Implementation of Enhanced Severe Accident Management Guidance at OPG and Bruce Power

J. Morris[1], M. Huang[1], R. Henry[1], S. Donnelly[1], W. Tse[2], R. Patel[2] and L. Gilbert[3]
[1]Amec Foster Wheeler Nuclear Canada, Toronto, Ontario, Canada
[2] Ontario Power Generation, Pickering, Ontario, Canada
[3] Bruce Power, Tiverton, Ontario, Canada
jim.morris@amec.com, michael.huang@amec.com, ronald.henry@amec.com,
sean.donnelly@amec.com, william.tse@opg.com, ravi.patel@opg.com, lovell.gilbert@brucepower.com

Abstract

As a part of the post-Fukushima response, OPG and Bruce Power have enhanced their SAMG programs to provide the capability to respond to a wider range of event progressions such as multi-unit events or IFB events. In many instances, these enhancements were adapted directly from a COG Joint Project undertaken by the CANDU industry. However, as a part of the station-specific SAMG updates, opportunities were identified to enhance the practical implementation of the COG recommendations. Most notably, these include an alternative approach to managing IFB events, a simplified approach to hydrogen management, and guidance on comparing between containment venting and leakage at elevated pressures. These enhancements are being exercised through a combination of tabletop exercises and drills to confirm usability. The outcome of this process is a SAMG program that retains key features from the COG work in a format that is readily integrated into the pre-existing SAMG for each station.

1. Introduction

A severe accident is an accident that has progressed beyond the conditions addressed by design basis-relatedprocedures and that results in widespread damage to fuel and core structures accompanied by a large release of fission products from the fuel. Severe Accident Management Guidance (SAMG) for OPG and Bruce Power was initially developed for single unit accidents starting from full power operation, consistent with the scope of the initial development of SAMG by the CANDU Owner’s Group (COG). As a part of the post-Fukushima response, OPG and Bruce Power have enhanced their SAMG programs to provide the capability to respond to a wider range of event progressions such as multi-unit events or Irradiated Fuel Bay (IFB) events. Theseupdates have enhanced station-specific SAMG documentation to align with recent changes made to the COG Generic SAMG documents, COG Technical Basis Documents and new knowledge obtained from the Topical Reports for COG Joint Project (JP) 4426: "CANDU Severe Accident Support to Industry Post-Fukushima" in support of Beyond Design Basis Accident response.

The vast majority of the recommendations from the COGreports were implemented as suggested, with necessary adjustments made to account for unique characteristics of each station. However, there are instances where in the process of updating the station-specific SAMG documentation, alternative approaches were identified in relation to the proposed changes in the COG JP 4426 reports. These variations represent conscious decisions that were made during the documentation update process to enhance the practical implementation of the COG recommendations. In other cases this was done to maintain consistency with the structure and format already inherent in existing OPG and Bruce Power SAMG documents. This is considered desirable to maintain consistency fromthe user's perspective and to minimize the impact on training requirements.

2. General Project Description and Objectives

OPG and Bruce Power projects have been initiated with Amec Foster Wheeler over the last several years to update SAMG documentation for Pickering A, Pickering B, Darlington, Bruce A and Bruce B Nuclear Generating Stations. The primary objective of these projects wasto incorporate applicable information from the work done in support of COG JP 4426.Prior to updating the SAMG documentation for each station, every item considered for modification was subjected to a screening assessment to ensure that the technical basis for the recommended changes to SAMG documents was clearly documented. The screening assessments also examined the practicality of implementing COG JP 4426 information. Where necessary, the above noted enhancements were implemented, while sustaining the high level intent of the update.

The main station-specific SAMG documents updated or created under these, fall into the general categories listed below:

- SAMG Technical Support Group (TSG) User's Guide which provides a high level overview of the SAMG documents and their use.
- Severe Accident Control Room Guides (SACRGs) which are used by plant operating staff to respond to a Severe Accident;
- Diagnostic Flow Chart (DFC) and Severe Challenge Status Tree (SCST) which are used to identify out-of-range plant parameters for which mitigating strategies are required;
- Severe Accident Guidelines (SAGs)whichcontain strategies to return the plant to a controlled stable state and mitigate potential challenges to containment integrity;
- Severe Challenge Guidelines (SCGs)whichcontain strategies to mitigate imminent threats to containment integrity or IFB cooling/integrity;
- Computational Aids (CAs)which allow essential information to be derived that is not provided directly by plant instrumentation or operator measurements;
- Enabling Instructions (EIs)which provide detailed instructions for plant operating staff to implement recommended strategies in SAGs/SCGs; and
- Severe Accident Exit Guidelines (SAEGs)which are used to manage long-term concerns associated with implementation of SAG/SCG strategies and provide a mechanism for exiting SAMG.

The result of incorporating the recommended changes from the various screening assessments into the affected SAMG documents for each station is that they now contain a significant amount of new information including the topics listed below:

- Guidance on the response to a multi-unit severe accident;
- Guidance on the response to a severe accident originating from shutdown/low power state;
- Guidance on the response to a severe accident in the IFB;
- A prioritization framework for the overall station response to SAMG, accounting for the potential for competing demands between multiple severe accident units, non-severe accident units, shutdown/low power units, and IFB events;

- A restructured CA-4 for hydrogen management which is significantly easier to use and includes a more pragmatic method in estimating the hydrogen source term;
- A restructured CA-1 for estimating dose to a member of the public resulting from a containment vent which includes a new section for containment leakage to compare between a controlled vent and leakage at positive containment pressure;
- A new CA-7 for accident progression timing evaluations which supports the use of CA-4 and also includes calculations that can be used to predict the time at which entry to SAMG may occur; and
- Estimates for strategy implementation times and estimated timeframe for strategy effectiveness for all strategies that have an applicable implementation procedure; and guidance in the strategy selection process for SAGs and SCGs as to how this new information should be used by the SAMG TSG.

Considerable care was taken during the execution of the updates to integrate the new information indicated above into the existing SAMG documentation set in such a way that the basic logic, structure/format and intended use of the SAMG was not altered. Thus, even though extensive new information has been incorporated, the overall impact on the documentation and on the need to retrain previously qualified individuals has been minimized, which supports ensuring human and organizational performance. Training seminars were held to update the qualified SAMG TSG staff.

In the process of incorporating the above into the SAMG documentation, significant development occurred in several key areas, relative to new information that was recommended for inclusion from COG JP 4426. The following are specific examples:

- The IFB SAMG material from the COG reports proposed a logic and structure that was significantly different than the existing station-specific SAMG and contained a number of elements that were not practical to implement at the stations. The IFB SAMG material was substantially revised to make it practical to implement, and adapted to the same logic and structure used in the rest of the SAMG. This is further discussed in Section 3.

- CA-4 material from the COG reports also proposed a logic and structure that was significantly different than the existing station-specific SAMG. While it accomplished the objectives of increased simplicity and conservatism, it eliminated the use of plant data as an input and in so doing, increased the likelihood of driving decisions in an inappropriately conservative direction. A revised format for CA-4 was developed that remained consistent with the existing CA-4, while still incorporating the beneficial aspects of the COG recommendations. This is further discussed in Section 4.

- CA-1 has been updated incremental to the COG recommendations, in order to provide some guidance on how to compare the potential dose impacts of a containment vent against containment leakage at positive pressure. This is further discussed in Section 5.

The SAMG process is shown on Figure 1, as it relates to the Site Management Centre (SMC) at OPG and the Emergency Management Centre (EMC) at Bruce Power. Tabletops and validation drill exercises have taken place at OPG and are being planned by Bruce Power to ensure the enhanced SAMG provide guidance on how to manage the severe accident to achieve the objectives over the full range of potential accident conditions. These objectives are to: 1) terminate core damage progression, 2) maintain the capability of containment as long as possible, 3) maintain cooling of fuel in the IFBs, and 4) minimize on site and off site releases and their effects.This is further discussed in Section 6.

Although not discussed further in this paper since it did not lead to significant changes to the SAMG, the OPG and Bruce Power implementation effort also included extensive assessments to demonstrate reasonable confidence of survivability for instrumentation and equipment important to the successful execution of SAMG.

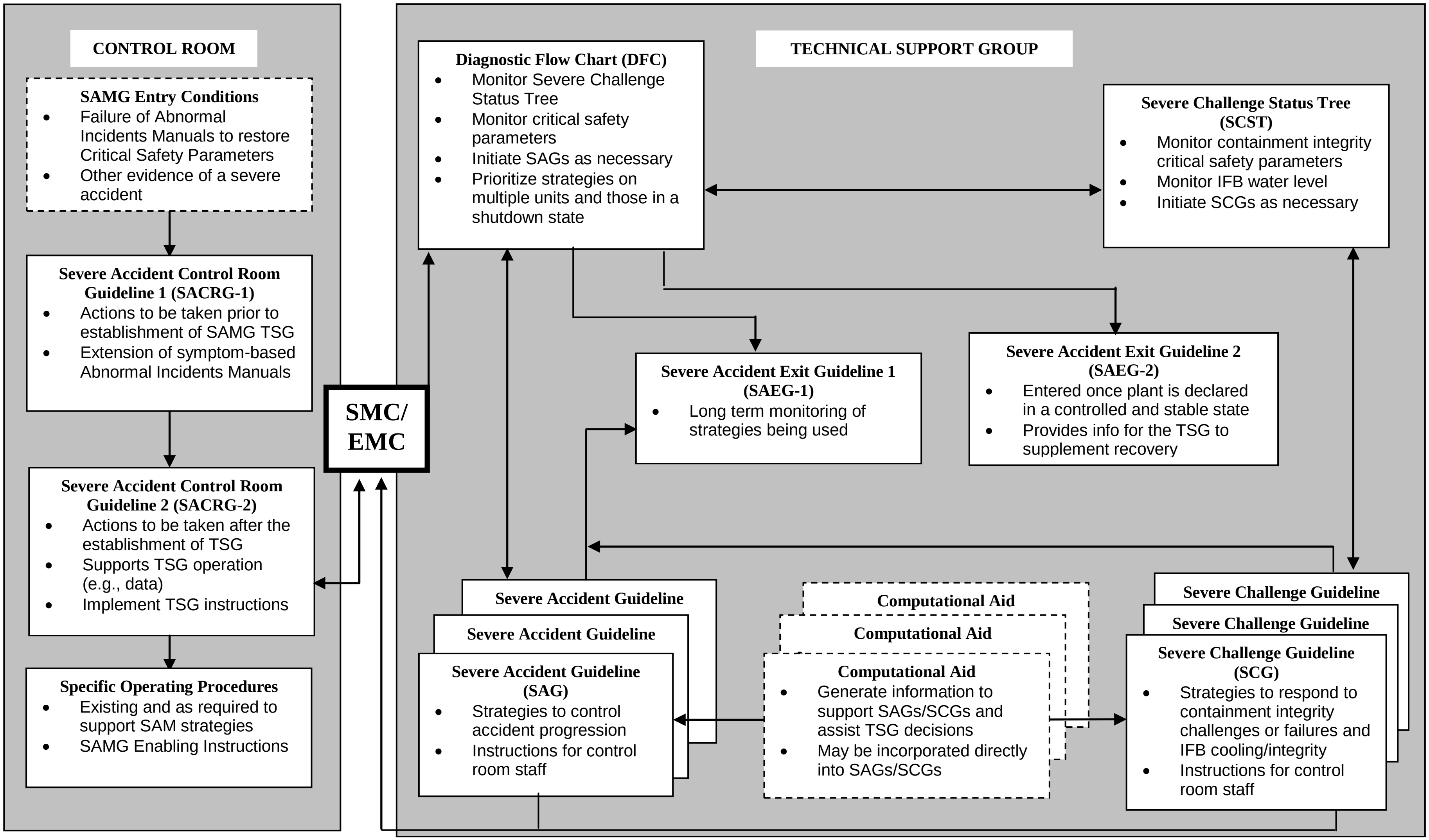

Figure 1Overview of Enhanced SAMG Process at OPG and Bruce Power

3. Enhanced SAMG for Irradiated Fuel Bays

As an example of the approach taken in the station-specific implementation, guidance in the COG IFB Topical Reports was followed, to the extent practicable, when preparing the newly developed IFB station-specific SAMG documentation. The IFB SAMG strategy descriptions contained in the 'COG Update of SAMG for IFB' (Attachment A of Reference [1]) specify high-level objectives. Where ambiguity or room for interpretation existed in application of the guidance provided in the COG IFB Topical Reports, options for station-specific implementation were identified. SAMG changes which varied from the general guidance of the COG documents were made where deemed necessary with technical/practical rationale. Several areas are discussed below.

3.1 IFB SAMG Documentation Format

The generic COG IFB documentation provided in Attachment A of Reference [1]is in the form of a three-part SAG Background Document (SAG-IFB-1/2/3). The approach taken in the station-specific SAMG documentation updates was to utilize a single SCG for IFB events, as opposed to a three-part SAG. The IFB SCG decision framework is shown onFigure 2. The rationale for this approach is as follows:

- The SCST (and SCGs) are designed to protect containment. Unmitigated fuel damage can, on its own, lead directly to significant releases outside of containment (since the IFBs do not have a containment structure). For reactor events, mitigation/response to an imminent or actual breach of containment is characteristic of actions taken via the SCST and associated SCGs, rather than the DFC and associated SAGs. Hence, the IFB SAMG has been incorporated into the OPG and Bruce Power SAMG documentation via the SCST and SCGs.

- A single SCG was created to reduce the complexity of the event response and the burden on SAMG users, including the SAMG TSG and the Technical Support Director or Station Support Technical Lead[1]. A single SCG entry condition was deemed sufficient owing to the likelihood of IFB events progressing at a slower rate than reactor events, and the common objectives of the IFB SAMG strategies.

- Monitoring and response for IFB events has been incorporated into the existing SCST for reactor events (e.g., a stand-alone IFB SCST was not developed). This has been done by adding the check for IFB conditions at the bottom of the SCST which avoids the complexity of having to work with more than one SCST. This treatment is considered appropriate since event progression in the IFBs is expected to be on a longer term timeline compared to the reactor units, given a site-wide event.

- One IFB SCG was prepared for each distinct Irradiated Fuel Bay at each station (e.g., one each for the Primaryand Secondary IFBs at Bruce A). The SCGs were produced with the same genericformat, steps, and content as the corresponding documents for reactorevents. This is a departure from the COG IFB SAG Background Document[1]which developed a new format and it is preferable from human and organizational performance, and training perspectives to maintain consistency withthe rest of the SAMG documentation set.

[1]Responsibility varies between OPG and Bruce Power, the latter of which has recently adopted roles and structure ofOntario's Incident Management System (IMS) structure in its Emergency Response Organization.

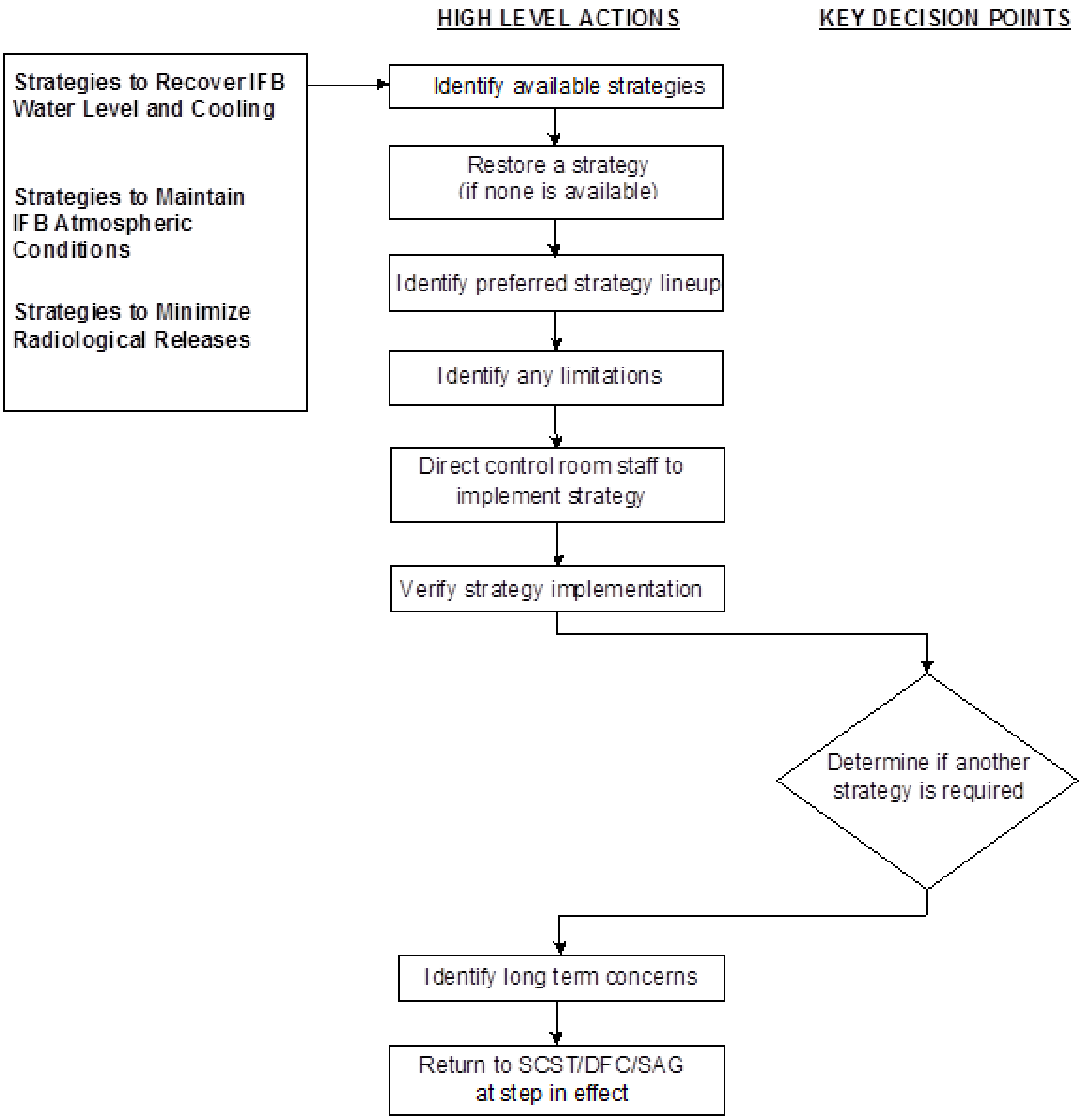

Figure 2 Station-Specific SAMG Decision Framework for Irradiated Fuel Bays

3.2 SAMG IFB Entry Conditions and Setpoints

Another significant difference compared to the COG IFB SAMG is that the logic and decision making structure of the IFB-specific portions of the SCST has been kept the same as the rest of the SCST. For reactor events, the SCST and DFC define setpoints that, when reached, indicate the need for actions to be taken. The generic COG IFB guidance [1] states to "take action before" meeting one or more of the specified IFB setpoints. In the COG IFB SAMG, it is unclear when actions should be initiated to address deteriorating conditions, particularly if competing priorities were present. Therefore, the joint reactor events/IFB SCST has a consistent decision making structure, which avoids complexity and potential confusion during implementation. Hence, setpoints for entry into the IFB SCG have been defined applying the same logic structure as for all other SCST setpoints.

The COG IFB SAMG also defines different setpoints on low IFB water level for enteringSAMG and for initiating the use of strategies to mitigate IFB events. The application of variations in IFB SAMG priority on account of changes in setpoint is not warranted owing to the likelihood of IFB events progressing at a slower rate than reactor events. The decision to enter SAMG triggers a reduction in the autonomy of the plant operating staff to respond to the event. This should only happen when it becomes necessary to manage the event differently. Therefore, setpoints are defined in the station-specific IFB documentation based on when SAMG actions are recommended to start. The same setpoints are used to enter the IFB SAMG and to initiate IFB mitigating actions.Other variations from the COG-defined SAMG IFB setpoints were incorporated into the station-specific documentationto account for features unique to each station.

3.3 SAMG IFB Strategies

The IFB SCG strategies developed for implementation at Pickering A, Pickering B, Darlington, Bruce A and Bruce B stationsfollowed the guidance provided in the COG IFB Technical Basis Documents to theextent practicable. Notable differences from the COG approach are as follows:

- Strategy for re-establishing IFB engineered heat sinks: High temperature in the IFB was identified in the generic COG IFB guidance[1]as a condition of concern for temperature sensitive stations. However, no strategies were provided for re-establishing IFB cooling in the COG document. It was decided that the station-specific SAMG IFB documentation should explicitly address strategies for re-establishing engineered IFB cooling systems (e.g., if AC power is available to do so, and IFB water level has been recovered to the point that this is possible).

- Spraying of (uncovered) fuel in the IFBs to mitigate radiological release: The COG IFB Technical BasisDocument[2] discusses sprays in the context of cooling the fuelif bay water level has decreased to the point that fuel is uncovered(exposed to air). However, sprays as a cooling strategy are not addressedin the generic COG IFB guidance[1]. Conceptually, utilization of different strategies for waterinjection into the IFB (if fuel is covered) or sprays (if fuel is uncovered)makes sense. However, a direct fuel-spraying strategy (e.g., via Emergency Mitigating Equipment) wasnot employed for the station-specific SAMG, since: i) implementing a spraystrategy would likely not be feasible, in practice, given that radiation fieldswould be extremely high in the IFB and that a pre-engineered spray systemis not in place (i.e., worker dose considerationswould preclude the strategy from being implemented in the first place), andii) even if a spray strategy could be devised which ensured appropriateworker doses, an appropriate demarcation between water injection andspraying would be difficult to ascertain and require further analysis justification. Therefore, strategies for direct spraying of the fuelwere not developed.

4. Enhanced SAMG for Hydrogen Management

The objective of the enhancements recommended to Computational Aid 4 (CA-4) was to address the following concerns that were previously identified with the CA-4 that was developed as a part of the original COG SAMG:

- The existing CA-4 required complex calculations to be performed. This creates the possibility for error-likely situations and delays that may impact its suitability to support real-time decision making; and

- In light of the uncertainty surrounding the source and magnitude of the hydrogen generated at Fukushima, the analytical assumptions used in the original CA-4 need to be revisited to ensure that an appropriate level of conservatism is contained in the estimates for the hydrogen source term obtained from the use of CA-4.

The generic CA-4 produced under COG JP 4426 [3][4]represented a significant change from the previous CA-4. Specifically, the proposed approach was based on a conservative application of analytical results and assumptions and was biased towards driving early entry into the hydrogen-related Severe Challenge Guideline (SCG-3) as opposed to the Severe Accident Guideline (SAG-6). Premature entry into SCG-3 is not considered optimal since it can force the potentially unnecessary implementation of strategies that have significant negative effects (e.g., pressurizing containment, unfiltered venting). In addition, it would preclude the use of strategies such as hydrogen igniters, which may still be appropriate to use and could prevent hydrogen from becoming a significant hazard. Further, drawing attention toward a problem that has not yet developed can result in diverting response away from real issues that should be taking priority, at that point in time.

An alternative approach was adopted that preserves desirable aspects of the existing station-specific CA-4’s. In particular, while conservative analytical assumptions may be appropriate to use if no other information is available, this should not be the default position if information about plant conditions is available that can be used to guide the decision making process. The revised CA-4 continues the use of radiation measurements as a means to assess the potential degree of core damage and resulting hydrogen generation during core disassembly, recognizing that this is a very coarse approach. As recommended in the COG CA-4, additional factors such as moderator level, the status of actions taken to reflood the core or indicators that Core-Concrete Interaction (CCI) may be happening or imminent are also taken into consideration. Other considerations have also been incorporated, such as accounting for the effect of Passive Autocatalytic Recombiners (PARs) or igniters, and other factors that can influence the event progression (e.g., multi-unit events). Criteria have also been added for determining when SCG-3 or SAG-6 exit is appropriate, or for when re-entry into these guidelines may be required.

The revised CA-4 retains the original CA-4 structure that SAMG users are already familiar with. Thisalso meant that the guideline documents for hydrogen mitigation (SAG-6 and SCG-3) did not require modification due to the changes to CA-4.

5. Enhanced SAMG for Containment Venting and Leakage

Incremental to the COG recommendations, an assessment was conducted on the use of the Emergency Response Projection (ERP) code[5] during a severe accident. ERP is used to assist with accident management by providing estimates for containment repressurization time, and public doses if venting is subsequently implemented to maintain containment sub-atmospheric. If containment is approaching atmospheric pressure, it is anticipated that outputs from the ERP code could prompt other members in the Emergency Response Organization (ERO) to seek advice from the SAMG TSG on whether there is a need to vent containment. Requests of this nature could be encountered prior to entry into SAMG (e.g., if the station is experiencing beyond design basis conditions such as a Station Blackout) or during the SAMG response.

Computational Aid 1 (CA-1) provides a means to estimate the potential dose to a member of the public resulting from containment venting when containment pressure is above atmospheric. It is intended primarily for use by the SAMG TSG to assess the potential negative impacts of recommending containment venting as a SAMG action. In exceptional circumstances, the outputs from CA-1 could be requested by other members of the ERO to inform off-site actions that may need to be completed. Specifically, CA-1 can aid in providing insights to potential dose projections in the absence of any other information. Outputs from CA-1 should only be communicated to other members of the ERO in instances where dose projections that would normally be obtained from the ERP code are unavailable, and include identification of potential limitations related to assumptions made in performing the calculations (e.g., weather conditions, distance from site).

CA-1 has been updated to provide some guidance on how to compare the potential dose impacts of a containment vent against containment leakage. The leakage estimation feature (Vent Equivalent Leak Period) of CA-1 can be used at the discretion of the SAMG TSG Leader, as resources permit, to provide additional information to confirm that a decision to not vent is appropriate (e.g., dose consequences due to leakage expected to be less than those due to venting, or to be low enough over a time period that allows for a mitigating strategy to take effect). Estimates of public dose due to containment leakage are only considered representative for the purposes of performing coarse comparisons of “wait-and-leak” strategies against intentional venting strategies (e.g., is one approach clearly better than the other). Due to the uncertainties involved, use of these estimates for other purposes (e.g., determining if Protective Action Levels have been met) is expected to be subject to significant error and is not recommended.

6. Tabletops and Validation Drill Exercises

As discussed above, the station-specific SAMG documents at OPG and Bruce Power have undergone significant revisions to include the enhancements identified in the COG JP 4426 scope of work. Tabletops and validation drill exercises have taken place at OPG and are being planned by Bruce Power to ensure the enhanced SAMG provide guidance on how to manage the severe accident to achieve the objectives over the full range of potential accident conditions.

The ability to exercise all elements of the SAMG program in a station drill exercise is not always practicable given the resources required and the need to make the drill scenario as realistic as possible for participants. While this can be accommodated in multiple drills staggered over time, tabletop exercises allow more flexibility to simulate event progressions that would be difficult to choreograph in large scale drills. They allow the flexibility to exercise SAMG guidelines that are seldom, if ever, exercised during the large scale drills. For this reason, tabletop exercises have been used to supplement large scale drills at each station as they permit time stepping through the accident sequence to focus participants on enhancements such as multi-unit prioritization, usage of new and revised CAs, and the response to IFB events. They also allow a broader range of SAMG documents to be used during the course of a single exercise.

The following process was followed to identify the required scope of the tabletop exercises completed for OPG:

- Review the SAMG documents and identify SAMG elements to be validated;
- Develop the validation scenarios;
- Conduct validation exercises; and
- Produce SAMG Process & Validation Report.

The tabletop drills are being conducted to assess the usability of the SAMG document set. The objective is to confirm that the SAMG documents are clearly written, are technically complete, interface smoothly and logically progress through the expected stages of Severe Accident Progression. In so doing potential enhancements to the SAMG documentation and process can be identified for future consideration. In addition, the SAMG technical documents are being exercised in validation drills to ensure reasonable SAMG TSG workload to allow the SAMG TSG to maintain situational awareness.

7. Acknowledgments

We would like to acknowledge the dedication of the staff at OPG, Bruce Power and Amec Foster Wheeler that contributed to the successful execution of these projects.

8. Conclusion

The recommendations from the COG JP 4426 work have been implemented into the OPG and Bruce Power station-specific SAMG documentation to address post-Fukushima lessons learned. The vast majority of the recommendations from the COG Topical Reports, the new COG Technical Basis Documents and new COG Generic SAMG documents were implemented as suggested into the station-specific SAMG documentation, with necessary adjustments made to account for unique characteristics of each station.In instances where the changes made to the station-specific documentation varied from the recommended changes in COG JP 4426, supporting rationale has been provided to demonstrate how the alternative approach is preferable to meet OPG and Bruce Power needs while still satisfying the intent of the corresponding recommendations in the COG Topical Reports. As such, the OPG and Bruce Power SAMG programs have been updated to retain the key features from the COG work in a format that is readily integrated into the pre-existing SAMG for each station.

9. References

[1] CANDU Owners Group, “Update of SAMG for IFB”, COG-JP-4426-017 R0, 2013.

[2] CANDU Owners Group, “Irradiated Fuel Bay/Spent Fuel Bay Behaviour in Severe Accidents – Methodology”, COG-JP-4426-015 R0, 2013.

[3] CANDU Owners Group, “CA-4 Background Document, Computational Aid 4: Hydrogen Flammability in Containment”, COG-JP-4426-027-R0, June 2014.

[4] CANDU Owners Group, “Containment Integrity – Hydrogen Management,” COG-JP-4426-012-R00, December 2013.

[5] R.M. Zimmerman and K.S. Dinnie, “The Darlington Emergency Response Projection Code”, Proceedings of the12th Annual Conference of the Canadian Nuclear Society, Saskatoon, Saskatchewan, Canada, 1991 June 9-12.