IAEA International Experts' Meeting on Severe Accident Management in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant

Enhancements to Severe Accident Management Guidelines to Address Fukushima Daiichi Lessons Learned

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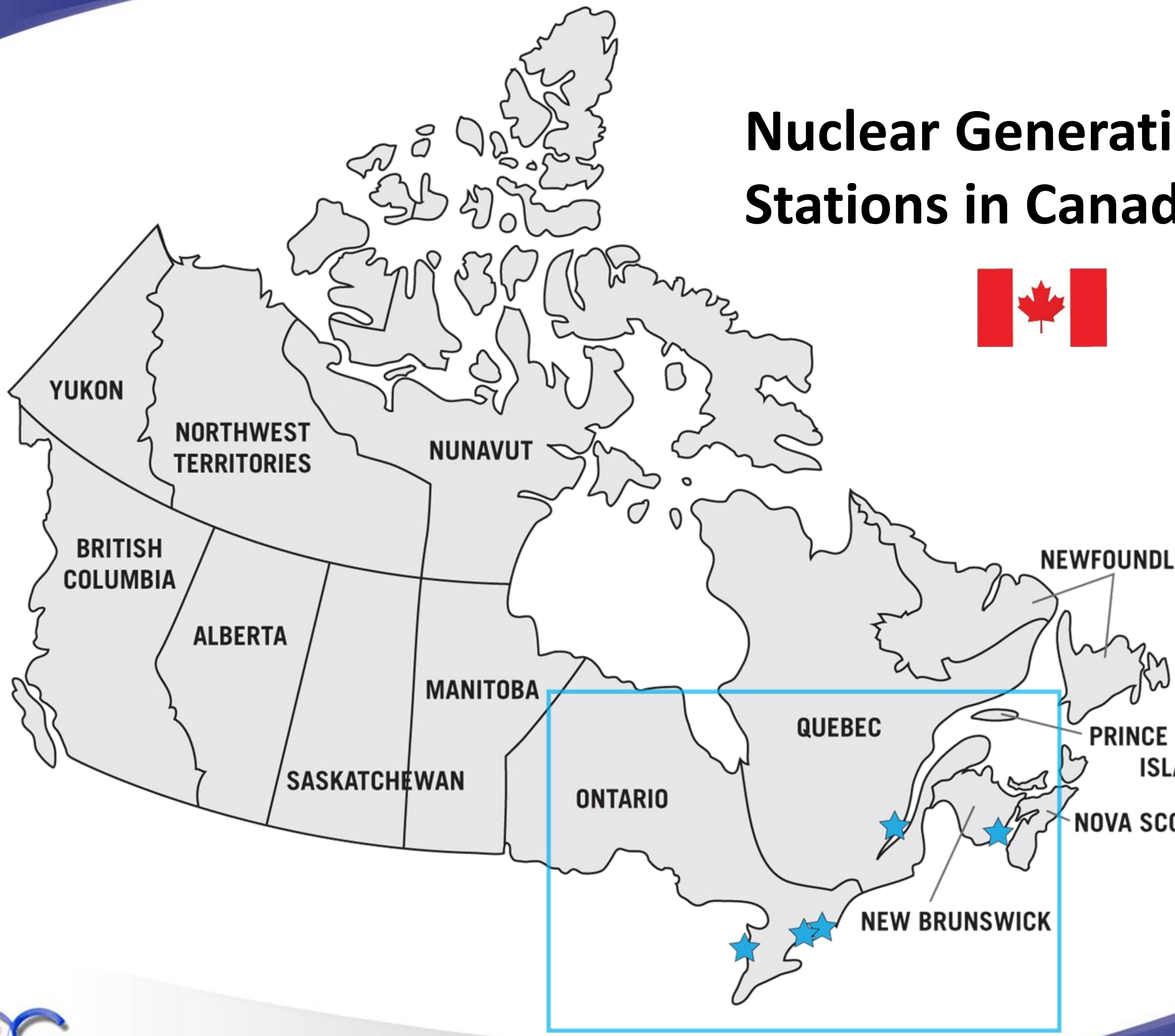
Presentation Sequence

- Plant locations
- SAMG background and overview in Canada
- Fukushima Lessons Learned

Nuclear Generating Stations in Canada



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CANDUs provide a relatively small fuel to coolant density ratio. That is, in the event of a loss of normal heatsinks, heat from the fuel is absorbed by the primary coolant, the moderator volume, and the endshield/shield tank volumes. Defense in depth is protected by the various strategies that can be used to maintain cooling at these interfaces.

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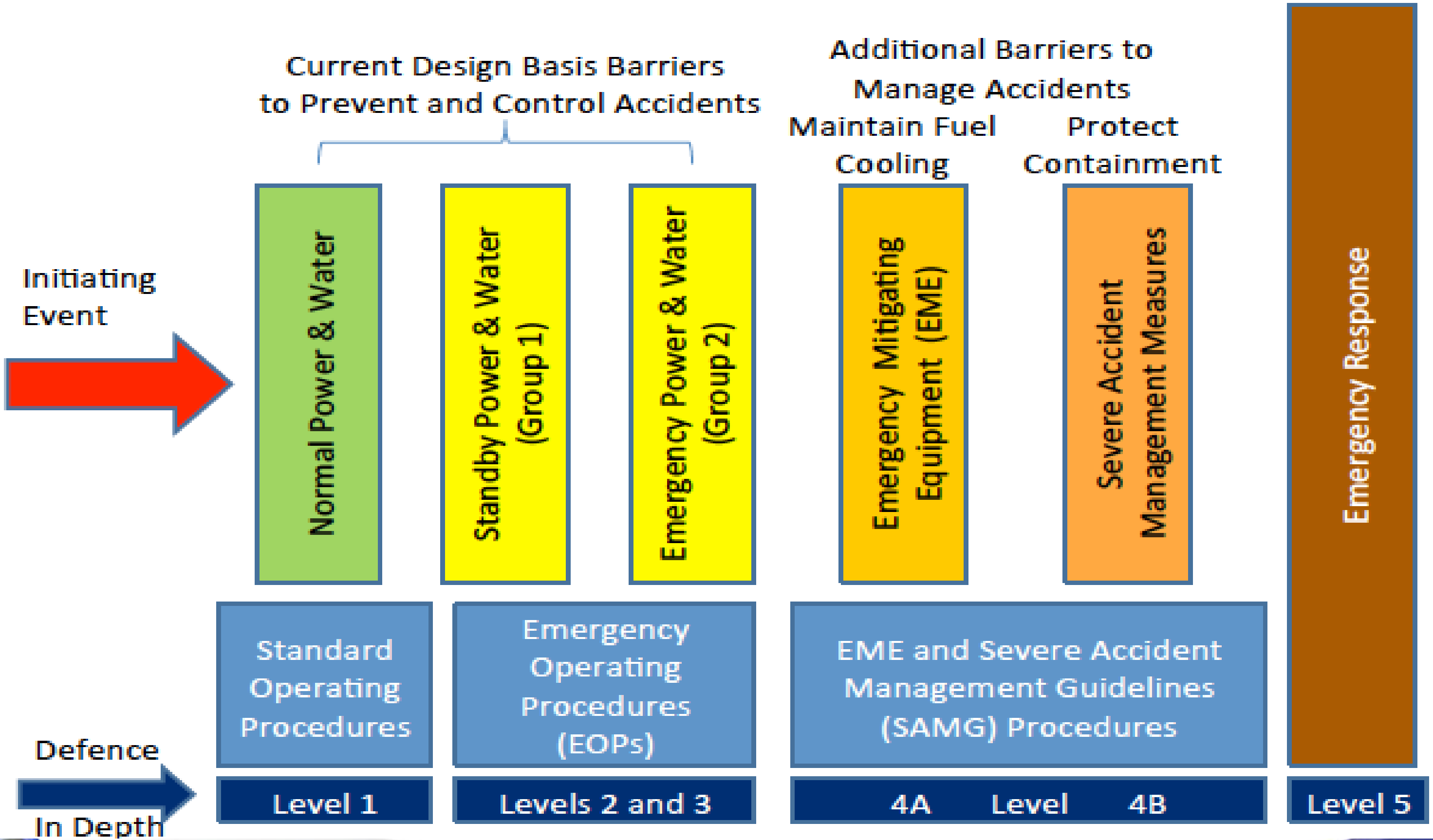
Framework for Accident Prevention, Control and Management



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Severe Accident Management in Canada

- The Severe Accident Management Guidelines (SAMGs) used in Canada were develop through an industry initiative via the CANDU Owners Group (COG).

- Currently COG membership includes 5 Canadian and 6 offshore Members. The activities of COG cover four programs for collaboration; research, information exchange, joint projects and regulatory affairs.

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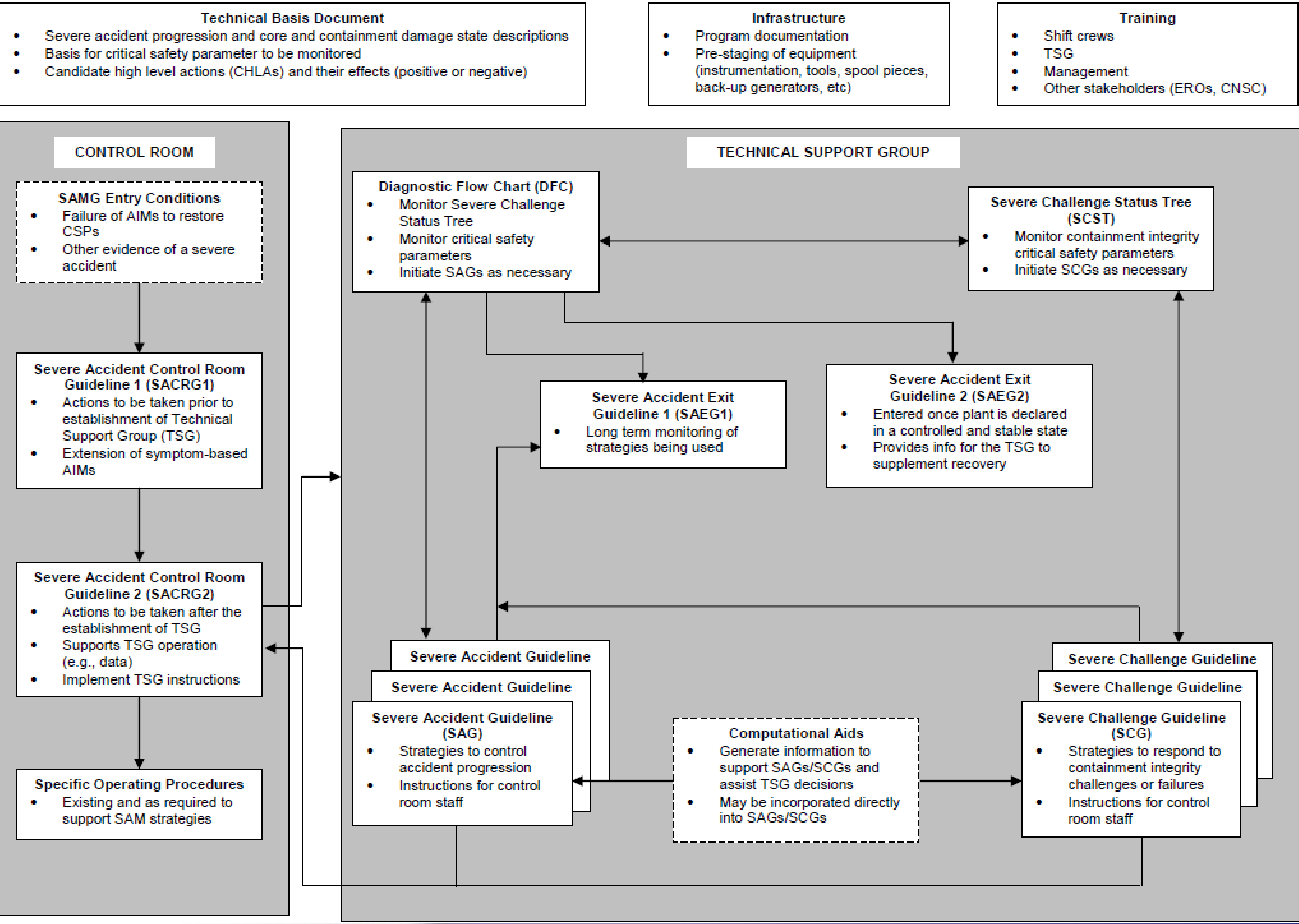
Basis for Severe Accident Management in Canada

- Review of U.S. and international positions on SAM Guidance resulted in a recommendation for the adoption of the Westinghouse Owners Group (WOG) approach suitably modified for the CANDU plants

- This WOG approach was chosen because
  - it is internationally accepted
  - there is similarity in the phenomenology of severe accidents between the CANDU and PWR designs.

SAMG OVERVIEW



Fukushima Related Lessons Learned

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Industry Overview

Following the events which occurred at the Fukushima Daiiachi, the Industry undertook a COG joint project JP4426 to update the Generic SAMG package to reflect:

- Fukushima lessons learned
- OPEX from SAMG Implementation by Industry
- OPEX from original SAMG development under JP4056
- Information from technical deliverables under JP4426 Industry learned are well aligned with the CNSC Safety Review Criteria

Areas for Enhancements

The significant enhancements made to the generic SAMGs include:

- Update of SAMGs to address multi-unit events
- Update of SAMG to address Spent Fuel Pool (SFP) events
- Update of SAMGs to address shutdown and low power operating states
- Consideration of damaged infrastructure both on-site and off-site to the plants

Two additional areas were identified as a result of the postulated harsh environment following a severe accident, these include:

- Instrumentation and equipment survivability assessments
- Habitability considerations

Update of SAMGs to address Multi-unit Events

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Update of SAMGs to address multi-unit events

- For multi-unit sites, SAMGs needs to consider the possibility of accidents occurring concurrently on more than one unit. Above and beyond challenges faced by multi-unit sties, additional challenges, mitigating strategies, and priorities may be impacted for stations with multiple units connected to the same containment as is the case at some CANDU stations. For any multi-unit site, priorities for the use of shared resources may be impacted.
- There is effectively no change on how SAMG is currently entered for the case where more than one unit has experienced a severe accident.
- In the event that the Technical Support Group (TSG) is dealing with more than one unit in SAMG, additional resources will be required to provide support directly to each unit and to the station as a whole where common systems are involved.

Multi-Unit SAMGs (cont).

SACRG-2: Severe Accident Control Room Guide # 2 - Technical Support Group Functional

- Should any one unit satisfy the SAMG entry conditions, the station should enter into SAMG. However, for units not in SAMG, activities being performed to maintain core cooling should not be interrupted.
- When assessing strategies to use on individual units, the overall station status needs to be considered to develop an integrated response. The relative priorities between units and the potential impacts of actions taken on other current strategies in place need to be addressed.

Prioritization of Multi-Unit SAMG Actions

The extent of core damage would likely be different across the units due to:

- the effect of the initiating event on each unit,
- unit status before the event,
- the timing of mitigating actions, and
- whether they have been successful to some degree.

Prioritization of Multi-Unit SAMG Actions (cont.)

- The primary means to prioritize actions is provided by the Severe Challenge Status Tree (SCST) and Diagnostics Flow Chart (DFC) (for both the reactor and SFP).
- Actions should be put in place based on restoring the parameters monitored as part of the overall SAMG framework. This occurs across multiple units and SFPs.
- There may be situations in which multiple parameters are outside of the acceptable SAMG range. The ability to prioritize different actions to restore these parameters should utilize a combination of the
  - Prioritization assigned in the DFC, SFP-DFC and SCST structures
  - Time expected before different parameters are expected to reach their SAMG setpoints

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Additional Guidelines for contending with Multi-Unit Accidents

- Selection of strategies needs to take into account that station resources will have added demands. When possible, recommended strategies should be focussed on those that require the least resources (e.g., minimizing the need for complex actions to execute strategies, or those that require new enabling instructions).
- There should be a higher priority on strategies that have sufficient capability to provide mitigation to multiple units simultaneously. Emergency Mitigating Equipment (EME) where available, Group 2 systems and other common systems (e.g., common ECI) have this capability.
- To reduce the likelihood of human error, the same strategies on each unit should be selected to the greatest extent practical, to allow for the same equipment and enabling instructions to be used.
- If more than one unit has entered into SAMG it is likely that this has resulted from a total loss of site power and a potential subsequent loss of all heat sinks. Therefore, until services are restored, available strategies will be those that do not rely on power, (e.g., gravity feed from the ECI storage tank), or portable systems with their own power, such as EME.

Additional Guidelines for contending with Multi-Unit Accidents (cont.)

- Water, air and power sources will need to be shared between units and given the increased demands for them, will need to be replenished more often. For stations with EME, it may have been designed so it can supply multiple units previously operating at up to 100% full power. Therefore use of EME to supply water and power should be a preferred strategy.
- The rate of water injected to units should be controlled where possible, so that the minimum required flow rates are satisfied with some margin, while preserving water supplies for other units and other future needs.
- When concurrent strategies are put in place, negative implications could be compounded. The effects of these compounded impacts need to be considered (e.g., simultaneous water addition to the calandria vessel will lead to increased rate of increase of water levels in the Fuelling Machine Ducts).

Update of SAMGs to address Shutdown and Low Power Operating States

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Update of SAMGs to address Shutdown and Low Power Operating States

- In general, the at-power SAMG documentation is fundamentally sound and largely applicable to shutdown and low power operation.
- For prior shutdown or outage states there is expected to be considerably more time available before a severe accident occurs.
- The initial hazards are not different in nature or more severe than those associated with design basis accidents. The TSG can evaluate the prevailing conditions based on the decay power and potentially forecast when severe core damage may occur.
- It is appropriate for Operations to continue their attempts to prevent a severe accident using plant operating procedures (i.e., not SAMG) to stabilize the HTS and/or moderator rather than prematurely entering SAMGs.

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LP/SD Unit SAMG Entry Criteria (SACRG-1)

SACRG-1 defines the entry conditions for SAMG specifically for LP/SD units as follows:

- Beyond design basis measured radiological dose rate (indicative of significant fuel damage).
- Additionally, entry into SAMG from the shutdown state should be allowed based on:
  - Direction from the Shift Manager; or
  - Direction from the Site Management Center (either on its own or in consultation with the SAMG TSG).
  - Advice from the SAMG TSG that the onset of core damage is expected to be imminent (e.g., based on calculations or extrapolation of available analytical results).
  - Sustained HTS Sub-Cooling Margin = 0°C (or header level below inlet to feeders) and top row of fuel channels uncovered (i.e., it can no longer be guaranteed that channel failure cannot occur).

LP/SD Unit changes to SACRG-2

SACRG-2 has been revised as follows to address LP/SD units:

- The guide emphasizes that once SAMG is entered for a unit in a low power/shutdown state, information about out-of-service equipment should be transmitted to the Site Management Center (SMC) and TSG. This information should be updated, as equipment status changes, throughout the course of the event.
- A flag has been added to indicate that if Guaranteed Shutdown State (GSS) is in place, some moderator make-up flow paths may not be available. Highlights that higher pressure make-up may be required if the rupture disks have not operated.
- It is noted that D2O should not be added unless the risk of positive reactivity addition has been assessed to be acceptable and appropriate precautions have been taken.

Update of SAMG to address SFP events

Updates to SACRG-1

SACRG-1: Severe Accident Control Room Guideline # 1 - Initial Response, has been revised as follows:

- Now indicates entry into SAMG can occur due to either reactor or SFP conditions. The criteria for entry into SAMG because of off-normal conditions in a SFP are as follows:
  - Low water level in the SFP, or
  - High water temperature in the SFP

  These two entry criteria are intended to ensure that actions are taken prior to a challenge to irradiated fuel cooling occurs.
- New diagnostic flow chart (DFC)
  - Explains the methodology for diagnostics of SFP events. The DFC is both a tool for diagnosis of SFP status and for the early indication of potential challenges to irradiated fuel. The DFC identifies the key parameters and setpoints to be monitored and points to the appropriate guidelines to achieve a controlled stable state.

Updates to SACRG-1 (cont.)

- Basis for the Selected Setpoints
  - Guidance on injecting water into the SFP
  - Guidance on ventilating the SFP area
  - Guidance on spraying external release points from the SFP
- There is no change to the method of entry into SAMG for subsequent unit(s) or SFP(s).
- The priority of actions would generally be assigned to the first reactor unit to enter SAMG. This is due to the relatively rapid development of challenges to containment integrity once core damage has occurred. By contrast, the time available for actions to be taken to mitigate degradation of SFP conditions is generally much longer than a degrading reactor core.

Specific Considerations for SFP SAMG

- The structure for addressing degraded conditions in a SFP is somewhat different from that employed for reactor severe accidents. This is primarily due to the SFP:
  - not being located within a containment structure
  - typically progressing to severe conditions only after a long period of time (relative core damage events). The timeframe for providing makeup to prevent a severe accident is 8 to 70 hours depending on the facility and failure scenario.
- Unlike the reactor severe accident, the implementation of different mitigating strategies follows from a single DFC for the SFP. This is due to the relatively few challenges that much be mitigated for an SFP event.

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SFP Severe Accident Guideline (SAG-IFB)

- SAG-IFB-1 – Inject into SFP
- SAG-IFB-2 – Ventilate SFP
- SAG-IFB-3 – Spray External Release Points from SFP

Consideration of Damaged Infrastructure both On-site and Off-site to Plant

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Consideration of Damaged Infrastructure both On-site and Off-site to Plant

A major lesson learned from the Fukushima Daiichi nuclear event concerns preparedness for loss of core cooling events due to damaged infrastructure on- or off-site including a complete loss of onsite and offsite electrical power. To cater to such events, Canadian utilities have procured portable AC power generators to power critical instrumentation and components and portable water pumps to provide cooling water to the reactors and SFPs during a loss of engineered heat sinks. The portable mitigating equipment is collectively referred to as Emergency Mitigating Equipment (EME). The EME will used to prevent beyond design basis accidents from progressing to severe accidents, but will also be available for use in SAM strategies.

EME use in SAMGs

The EME will be used as high level strategies to provide additional redundant and diverse water supply capability to the:

- Boilers (via gravity (dearator or dousing tank) or portable driven pumps terminates accident by maintaining fuel cooling through thermosyphoning and intermittent buoyancy induced flow for as long as necessary to restore engineered fuel cooling provisions)
- Heat Transport System ((SAG-1) Inject Into the Heat Transport System)
- Moderator System ((SAG-2) Control Moderator Conditions)
- Calandria vault or shield tank ((SAG-3) Control Shield Tank/Calandria Vault Conditions)
- Spent Fuel Pool

EME Installation Drills

Supply water to CANDU heat sinks with portable pumps

Heat Transport   Steam Generators   Moderator   Shield Tank

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Instrument and Equipment Survivability Assessment

Instrument and Equipment Survivability Assessment

- Utilities have developed a generalized methodology that is used for performing site specific instrumentation survivability assessments.
- The methodology is used to demonstrate survivability of the preferred lineups, along with instrumentation sufficient to measure if the strategy lineup is being effective.
- Where survivability of a preferred lineup or instrumentation cannot be demonstrated, reasonable assurance can still be provided by demonstrating survivability of alternatives, or if it is determined that unavailability of the lineup or instrumentation will not affect the overall defence in depth.

Instrument and Equipment Survivability Assessment (cont.)

- Because reasonable assurance is a qualitative measure based on available information, determination of the overall health is up to the owner of the Severe Accident Management Guidance (SAMG).
- The instrumentation and equipment survivability methodology consists of five steps. These steps need to be conducted by the utility on a station specific basis, taking into account local factors and specifics of the mitigating equipment at each site.
    1. Define severe accident environmental conditions.
    2. Extract high level mitigating and control actions.
    3. Compile list of instrumentation and equipment for above actions.
    4. Screen and align items with accident characteristics.
    5. Assess survivability.

Severe Accident Habitability Considerations

Severe Accident Habitability Considerations

- Severe accident phenomena may create harsh environments, radiological and non-radiological outside as well as inside containment, resulting in unacceptable habitability conditions that may impair personnel in the control room and other areas of interest, in performing their accident mitigating activities. Analysis should demonstrate there is a reasonable level of confidence that essential severe accident mitigating strategies can be performed under acceptable habitability conditions.
- Where acceptable habitability conditions cannot be demonstrated alternative accident mitigating strategies or modifications in support of the strategies may be considered.
- The general habitability assessment method outlined in the IAEA Safety Series No. 98 includes the following steps:
  - Defining the accident scenarios,
  - Evaluating the hazard sources associated with the accident scenarios;
  - Determining the general areas of interest;
  - Evaluating the transport mechanisms to the areas of interest;
  - Quantifying the level of hazard in the areas of interest;
  - Applying the habitability criteria; and
  - Determining if habitability is acceptable

Determining the General Areas of Interest

Areas of interest to maintain habitability can be divided into two categories:

i. Areas that are required to be occupied continuously in order to bring non-accident units to a safe state and maintain this condition, and

ii. Areas into which operations staff may be required to access in order to carry out or recover necessary mitigating functions on the accident unit(s).

Areas of Interest for Performing Habitability Assessments

The following are examples of areas of interest for a CANDU station:

- Main Control Room (MCR)
- Secondary Control Areas (SCA) (both “unit” and “common”) and the pathways from the MCR to these secondary control areas;
- Instrument rooms and the pathways from the MCR to the instrument rooms;
- Other buildings such as the emergency filtered air discharge system (EFADS) building and the emergency water and power supply building;
- Areas of the station that would be accessed in the performance of essential field actions required following a severe accident; and
- Areas of the station required to deploy the EME, e.g., make-up to the heat transport system, calandria and shield tanks.