Update of Severe Accident Management Guidelines at Point Lepreau Generating Station

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Abstract

In response to the events at Fukushima Dai'ichi, the CANDU Owners Group (COG) embarked on Joint Project JP4426 to update the overall framework for Severe Accident Management Guidelines (SAMG) to reflect lessons learned. This includes enhancements to consider SAMG in the shutdown/low power state, more extensive consideration of Spent (Irradiated) Fuel Bay (SFB) events and to address plant habitability issues. Point Lepreau is in the process of applying the COG methodologies in developing site-specific basis documents and revisions to SAM guidance documents. The paper will also describe SAMG for the Canister site, emergency procedure revisions to deal with extreme natural events and recommendations for evacuation of protective zones based on plant state criteria.

1. Introduction

Point Lepreau Generating Station is unique in several ways compared to the rest of the nuclear generating stations in Canada and this has resulted in some differences in the way emergency response is approached in general and Several Accident Management in particular.

Point Lepreau is unique in having only a single reactor unit in a small utility, for which this single unit represents 25 to 30% of the electrical generation in the province. Point Lepreau is unique in that the unit is a Candu-6 and while comparable with similar designs in Romania, South Korea, China and Argentina, there are some significant design differences from the multi-unit vacuum containment Candu designs unique to Ontario. The plant is also unique in that it is located on the east coast of Canada with a fine view of the Bay of Fundy rather than being located on a lakefront. The plant's location in a relatively low population zone on a peninsula more readily allows for evacuation in an emergency, and the province has a well-integrated emergency response capability using an all hazards approach in which the nuclear emergency response capability is included.

The NB Power approach to nuclear emergency planning and response has been largely based on IAEA guidance, and NB Power continues to closely follow developments in this area.

2. Emergency Response Organization

The Emergency Response Organization at Point Lepreau is modelled on the Incident Command System (ICS); this is activated for any type of emergency and also at the alert level for radiation contingencies. The Shift Supervisor is the Incident Commander and Operations Section Chief. Incident command may be delegated during larger incidents to the on-call Station Director once the command post is operational and fully briefed on the contingency and response status.

A key feature of the Point Lepreau Incident Command System is the composition of the Planning Section which takes the role of the technical support organization and in a severe accident uses the Severe Accident Management Guidelines (SAMG) to direct the tactical response to the incident. As with the entire response under the Incident Command System, the scale of response of the Planning Section can be expanded to deal with the scale and nature of the incident; however, NB Power believes the core membership of the Planning Section is key to its success.

The Planning Section Chief is a current or former Shift Supervisor and is on-call during the training week of the shift cycle. This ensures that the Planning Section Chief has the same operational and systems knowledge and speaks the same technical language as the Operations Section Chief with whom close interaction is required. This is key to the success of the advisory role undertaken by the Planning Section during response to a design basis incident and key to the ready acceptance of recommended strategies during the response to a severe accident. The Operations Shift Supervisor has the advantage of having been trained for and played as the Planning Section chief during drills and exercises, so is fully familiar with both roles. Other core members of the Planning Section are two specialists assigned to Fuel Cooling and to Containment/Release mitigation respectively: the Fuel Cooling Specialist is a current or formerly authorized Control Room Operator, while the Containment Specialist is a member of the Engineering Department with experience in Containment and its subsystems. The fourth core member of the Planning Section is a Senior Technical Advisor with experience in Reactor Safety, Operations support during plant outages, and has served as or currently is a member of various inter-utility working groups. The Planning Section thus brings to the table a broad range of Operations, Reactor Safety and Technical expertise, and the necessary level of relationships with other nuclear support staff both within NB Power and within the broader nuclear industry.

A key role for the Planning Section is to monitor critical safety parameters and, where necessary, to provide advice to off-site respondents on public protection action recommendations based on plant conditions. The two key advisory points related to severe accidents are:

- Evacuation of the Precautionary Action Zone (PAZ) in the event that severe accident entry conditions are met. The PAZ for Point Lepreau is a 4 km radius around the station. This advisory is based on the existence or imminence of severe core damage even with an intact containment, on the basis that containment is going to be challenged by increased pressure and there would be insufficient reaction time for a reactive evacuation should that fail.

- Evacuation of the Urgent Protective Action Zone (UPZ) in the event that, during a severe accident, containment pressure increases give rise to an anticipated need to vent containment using the emergency filtered venting system. The UPZ for Point Lepreau is a 12 km radius around the plant. This radius was established on the basis that despite the best design intentions of retaining the radioactivity during containment pressure increases and, only if absolutely necessary, releasing it through a very high grade high capability filter system, complications might nevertheless arise which lead to a significant sustained unfiltered release. If such a release were to occur, it could travel quickly beyond the 4 km PAZ boundary to an estimated distance requiring evacuation of 12 km.

The radius around the station is specified in the above cases, rather than the downwind direction, as wind directions are prone to rapid changes locally and timing and duration of unintended releases is not predictable. NB Power's understanding, based on discussions with NB Emergency Measures Organization (NBEMO), is that based on a recommendation from the station about such plant conditions, under favourable weather conditions a proactive evacuation of the 20 km zone around the station would be undertaken before any potential release. This avoids the complexity of having to undertake a reactive evacuation under known contamination conditions involving decontamination of the evacuees.

Drill practice based on a wide variety of scenarios involving a full range from non-emergency severe weather events through design basis events to severe accident response with and without Emergency Mitigating Equipment have shown the overall response has sufficient depth and breadth to effectively respond. Another key part of the overall response design is that response procedure prompts ensure that more than one individual role ensures that critical issues get addressed. This allows for effective response for events where command and control is disrupted and designated respondents are not available to fill all roles.

3. Severe Accident Management Guidelines – Reactor in Power Operation

At Point Lepreau, Severe Accident Management Guidelines (SAMG) are entered directly from the key generic Emergency Operating Procedures (EOPs) assuming the Main Control Room is directing the response. Entry criteria are based on no heat transport system header subcooling and EITHER low moderator level OR very high radiation at the equipment airlock. For fast developing scenarios, the Main Control Room would transfer from EOPs to SAMG Control Room Guide #1 (shift supervisor initial response), which directs the initial phase of control room response to a severe accident. In scenarios in which the Planning Section had sufficient time to activate, become fully operational and pro-actively develop an action plan for severe accident response by the time entry conditions were met, then on entry to SAMG, tactical command of the incident response would transfer to the Planning Section and the Operations Section would follow the action plan and provide available plant response data as outlined in SAMG Control Room Guide #2 (ICS Planning Section Functional).

Point Lepreau does not have an intermediary level between the generic EOP response and SAMG where Emergency Mitigating Equipment (EME) would be used. Instead, the use of Emergency Mitigating Equipment is called up directly from any relevant event specific Abnormal Plant Operating Procedures, the generic Emergency Operating Procedures and Severe Accident Management Guidelines, in essence from any accident response procedure where it may provide necessary benefit.

Both the provision of Emergency Mitigating Equipment and the addition of other features post-Fukushima Dai'ichi have extended the options available for Severe Accident Management, providing a larger tool chest to facilitate response to extreme events.

- Steam generator (boiler) secondary side make-up to prevent progression to a severe accident– additional water addition options using EME through the Emergency Water Supply either directly at the EWS pump-house or at the Secondary Control Area adjacent to the Reactor Building. .
- Heat Transport System makeup – the connection points are the same as for the steam generator make-up (see above) with the exception that the flow is directed to the HTS via Emergency Core Cooling pipework
- Moderator System makeup – additional water addition via a firewater/EME connection to the moderator purification system (planned for 2015), plus EME electrical capability to power a moderator pony motor (planned for 2015)
- Calandria Vault Makeup – additional water options via EME supplement the firewater addition capability provided during refurbishment, and EME electrical capability to power an end shield cooling pump
- Additional severe accident-grade reactor building and calandria vault level indication instrumentation, and EME capability to power key instrumentation for monitoring and controlling plant systems

4. Severe Accident Management Guidelines – Shutdown State

At Point Lepreau, Abnormal Plant Operating Procedures (APOPs) and generic Emergency Operating Procedures (EOPs) are designed for use only when the reactor is in power operation: they do not cover the shutdown state. For outages, this contingency response role is managed with an Outage Heat Sinks Management Manual.

Revisions to the shutdown state contingency response strategy are in progress to incorporate call outs for EME deployment and use, and to interface with SAMG. There are some additional considerations for a major incident developing from a shutdown state, such as; the potential for major equipment outages; breaches in primary, secondary or containment boundaries; disabling of some automatic safety system responses applicable at full power conditions; the lock-out and disabling of moderator makeup provisions for the Over-Poisoned Guaranteed Shutdown State (OPGSS); and, the generally longer response timeframe available for accidents from a shutdown state. However, the ultimate strategies for managing a severe accident are broadly similar to those for at-power operations but the available response options may be significantly different.

In the event that a serious shutdown state contingency were to deteriorate to a severe accident, the Outage Heat Sinks Management Manual will interface with our Shutdown State SAMG, which describes the additional issues requiring consideration for Severe Accident Management from a shutdown state before providing entry into the SAMG guidance developed originally for entry from power operation. The overall work flow is provided in Figure 1.

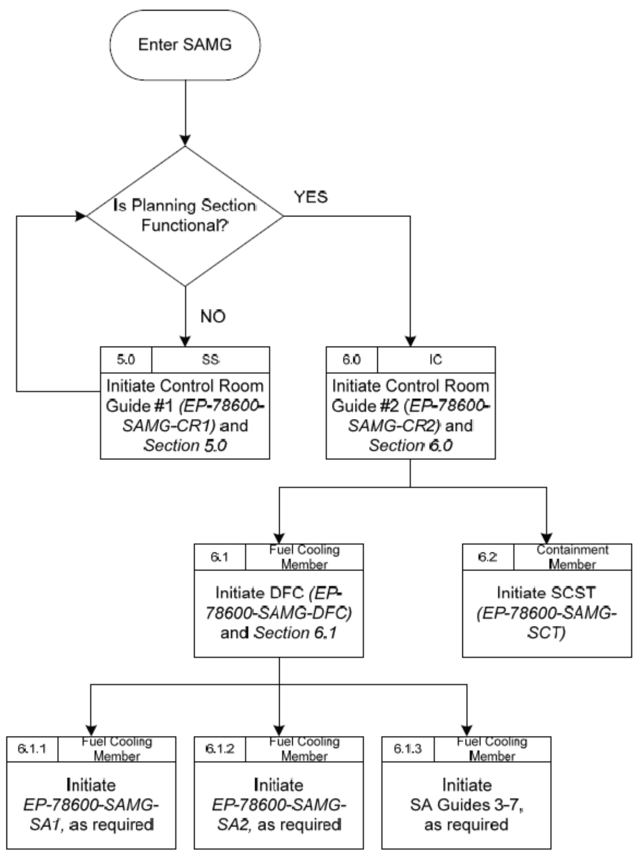

Figure 1: Overall Shutdown State SAMG Work Flow

The entry conditions into the shutdown state SAMG are as follows:

A. Measured dose rate > 1Sv/h at the Service Building equipment airlock door

AND

A.1 Subcooling margin close to 0ºC if Heat Transport System (HTS) is full

OR

A.2 Header level = 0 or Irrational if HTS is drained

OR

B. Authorization from the Shift Supervisor or the Incident Commander (IC)

One of the first steps in attempting to prevent degradation of core conditions is to address moderator circulation and inventory. Normally, D_2O supply sources would be utilized for the make-up. However, one primary consideration when making up water to the moderator during SAMG execution in the Over-Poisoned Guaranteed Shutdown State (OPGSS) includes potential positive reactivity that may be inadvertently added if heavy water is injected that might dilute the moderator poison inventory. To alleviate this concern, only light water will be injected into the moderator via a moderator purification circuit connection point that will be installed by the end of 2015, and also the Shift Supervisor is directed to consider the status of shutdown systems to respond to any reactivity concerns. As NB Power progresses towards implementation of an alternate rod-based GSS (RBGSS) strategy, it may be possible to admit D_2O to the moderator; however, further work is required to determine the acceptability for doing so.

Other plant state considerations must be made in choosing to inject to the HTS as well via the high pressure Emergency Core Cooling (HPECC) injection valves. If the PHT is drained at the onset of the initiating event, injection of HPECC into a partially draining HTS could cause water hammer effects and challenge HTS integrity. Depending on available options and the status of the HTS, other options, such as medium pressure ECC, may need to be considered before initiating HPECC.

Consistent with SAMG for the at-power state, challenges to containment in the shutdown state are also a prime consideration. While the reactor is in OPGSS, Point Lepreau Operating Policies and Principles allow for containment isolations to be opened subject to a 30-minute recall time upon detection of an initiating event that could progress to worse consequences if not mitigated. The box-up of containment will likely have been initiated through the Outage Heat Sink Management Manual; however, the shutdown state SAMG also includes a step to confirm that the action is being taken.

5. Severe Accident Management Guidelines – Spent Fuel Bay

Candu Spent Fuel Bays have significant differences from the elevated Spent Fuel Pools at the Fukushima Dai'ichi BWRs. However, there were some major issues with speculation during the Fukushima Dai'ichi aftermath regarding spent fuel cooling which contributed to a need not only to ensure Point Lepreau can deal with severe events at the Spent Fuel Bay (SFB) but also to deal with scenarios that were speculated to have happened at Fukushima Dai'ichi. During the first weeks after the event, various statements were issued on whether:

- spent fuel bays had boiled dry or fuel remained covered,
- spent fuel had been ejected from the pools,

- enriched spent fuel and adjacent unused fuel may have reached criticality,
- uncovered fuel had generated hydrogen to cause the major explosion in units that had been shut-down at the time of the initial event, and
- pool wall integrity may have been structurally compromised by the initial beyond design basis earthquake, subsequent repeated aftershocks and overheating of uncovered spent fuel.

In the event the Spent Fuel Bay suffered a sustained total loss of cooling it would take a significant time, of the order of days depending on the initial spent fuel bay heat loading, for the fuel to heat the water close to boiling and many more days to uncover spent fuel and eventually boil dry. This allows significant time to provide for inventory makeup and restoration of cooling. The original plant design provided for emergency makeup to the Spent Fuel Bay from the firewater system. Use of this capability is covered by an Emergency Standard Operating Sequence initiated from Spent Fuel Bay alarms. The provision of EME has supplemented this with inventory makeup capability which bypasses the firewater system to provide capability using an independent diesel driven EME pump and hose delivery system to a fire monitor directing a stream or fog pattern into the SFB.

For most scenarios this would be sufficient: the two additional extremes required from Fukushima Dai'ichi speculation relate to the potential for an extreme event to result in extensive delays (of the order of days) in being able to start to replenish spent fuel bay inventory per the above provisions. These extremes assume the fuel may have been extensively uncovered, and now has embrittled sheaths that will fail when re-wetted and has significant potential for hydrogen generation. This could lead to explosive mixtures which might demolish the building structure causing permanent loss of confinement and collapse onto damaged fuel, increasing fission product releases to the environment.

At the extreme, Spent Fuel Bay (SFB) severe accident management, in addition to providing for inventory makeup using monitors in the fog position (to condense steam and wash out radioactive contaminants) rather than a straight stream or more severe spray stream, has to allow for fire monitor fogging of potential radiation release points and for venting the building to disperse potential confined space hydrogen accumulations.

The objectives of the SFB severe accident management guidelines are to:

- Initiate monitoring of prioritized severe accident and severe challenge parameters against setpoints that trigger Emergency Standard Operating Sequence and/or Enabling Instructions for execution by Control Room staff.
- Perform remedial actions for conditions which might challenge the integrity of the SFB building and remedial actions to recover SFB water level.
- Initiate monitoring of long term concerns using the Severe Accident Monitoring and Recovery Log once diagnostic flowchart and severe challenge parameters return to acceptable and stable values.
- Provide criteria for termination of Severe Accident Management Guidelines.

The severe accident entry criteria for the Spent Fuel Bay assume that the methods provided for in the Emergency Standard Operating Sequence were not successful and includes any of the following criteria being met:

- SFB water level < 11.65 m (38'-3")
- Measured gamma dose rate > 1 mSv/h at the SFB swinging door
- Measured gamma dose rate > 1 mSv/h at the door to the spent fuel receiving and transfer bay AND measured gamma dose rate < 1 Sv/h at the Service Building-side door of the equipment airlock.

A cautionary note is provided that in the event of a simultaneous incident with the reactor, care must be taken to ensure that the radiation dose rate measured in the SFB (which is intended to be used to measure the SFB water level related to reduced shielding of the spent fuel) is indeed coming from the spent fuel and not from the reactor building (R/B) ventilation intake ductwork or the R/B equipment airlock, and that it is not related to venting of the R/B via the adjacent containment emergency filtered vent system.

Figure 2 provides an example of the spent fuel SAMG actions. The structure is similar to EOPs and APOPs to facilitate ease of use by and training for operations staff.

6. Severe Accident Management Guidelines – Canister Site

The canister site comprises extremely robust reinforced concrete structures for medium term storage and passive cooling of aged spent fuel that no longer requires active cooling in the Spent Fuel Bay. The only types of events that could be envisaged to cause significant damage to spent fuel in these structures would be well beyond the design basis natural or security events that might be capable of breaching a canister and simultaneously damaging the spent fuel baskets within the canister. The fuel is old enough that it will not overheat the basket and damage itself as it might have when still in the reactor or Spent Fuel Bay. While such a degree of damage is for most purposes incredible, there is an IAEA expectation that emergency response planning and severe accident management address irradiated nuclear fuel regardless of its storage location.

The Point Lepreau Severe Accident Management Guidance for the Canister site deals with a major incident of this type at the Solid Radioactive Waste Facility in accordance with guidance for managing the response to a "dirty bomb" incident which might have similar impact and consequences from an intentional release and dispersal of potentially high activity radioactive material.

As with the Spent Fuel Bay, a major initiating event has the possibility for causing simultaneous problems at both the reactor and spent fuel storage locations and the response organization and strategies must be designed to prioritize response to deal with the most pressing issues, probably in parallel with having diminished resources (due to event induced damage and casualties), and disrupted command and control capability, as was the case at Fukushima Dai'ichi.

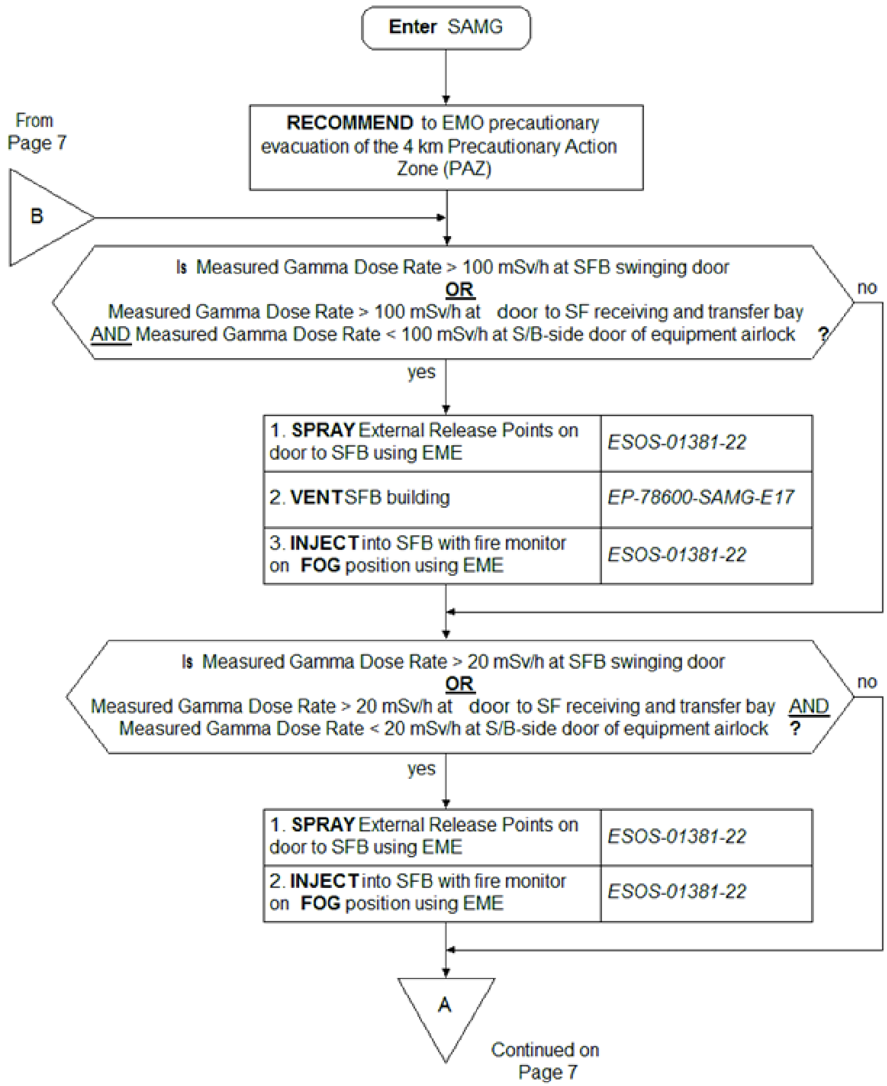

Figure 2: Sample of SFB SAMG Procedure

7. Extreme Natural Events

Local weather events and the events at Fukushima Dai'ichi have heightened sensitivity so that emergency response must cater to the potential for extreme natural hazards. While the Point Lepreau SAMG framework provides an all-hazard approach regardless of cause to the event, external hazards pose additional challenges that may hamper emergency response, particularly in terms of site accessibility, on-site debris deposition, structural damage, etc. NB Power has embarked on hazard assessments utilizing the latest state-of-the-art modelling and knowledge to determine if the hazard has changed substantially since the plant was first constructed and to determine if design protection requires augmentation to withstand beyond design basis events. Similar to the rest of the Canadian nuclear industry, NB Power has adopted Review Level Conditions (RLC) equivalent to a return period of 10,000 years in determining a credible magnitude of the natural event to confirm plant robustness. The assessments that are being performed include a probabilistic seismic hazard assessment [1], a high wind assessment [2], and a probabilistic tsunami hazard assessment [3] given the plant's coastal location.

The seismic hazard assessment indicates that the magnitude of smaller, more frequent earthquakes is less than presumed when Point Lepreau was constructed, but that the rare, very large earthquakes could be larger than originally presumed. Significant seismic improvements were made to Point Lepreau during plant refurbishment and, therefore, it has been determined that the design basis for the plant is largely unaffected. From a beyond design basis perspective considering event magnitudes at the RLC, an interim seismic risk estimate that credited Emergency Mitigating Equipment demonstrated that the risks to the plant in terms of potential core damage and large radioactive release were sufficiently low and that public health risk is unlikely to be affected. To more formally evaluate the risks associated with seismic events, a seismic Probabilistic Safety Assessment (PSA) is planned. Insights from the seismic PSA will then be considered in the context of future SAMG modifications, if deemed necessary.

The high wind assessment [2] for Point Lepreau has been completed. An evaluation has determined that the design basis of the station is sound and that design modification is not necessary. From a beyond design basis perspective, the wind hazard assessment is being screened to determine if a formal high wind PSA is necessary and from which additional insight may be gained.

The tsunami hazard assessment [3] will be completed in the near future. Paleotsunami study results and deterministic modelling of the worst-case plausible tsunami from any tsunamigenic sources does not indicate a hazard that will overtop the Point Lepreau site. Regardless, the storage location for EME that will be available for severe accident response has been conservatively selected to be well above an arbitrary run-up height that is 10 feet above the plant grade.

8. Emergency Mitigating Equipment

Prior to industry response to the CNSC Fukushima Action plan, the Canadian industry application of SAMG relied upon existing engineered features within the plants. However, it was recognized that the flexible response strategy is required to provide a higher degree of successful accident mitigation following a beyond design basis event. Therefore, the Canadian Chief Nuclear Officers of each utility signed a set of principles to guide industry response to reassure the public. The objective is to practically eliminate the potential for societal disruption due to a nuclear incident by maintaining multiple and flexible barriers to severe event progression. A key element of addressing those principles is the provision of portable diesel power generators and portable water pumps, which are generally termed Emergency Mitigating Equipment.

Under the scope of work for the related design modifications, SAMG procedures, Emergency Mitigating Equipment Guidelines (EMEGs) and Enabling Instructions are being revised or developed to ensure effective deployment and operation of the EME. Deployment teams comprising Emergency Response Team, Security and Operations members have been trained and practiced in Emergency Mitigating Equipment deployment and Planning Section and Operations staff have been trained in EME capabilities, deployment criteria and use.

Critical performance objectives (CPO) for drills have been established to ensure that deployment times are consistent with severe accident progression timelines from representative severe accident analyses and the results are being recorded. Results showing a 6-week average are provided below, which demonstrates that all critical performance objectives are being met with time margin available.

	7860-PDG-03	7860-PDG-01	7860-P-01	Above Ground Header	Refuel PDG-03
	CPO= 240 min	CPO= 120 min	CPO*	CPO*	CPO= 360 min
Nov.13	49	85	26	60	24
Nov.20	35	43	31	57	20
Nov.27	54	70	42	58	23
Dec.4	31	42	42	58	26
Dec.11	50	35	30	51	27
Dec.18	52	36	51	70	25
Avg.	**45**	**52**	**37**	**59**	**24**

* Point Lepreau has about 4 days of Boiler Make-up Water (BMW) in Dousing Tank inventory. However, assuming BMW is unavailable places the most restrictive demand on pump deployment of 1.9 hours. Therefore a CPO of 1.5 hours (90 minutes) has been established.

Table 1: EME Deployment Times from 2014 Directed Drills (minutes)

9. Plant Habitability

Plant habitability during accident response has always been a significant concern at Point Lepreau. Design changes were initiated and completed before initial operation to improve post-accident radiation shielding and equipment accessibility to improved post-accident operability for the worst case design basis events. Refurbishment saw the installation of improved main control room ventilation filtration and the installation of remote manual operators for the passive severe accident grade emergency containment filtered vent system which complements calandria vault emergency water makeup capability for severe accident management. More recently post severe accident habitability studies [4] have focussed on issues such as secondary control area ventilation control needs to assure minimization of operator dose under adverse weather conditions following a need to vent containment following a severe accident. A significant concern here is the dose from noble gases that might impact the secondary control area, combined with potential leakage through the adjacent containment wall.

Measures are under consideration on how to best optimize secondary control area ventilation management for various scenarios based on “as seen” conditions, as the optimum actions to take depend on various factors involving actual containment through-wall leakage, containment venting strategies and venting operations management and current weather conditions. Design modifications are also in progress to better protect the secondary control area and its tunnel from potential flooding sources.

10. Conclusion

NB Power has developed a robust and comprehensive set of Severe Accident Management Guidelines (SAMG) and Emergency Mitigating Equipment Guidelines (EMEGs) to provide an effective response to postulated severe accidents developing from beyond design basis conditions cause by either internal events or external hazards. Work is on-going to examine the SAMG framework at Point Lepreau in light of new WANO performance objectives and criteria and to determine if there are further opportunities for improvement.

11. References

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