The Optimization of Plant-specific CANDU SAMG after Fukushima Accident

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Abstract

The Fukushima accident shocked the whole nuclear industry, which result in the introspection of the Severe Accident Management. On the basis of lessons learned from Fukushima accident and the new regulation requirements in light of the Fukushima accident, this article gives the optimization suggestions for plant-specific CANDU Severe Accident Management Guideline.

1. Background

A magnitude 9.0 earthquake followed by a devastating tsunami struck off the northeast coast of Japan's main island on March 11 2011. The combined impact of the earthquake and tsunami on the Fukushima Daiichi nuclear power plant (NPP) caused one of the worst-ever nuclear accidents. Three of the six reactors at the site melted down and released radioactive material over the surrounding region and to the sea. The live broadcast of hydrogen explosion at Fukushima drew the world's attention. Government as well as the nuclear industry started to review the development of nuclear industry under the public stress. Some countries even stop the nuclear power development.

Severe Accident Management Guideline (SAMG), as the specific document developed to deal with severe accident, has been put to a foremost important position more than ever before. The implementation of SAMG is required by regulator rather than just an option. The lessons learned from Fukushima are also required to be incorporated into SAMG.

2. The new requirements aroused from Fukushima accident

2.1 The initial findings of Fukushima accident

Based on IAEA expert mission report [1], Japanese government report and the fact of the survival of Fukushima Daini nuclear power plant, some conclusion could be made as follows:

- Multiple units failed for the same reason of Earthquake and Tsunami (Common Cause Failure)
- Spent Fuel Bay cooling could cause severe accident if not enough attention being paid
- The survival of Fukushima Daini nuclear power plant and failure of Fukushima Daiichi nuclear power plant indicated that design and siting is at least one of the important nuclear safety factor

- The success of SAMG is not only determined by the reasonable procedure to reflect plant configuration but more important determined by Skilled and knowledgeable staff

2.2 The regulation requirements of SAMG after Fukushima accident

In 2006, CNSC issued G-306 *Severe Accident Management Programs for Nuclear Reactors* [2], which help licensee to develop and implement a “severe accident management program” in accordance with the *Nuclear Safety and Control Act* (NSCA). After Fukushima accident, the regulatory authority of Canada has established Fukushima task force to evaluate operational, technical and regulatory implications on Canadian nuclear power plants from the 2011 nuclear accident in Fukushima.

A task force report [3] has been issued in October 2011, which summarized the actions on SAMG as follows:

- Licensees should provide a reasonable level of confidence that the means (e.g., equipment and instrumentation) necessary for severe accident management and essential to the execution of SAMGs will perform its function in the severe accident environment for the duration for which it is needed.
- Licensees should develop/finalize and fully implement Severe Accident Management Guidelines (SAMGs) at each station.
- Licensees should expand the scope of SAMGs to include multi-unit and IFB (Irradiated Fuel Bay) events.
- Licensees should demonstrate effectiveness of SAMGs. Licensees should validate and/or refine SAMGs to demonstrate their adequacy in the light of lessons drawn from the Fukushima Daiichi nuclear accident.

Another task force team in United states has been established by the United States Nuclear Regulatory Commission, which issued a report in July 2011 summarized the recommendations for enhancing the nuclear safety in the 21st century in light of Fukushima accident [4]. Specifically to the SAMG, a recommendation has been proposed to strengthen and integrate onsite emergency response capabilities. Two actions are developed according to this recommendation as follows:

- Order licensees to modify the EOP technical guidelines, to (1) include EOPs, SAMGs, and EDMGs in an integrated manner, (2) specify clear command and control strategies for their implementation, and (3) stipulate appropriate qualification and training for those who make decisions during emergencies.
- Initiate rulemaking to require more realistic, hands-on training and exercises on SAMGs and EDMGs for all staff expected to implement the strategies and those licensee staff expected to make decisions during emergencies, including emergency coordinators and emergency directors.

3. The introduction of plant-specific CANDU SAMG

3.1 The development history of Qinshan plant-specific CANDU SAMG

After Three Mile Island accident, the nuclear industry realized that the probability of occurrence of a beyond design basis event (BDBE) is very low, while the consequence of such kind of event could be relatively serious, which pointed out the risk of BDBE should not be underestimated for its low occurrence. It is with this backdrop that the concept of SAMG was developed. What happened in Fukushima reminds people again that the severe accident do occur no matter how small the probability it is.

In 2001, Candu Owner Group (COG) started to build a framework for the development of SAMG in Canada, which completed in 2002 and sets the direction for the development and implementation of Canadian SAMG. The generic CANDU SAMG was developed under this and finished in 2006 with the joint effort of the CANDU industry.

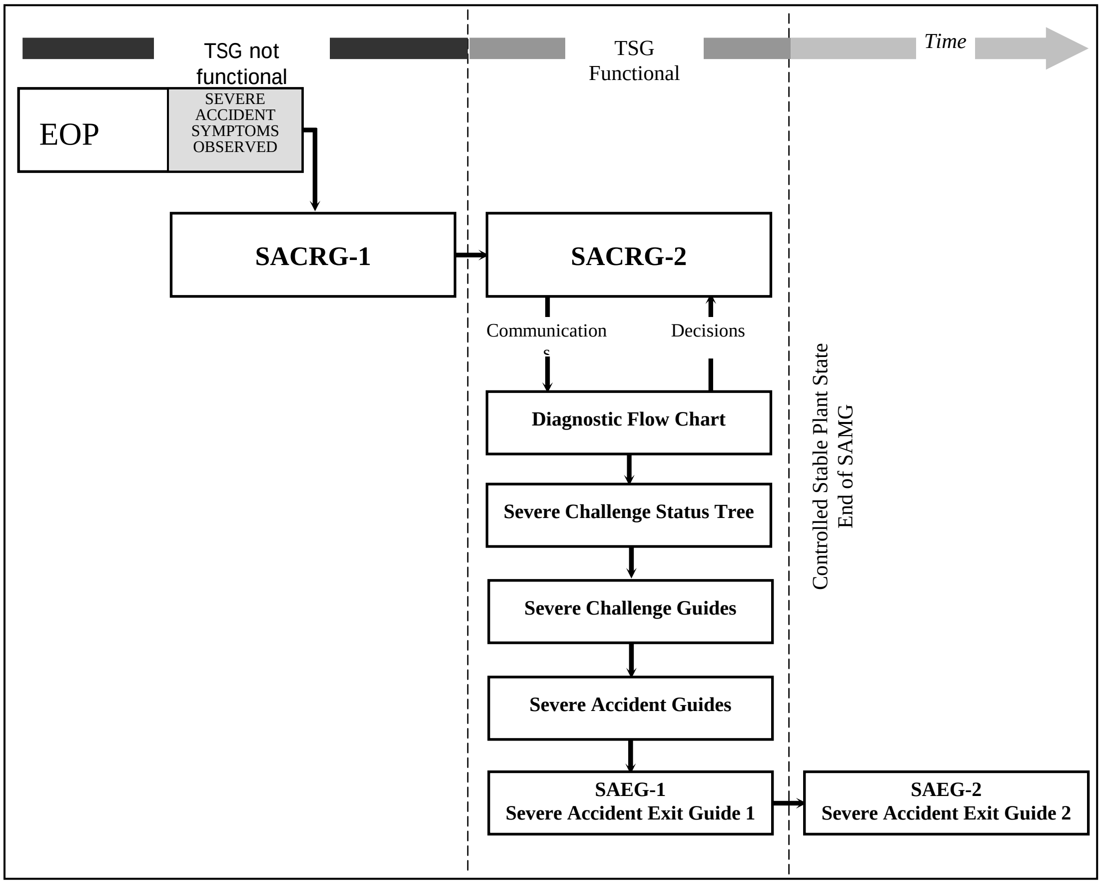
Third Qinshan nuclear power plant, operator of two CANDU-6 units, have developed the plant-specific CANDU SAMG based on generic CANDU SAMG by 2009.

3.2 The structure of Qinshan plant-specific CANDU SAMG

The generic CANDU SAMG is based on a modified version of SAMG that developed by Westinghouse Owners' Group (WOG) for Pressurized Water Reactors in U.S. The structure of Qinshan plant-specific CANDU SAMG is similar to WOG SAMG accordingly, which constitute of:

- Severe Accident Control Room Guides (SACRG);
- Diagnostic Flow Chart (DFC);
- Severe Challenge Status Tree (SCG)
- Severe Accident Guides (SAG)
- Severe Accident Exit Guides (SAEG)
- Computational Aids (CA)

An overview of the high level SAMG process and tools is as follows:



3.3 Goals of Qinshan plant-specific CANDU SAMG

There are three goals to be achieved through severe accident management as follows, which are consistent with IAEA guideline [5] and G-306 [2] requirements:

a) Minimize fission product releases from the plant
b) Maintain or return the containment to a controlled, stable state
c) Return the core to a controlled, stable state

In CANDU reactors, three basic safety functions are provided to ensure above goals could be achieved:

- Reactor shutdown
- Removal of heat from the fuel within the reactor core
- Containment of any radioactivity released from the core

Effective monitoring is also maintained as a necessary supplementary function. All of the severe accident management strategy of plant-specific CANDU SAMG, such as SAG, SCG and SAEG, are all developed around those functions.

3.4 Features of plant-specific CANDU SAMG

Generic CANDU SAMG is based primarily on observed plant conditions and not on the results of severe accident analysis, which involves the identification of strategies that differ in nature from conventional Emergency Operation Procedures. This is based on the expectation that the nature of the events and conditions that lead to the severe accident conditions may be very unclear. A key feature of SAMG is a process of diagnosis of plant conditions and evaluation of alternative strategies to bring the plant to a stable state, taking into account the benefits and negative impacts. To this extent, Generic CANDU SAMG could be defined as symptom-oriented guides, which is consistent with the international SAMG practice.

Generic CANDU SAMG so far does not include multiple reactor accidents, nor does it include spent fuel pool accident. The reason to exclude such kind of accident mainly due to the complexity of event and such accident is considered not justifiable at that early stage in the development of SAMG for use in Canada.

Qinshan plant-specific CANDU SAMG is derived from generic CANDU SAMG and inherits the features of generic CANDU SAMG.

4. The optimization of Qinshan plant-specific SAMG after Fukushima accident

According to current status of Qinshan plant-specific CANDU SAMG, the initial findings of the Fukushima accident and the new requirements of CNSC and USNRC aroused after Fukushima accident, the major improvements of SAMG could be summarized as follows:

- Include the capability to deal with Multi-unit event and Spent Fuel Bay (SFB) event
- Include the new installed equipment to deal with severe accident
- Enhance the training and drill of SAMG
- Validate the instruments and equipments during different kind of accident

4.1 Include the capability to deal with Multi-unit event

Current Qinshan plant-specific CANDU SAMG does not include multiple reactor accidents and spent fuel bay accident. What occurred in Fukushima proved that it’s necessary to include multiple reactor accidents and spent fuel accident inside SAMG.

Multiple units in Canada share some important system, such as Vacuum building; while typical twin CANDU-6 units design share few common systems between units. The emergency power system and emergency water system shared by both units of Qinshan are capable to deal with simultaneous failure of two units. The only problem is that this design can not meet the single failure criterion under such kind of multiple unit accident circumstance.

The plant-specific SAMG of Qinshan therefore has to be updated to accommodate multiple units’ failure event. The structure of SAMG would remain the same. The change of SAMG would be mostly on resources relocation. In the future, the SAMG will possibly be updated to reflect structure and components modification.

4.2 Include the capability to deal with Spent Fuel Bay (SFB) event

Compare to PWR, CANDU reactor use natural uranium, which have lower residual heat rate and thus less risk when spent fuel bay lost cooling. According to the calculation result of Qinshan, when the cooling of Qinshan spent fuel bay is lost, more than 72 hours is available for operator to recover cooling before the boiling of spent fuel bay inventory. About 14 days is available for operator to establish alternative cooling before the top column of spent fuel exposed to air.

The location of CANDU spent fuel bay usually has easy access compare to other kind of reactor. The spent fuel bay of Qinshan locates at the ground level and convenient for operator to provide alternative cooling methods. One fire truck or a portable pump is good enough to provide effective cooling.

The feature of CANDU fuel and spent fuel bay ensure that the safety of spent fuel bay could be guaranteed if the spent fuel wasn't totally forgotten by the operator. Consequently, the optimization of SAMG we needed is to add proper description to remind operator monitor the configuration of spent fuel bay and provide suitable cooling. Development of new SAG like *SAG-8 provides cooling to spent fuel bay* could be an option.

4.3 Include new installed equipment to deal with severe accident

Before Fukushima accident, the main stream of accident management in nuclear industry is to enhance the training of staff and provide effective documents to guide the operator rather than the modification of plant hardware. After Fukushima accident, things changed. The modification of hardware is impossible to be avoided as the stress from public as well as the regulator is so strong that it would not allow the utility to keep their original configuration. No matter it is old BWR designed in 1960s or newest AP-1000 designed in 2000s.

Passive Autocatalytic Recombiner and emergency containment venting facility is required to be installed. Portable pump and portable diesel generator possibly become a standard equipment to be adopted by the nuclear power plants. SAMG would have to be updated to accommodate those features, so does the plant-specific CANDU SAMG.

4.4 Enhance the training and drill of SAMG

The safety of the nuclear power plants mainly depends on two aspects, hardware and software. The hardware stands for the inherent safety feature, such as location, design configuration and the basic function of equipment. The software stands for the organizational feature, such as the skill and knowledge of staff, the administration of the plant and the actual performance of equipment.

Once the hardware of nuclear power plant was fixed, the only thing left is to perfect the software.

Proper person with proper procedure do the proper work at a proper time is our expectation, which indicates that the training of the staff is one of the important elements should be paid enough attention. This might be the reason that USNRC order the licensee to stipulate appropriate qualification and training for those who make decisions during emergencies.

From the practice of SAMG implementation in Qinshan, the unfamiliarity of SAMG is found as an important area need to be improved. The reason of this mainly lies in the shortage of experienced person. The fast expanding nuclear power market in China demands more and more experienced person, which dilutes the strength of existing staff. To solve the problem of human resources, continue recruiting would be necessary. Therefore training and drill would play a very important role in Severe Accident Management implementation.

The effectiveness of document is always determined by the people who really execute it. To this extent, the importance of SAMG training and drill would never be too much to be emphasized.

4.5 Validate the instruments and equipments during different kind of accident

There's no doubt that some instruments and equipment could fail because of the accident, which would baffle the implementation of SAMG. The questions are what kind of postulated accident we should consider to validate the instruments and equipment, how strong could the accident be and how strong should the instruments and equipment be.

Due to the uncertainty of severe accident, SAMG is symptom oriented and is written as guilds instead of procedure ever since its birth. The basic idea is that severe accident occurred because of the event had beyond the design expectation. Operator of the plant might not understand the whole part of accident, but they do know the reactor is endangered. What they should do and will do is to make best use of what they have to deal with accident. For instance, in Fukushima, people use car battery to power up the electric magnetic valves when the station was totally black out, which would be found no where in the description of procedure, but could be derived from the goal of SAMG strategy. The fundamental function of SAMG is to provide strategy and some alternative solution for operator to choose rather than give specific component or instrument for operator to follow.

There's no need to validate the instruments or equipments because the magnitude and depth of accident could be very much different. The massive efforts invested in the validation would have insignificant income in return.

Even if the weakness points are identified from the validation of instruments and equipments, the necessity to implement design modification would still be a question. Configuration of nuclear power plant is based on current regulation code and guide, which means the modification won't be necessary until there're new requirements emerged. Once the modifications be implemented, the update of SAMG would then be necessary thereon.

At this moment, it's better to leave the flexibility for the operator to make best use of whatever they have to deal with unexpected event, while at the same time, provide enough training to the one who make decisions during emergency to ensure their fully understanding of the nuclear power plant and SAMG.

5. Summary

From above discussion of the lessons learned from Fukushima and the new regulatory requirements, the optimization of Qinshan plant-specific CANDU SAMG so far could be summarized as follows:

- Include the capability to deal with Multi-unit event and Spent Fuel Bay (SFB) event
- Include the new installed equipment to deal with severe accident
- Enhance the training and drill of SAMG

Fukushima accident reminds people that severe accident does happen no matter how small the probability it is. SAMG, as the specific document to deal with such kind of mess, has to be updated and optimized continuously to protect the nuclear safety effectively. Qinshan plant-specific CANDU SAMG will keep on being optimized together with its peer.

6. References

[2] IAEA, IAEA international fact finding expert mission of the FUKUSHIMA DAI-ICHI NPP accident following the great east JAPAN earthquake and tsunami, June 16, 2011

[3] CNSC, G-306, Severe Accident Management Programs for Nuclear Reactors

[3] CNSC, CNSC Fukushima Task Force Report info 0824, October 2011

[4] USNRC, Recommendations for enhancing reactor safety in 21st century, July 12, 2011

[5] IAEA, Severe Accident Management Programmes for Nuclear Power plants, Safety Guide No. NS-G-2.15, 2009