of the most important listed issues are discussed. The authors' objective is to stimulate interest in extending this compilation. In this way it will continue to grow and benefit all those preparing for transition to decommissioning.

Introduction: The CANDU Reactor Fleet in Canada

The location and status of CANDU reactors in Canada is summarized in Table 3 at the end of this paper. Most of these reactors are in Ontario, and were built by Ontario Hydro in the 1970's and 1980's. CANDU reactors employ zirconium alloy pressure tubes whose full-power life is typically between 20 and 30 years. Keeping these reactors in service for longer periods requires replacement of the pressure tubes, part of the refurbishment option applied or planned for the largest of the reactors in the fleet. Refurbished reactors can therefore be expected to continue operation for 20-30 years. The economics of refurbishment of the smaller older reactors (e.g. G1, Pickering 1-8) is not generally favourable, so efforts at life extension through refurbishment is focussed on the Bruce and Darlington reactors. Planning for refurbishment of the Darlington reactors and for extended safe enclosure of the Pickering reactors is well advanced, with shutdown expected around 2020.

Strategic Options for Decommissioning and their Application to Canadian CANDU Reactors.

International (IAEA) guidance and various national standards [1-7] generally consider three strategies for decommissioning: (A) Immediate (prompt) dismantlement (B) Deferred dismantlement (C) Entombment. The most common approach historically, and the current preferred approach for CANDU reactors in Canada involves deferred dismantlement for NPPs. In this case, with the exception of some uncontaminated outbuildings, little or no dismantlement of facilities – reactor buildings, turbine halls etc – is carried out. This approach has been preferred in order to allow:

a) decay of short-lived, high energy gamma radionuclides to minimize occupational dose,
b) the licensing and construction of fuel and waste disposal,
c) funds to be accumulated for decommissioning,
d) management, staff and other resources to focus on their primary (operational) responsibilities, or multi-unit sites where some units remain in operation or transition, and
e) evolution of the technology and practices for safe dismantlement.

The most important factors affecting the current Canadian approach appear to be points a, b, and c, with b) – the schedule for availability of disposal facilities for decommissioning wastes and the fuel stored onsite - being the likely determining factor. At present the time-frame for initial L&ILW waste disposal in Ontario is likely to be the early 2020's, and for fuel disposal, the mid 2060's. The timetables for both of these are uncertain due to the extensive public consultation, stakeholder engagement, and licensing processes. Furthermore, formal, public discussion of VLLW disposal of CANDU Reactor waste has not begun, despite the fact that waste that could be classified as such is likely to constitute the largest single waste volume. OPG, which is responsible for decommissioning of both Bruce Power and its own reactors, anticipates a period of safe enclosure of about 30y so that there can be reasonable alignment between reactor dismantlement and the availability of fuel disposal.

Other nuclear power plants – particularly those in Europe - have proceeded with prompt dismantlement in the absence of radioactive waste disposal facilities by "repurposing" a portion of onsite facilities [8] to store decommissioning wastes, an option that could be explored in Canada in light of the large plant site areas and presence of large-volume structures associated with the multi-unit sites such as the power house. In general [3], the main factors motivating this immediate dismantlement have been:

i. a desire to retain skilled staff with knowledge of the plant specific to decommissioning,
ii. community pressure to maintain local employment,
iii. concern for structural and building envelope integrity leading to potential spread of contamination during extended safe enclosure,
iv. opportunities/need for re-powering and alternative use of the land and structures,
v. regulatory concerns that deferred decommissioning may lead to inter-generational debt transfer,
vi. availability of specialty firms with experienced staff and proven technology for safe dismantlement at reasonable cost,
vii. availability of effective clearance techniques and/or waste disposal paths, especially for waste containing very low levels of radioactivity (VLLW),
viii. the desire to proceed in a known regulatory environment, avoiding potential future restrictions or loss of waste disposal pathways, and
ix. to minimize possible future liabilities.

Recently, OPG undertook a project to establish options for repurposing of the Pickering site, and to consult with the communities involved concerning these options [10]. For a built-up site such as Pickering - which is now within a major metropolitan area - potential re-use of the land in a manner consistent with its value and regional growth objectives becomes paramount. These considerations inevitably put increasing pressure on a utility to accelerate activities permitting release of at least a portion of the land not required for future generation needs. Then IAEA has recently released an instructional video looking at many of the above factors as they pertain to major sites in Europe and Canada [11].

Experience with Extended Safe Enclosure in Canada.

Several of the reactors listed in Table 3 have been shut down for extended periods, and the experience gained from these shutdowns has contributed to the planning for extended safe enclosure. OPEX includes:

- incompletely drained process systems leading to leaks and contamination spread,
- problems with drainage collection, 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, and

iii. resin storage tanks (below grade) have been a source of concern for leakage of radioactivity to the environment. Leaving the resins in the storage tanks raises issues of their "setting up" during storage, making eventual removal difficult, and tank leakage could contaminate plant lower areas, structure and soil.

The longest periods of safe enclosure have been experienced by AECL's CANDU Prototypes at three sites (Table 3): Douglas Point (1968-1984), Gentilly-I (1972-1979) and the Nuclear Power Generation (NPD - 1962-1987). These reactors were placed in extended safe enclosure (Storage with Surveillance or SwS) in the absence of suitable waste disposal, and to take advantage of gamma-decay. All three have been shut-down for between 20 and 30 years. The most commonly encountered issues at these sites are summarized below [8].

Prolonged safe enclosure 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 structures communicating with the lake need to be considered when configuring these for safe enclosure.

Their proximity to these water sources particularly affects auxiliary buildings such as those associated with water treatment or pumping having 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 safe enclosure, 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 safe enclosure.

OPEX for Nuclear Plants in Extended Safe Enclosure: Organizing the Issues

Review of International experience with extended safe enclosure drew heavily on an IAEA consultant's report on this topic (8), prepared by experts who articulated 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 due to water entering buildings. For example, to a potential combination of water accumulation (from seepage, in-leakage, or condensation), entry/infestation via gaps in the building envelope, and daily/seasonal temperature-cycling and mould growth associated with spaces subject to periods of warm and damp conditions, corrosion of structural elements, structural failure of miscellaneous infrastructure elements, 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 (e.g. 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	Observe 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
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 safe enclosure. However, deterioration of fixatives may lead to subsequent loose contamination

Issue #	Potential Issue	Typical Indications of degradation,
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 main potential hazard. Closed/sealed areas may build up contaminants, have low O2
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
17	Inadequate “Housekeeping”, & 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

Mitigation of the Effects of Extended Safe Enclosure on Canadian CANDU Reactors

Guidelines, Codes and Standards

The starting point for mitigation of the above issues is the application of regulatory guidelines, codes and standards. Of particular utility amongst the IAEA references listed, is the content of Section 6 of [4], which breaks down the “critical tasks” associated with planning and execution of safe enclosure. Details of these activities provide a useful checklist:

1. Characterization of the installation (Survey immediately after operations are terminated)
2. Waste Management Plan (Separated by preparation and operation of safe enclosure)
3. Upgrading (of systems to remain in operation) and shutdown of systems (or portions)
4. Control of Areas (Access control to both to the site and to structures on the site)

5. Information Management (configuration restoration and retention of essential records)
6. Surveillance and Maintenance (equipment lists, maintenance and inspection activities)
7. Activities during safe enclosure (e.g. removal of superfluous equipment and structures)

In addition to those from the IAEA and National sources, provincial and local codes bear on the identification of the development of a list of “best practices” to mitigate the issues identified in Table 1.

For example, in Ontario, Canada, there are no specific requirements within the Codes which would be directly applicable to “disused” buildings, i.e., those disconnected from services and not occupied. The Codes do identify measures which apply to the demolition of facilities. Although, the measures may not be directly applicable to nuclear facilities, they will certainly surface in the form of public reaction to the condition of facilities left in safe enclosure for a protracted period of time. In general the Codes would discourage owners from allowing structures to become dilapidated, structurally unsound or degraded by permitting pests or moisture to enter the buildings. Similar, more stringent considerations, would likely apply for buildings which would be partially in service. For partially in service buildings full compliance with the Occupational Health and Safety policies could be anticipated.

Good Engineering Practices

At present, the requirements in the existing applicable guidelines and proven practice, codes and standards, supplemented by issues identified from the Canadian and International OPEX analysis, could be best presented as comprising “good engineering practices”. Those practices would allow establishment of the facility condition at the beginning of the safe enclosure, and what the facility should be during the period of the safe enclosure. Such practices aim to maintain the systems, structures and components in a stable and safe state by defining a set of specific criteria (actions) and related inspections to meet uniform, acceptable conditions for extended safe enclosure.

A typical list of such practices should include identification of systems remaining operational, isolation of buildings, reconfiguration of systems (electrical, communication, fire protection, ventilation, heating, etc.), isolation and draining/venting/flushing and removal of systems (water, air, gas, solids,), isolation, conditioning and removal of equipment and machines (turbine, generator, large storage tanks, etc.), identification of all areas with radioactive contamination and removal of unwanted/unneeded materials (radioactive, nuclear/radiological, hazardous and all miscellaneous materials), liquids and equipment on floors and other surfaces.

Suggested Measures to Mitigate Safe Enclosure Issues for Canadian CANDUs

The activities required to prepare Group A “Reactor Buildings” (see “building groups” in section “Periodic Inspections” below) for safe enclosure would include fuel and heavy water removal from the reactor and isolation of equipment not required during safe enclosure. Chemical decontamination of primary cooling channels may be carried out, although the value of this is reduced by the length of the safe enclosure period envisaged. Building ventilation may be configured (or resizing) to provide breathable atmosphere during entry and for air distribution, control and monitored exhaust, heating and dehumidification to prevent condensation, mould growth or local freezing. Drainage modifications may be needed to allow collection and removal of water due to in-leakage, condensation, etc., and annunciation for the drainage sumps, establishment of a central collection, sampling and transfer point for all the drainage collected, shutoff and isolation of all service water supplies. The main reactor building crane may be de-energized but maintained in a state that it can be readily returned to service if needed. Early removal of asbestos would limit its spread throughout the plant. Removal of liquid and solid PCB sources with the highest concentrations is foreseen. Where auxiliaries are not kept in service, local auxiliary system and procedural support will be needed, e.g. lighting, heating, air supply or local ventilation, communication, air sampling and monitoring at Zone interfaces.

Good engineering practice to establish the conditions at the beginning of the safe enclosure would also include complete removal of all stored resins, filters and hazardous materials, installation of barriers to control infestation, reduction of security footprint to include only that required for controlled substances, removal of all loose contamination, establishment of a monitoring program for any effluent streams, reconfiguration of the fire detection and suppression systems, removal of stores inventory for support systems and warehousing it offsite, establishment of laundry processing offsite, reconfiguration of communications, equipment salvage, and isolation or reconfiguration of all electrical systems and components.

Reconfiguration of the shoreline to increase its long-term stability and isolation of structures communicating with the lake should be considered. A possible method of isolation between the building and the lake would be a double wall barrier, i.e., with an inner space between the isolating barriers that can be inspected. The first isolation barrier would be installed at the water-side and the second barrier installed flush with the building wall. Furthermore, the space between the two barriers would then be covered by insulation and a steel plate. Filling of this interspace between the two barriers should be explored after a period of several years of proven successful implementation of the double wall isolation.

Periodic Inspections for Buildings During Safe Enclosure.

While most buildings can be designated as “out of service” during safe enclosure, some services may still be required in those designated as “partially in service”. For example: lighting, heating, ventilation, electrical power, drainage, emergency communication and service cranes may all be required during the safe enclosure, together with procedures to support their operation and maintenance.

The aim of periodic inspections is to maintain conditions that consider the physical characteristics and hazards of SSCs during safe enclosure, viz to:

- Eliminate risks to inspection personnel;
- Maintain reliable conditions for SSCs that remain partially in service; and
- Minimize the impacts of gradual degradation on eventual demolition and removal.

Most of the inspections required during safe enclosure would be visual. Guidance for observations and data to be recorded should be included in walk-down personnel training. Photographic records should be kept for comparison during subsequent inspections. Due to the inherently long periods involved, standardized training for inspectors is required, and should include descriptions and example photographs of modes of degradation.

For buildings that are routinely occupied or frequently entered during safe storage, the inspection practices should be tailored to the activities and operational systems and components in those buildings. For example, inspection checklists may be prepared but walk-down route specifications will likely not be necessary. Also, checklists do not need to be prepared to duplicate operating procedures and logs for systems, and components that remain in service.

A range of building purposes and types suggests that for inspection purposes, individual structures on the plant site be grouped according to common features, for example:

Group A – Reactor Buildings
Group B – Turbine Halls, Service Building
Group C – Deep Structures (e.g. deep basement and connection/proximity to water intake systems)
Group D - Steel frame buildings with metal\brick\block cladding
Group E – Tanks and Towers

There are a large number of buildings which comprise a typical nuclear generating station in Ontario. Figure 1 illustrates a multi-unit CANDU nuclear generating station site, individual buildings within the site and a portion of the water intake channel which is connected with the lake. Division of the various buildings into the Groups would facilitate applying the various assessment requirements and recommendation to the buildings, including appropriate inspections.

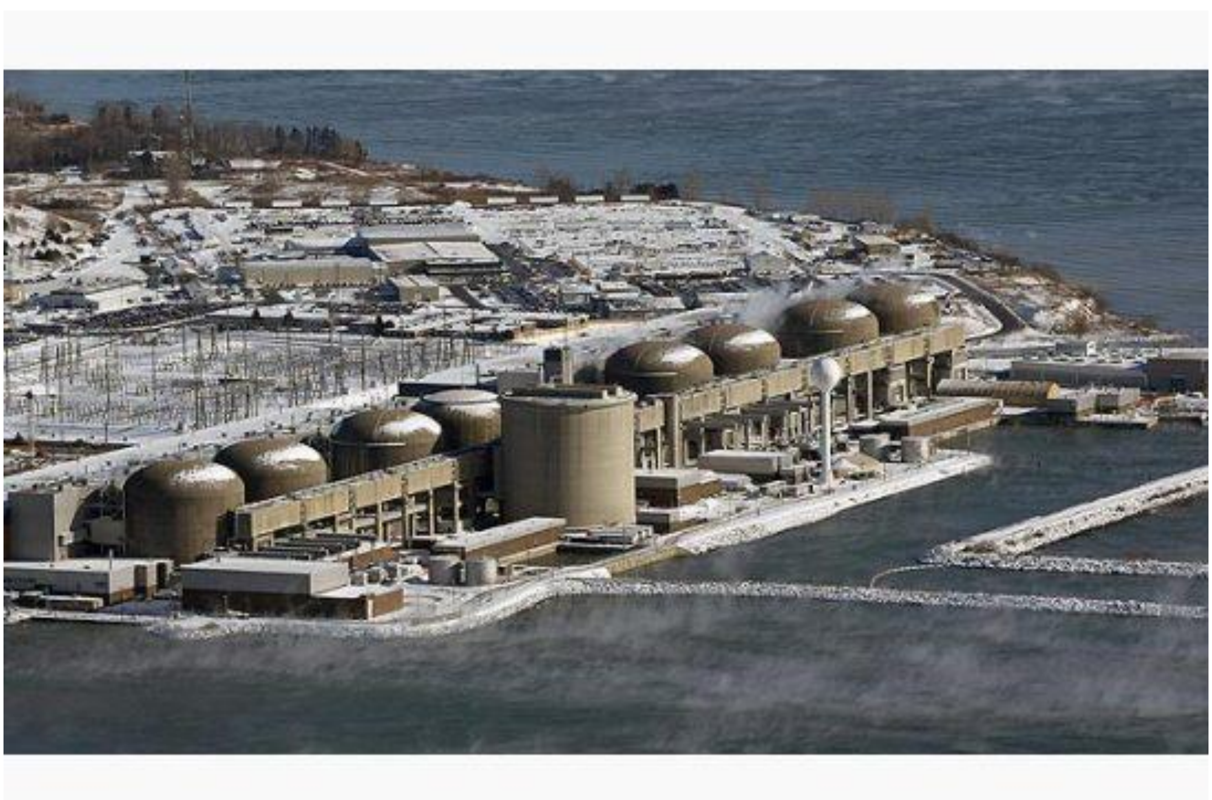

Figure 1: Pickering Nuclear Generating Station near Toronto, Canada

Periodic walkdowns (also referred to as “walkthroughs”) and inspections during the safe enclosure are needed to address the building structural and “envelope” integrity as well as general conditions. 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, resulting in personnel injury). Internal inspections would be inspections of all accessible areas and surfaces (inner, outer and surface interfaces) in the interior of the building including roof, walls, floor, openings, concrete components, metal components, joints, etc. “Walkthroughs” are a simplified form of inspection, following a predetermined path, which would be illuminated by permanent or fixed lighting, and kept free of hazards for the safety of the workers performing the “walkthrough”.

Inspections should include a baseline inspection (an inspection to act as a reference) which would be followed by subsequent inspections established at a given frequency. From the author’s assessment of Canadian CANDU reactors, an initial inspection frequency of once per year should suffice after baseline conditions are established. The frequency of subsequent inspection should be based on the results of these, and the period can be gradually increased to every 5 years. Frequencies should be set and revised systematically and involve the owners, the inspection agency involved and oversight authority. The typical minimum frequency of the “walkthrough” would be one (1) per month.

The elements to be monitored during safe enclosure and the typical inspection frequencies for building elements is suggested in [4] as initially every 6 months followed by yearly, with a major structural survey every 5 years and leak rate tests where applicable every 2 years.

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, 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 or, finger 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 &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, External	Visual, thickness gauge, knife and tape method for metallic coating, test method for blistering

Notes:

1. Field notes should be attached. Photographs should be taken and have captions.
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.

Conclusions and Recommendations

In general, effective approaches for Safe Enclosure are well defined in IAEA and other documents incorporating lessons learned over many projects. Applying these lessons to the safe enclosure of CANDU reactors requires these to be tailored to suit multi-unit reactor blocks on freshwater bodies, cold climate, and taking into account some of the unique design features of CANDU reactors. Experience with AECL prototype CANDU reactors is a primary source of such lessons. Based on national and international experience in establishing and maintaining Safe Enclosure for long periods, The following should be considered when establishing safe enclosure 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 site during the preparation for safe enclosure. This reduces surveillance and maintenance costs during extended safe enclosure. For those which may be required to remain partially or fully in service, or whose removal is problematic, a study should be carried out and to allow that case-by-case decisions be made 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, reducing security costs and freeing land for other uses. In practice this will be determined by the time required to complete spent fuel transfer to dry storage, and stored wastes such as resins (which are generally stored below grade) to be removed.
3. Condition Assessments should be carried out and Aging Management Plans drawn up. Of particular importance in this regard are 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 is inevitable due to the aggressive Canadian continental climate and siting near water bodies. In safe enclosure, Canadian reactors are particularly susceptible to effects such as freeze-thaw damage, wave erosion, water ingress (which can itself degrade structures), water accumulation from condensation, inadequate drainage & collection.
5. Control of moisture in reactor buildings requires their temperature and humidity to be monitored and controlled, likely necessitating heating and ventilation air flow to prevent condensation, mould-growth or local freezing. Ventilation exhaust on a unit by unit basis needs to 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 its removal (e.g. drying), collection (including drainage sumps), monitoring, treatment, transfer, and disposal. Canadian CANDU reactors take advantage of their CCW outflows for dispersal of low activity water, a facility not available on-site once CCW flow ceases.
7. Systematic removal of potential occupational hazards such as asbestos, mercury and PCB should be carried out during preparation for safe enclosure in order to prevent contamination spread throughout the plant – otherwise inevitable due to climatic effects.
8. Periodic inspections are required whose frequency and focus address the most vulnerable systems and structures. Inspection frequencies will 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 safe enclosure conditions are confirmed to be stable over longer periods. Buildings and structures with common features and needs for surveillance and maintenance should be considered together in defining periodic inspections.

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Table 3: Canadian CANDU Reactors

Operator	**Name**	**Unit**	**Capacity (MW_e)**	**Status: Shutdown (SD), Planned Refurbishment Start/Finish (9), Refurb-Returned to service (RTS)**
Ontario Power Generation	Pickering A	1	540	SD ~2020
		2	540	SD-1997
		3	540	SD-1997
		4	540	SD ~2020
	Pickering B	5	540	SD ~2020
		6	540	SD ~2020
		7	540	SD ~2020
		8	540	SD ~2020
	Darlington	1	881	2016/2019
		2	881	2019/2022
		3	881	2021-2024
		4	881	2022-2025
Bruce Power	Bruce A	1	750	Refurb-RTS 2012
		2	750	Refurb-RTS 2012
		3	750	2019-2022
		4	750	2016-2020
	Bruce B	5	785	2022-2025
		6	820	202402027
		7	785	2026-2029
		8	785	2028-2031
Ontario Hydro	Nuclear Power Demonstration	1	20	SD-1987
	Douglas Point (PHWR Prototype)	1	220	SD-1984
Hydro-Québec	Gentilly (BWR Prototype)	1	275	SD-1997
		2	675	SD-2012
NB Power	Point Lepreau	1	635	Refurb-RTS 2012