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Enhancements to PWR SAMG since Fukushima

R. Prior
(Consultant to Westinghouse Electric Co.)
R. P. Safety Consulting Ltd.
2 Elwick Road, Ashford, Kent, TN231PD, United Kingdom
bob.prior@rpsafetyconsulting.com

ABSTRACT

Plant specific Severe Accident Management Guidelines are provided to give guidance to plant staff to respond to a severe accident, to protect containment, minimise fission product releases and prioritise equipment recovery efforts while bringing the plant to a controlled stable condition.

This paper presents and discusses the enhancements that have been made particularly to widely implemented SAMG based on the Westinghouse Owners Group generic model (now part of the PWR Owners Group) since the Fukushima accident. Although U.S. and European responses to the accident may seem at first sight to be different, in fact, the enhancements needed to SAMG in order to address lessons learned were quite consistent. How to deal with loss of d.c. power and / or instrumentation, long term loss of a.c. power (much longer than had previously been considered), multiple unit severe accidents, accidents in the fuel pool, accidents from shutdown initial plant conditions and other issues and conditions that occurred during the event and which we must learn from?

This paper presents results of a number of projects aimed at providing SAMG enhancements to address these issues, some originating in the U.S. and some in Europe. Main enhancements addressing lessons learned from Fukushima are described.

The paper also summarises and describes an ongoing project to develop a fully revised generic SAMG specifically applicable to PWR plants in Europe (and also applicable to other designs, such as VVER) which benefits from all these efforts and will provide a single integrated and updated basis for plants with mitigation systems typical in Europe (often different from the US) to update their SAMG.

Keywords: *PWR SAMG, Development, Fukushima*

1 BACKGROUND AND EARLY DEVELOPMENT

Before the early nineties, guidance for plant staff to recover from an accident was limited to instructions contained within Emergency Operating Procedures (EOP). However, it was recognized that once core damage has occurred, the EOP actions (which place priority on protecting the core) may not be appropriate when priority needs to shift to protecting containment and minimizing fission product releases. It was also recognized that it would be hard to formulate specific procedure-based guidance for recovery from a severe accident (an event in which core damage has occurred), and that some sort of evaluation process would be needed in order to select appropriate recovery actions. This suggested that the role of determining strategies may be better suited to a Technical Support Center (TSC) rather than being solely determined by operations staff.

SAMG were developed to provide structured guidance to plant staff to stabilize the plant and return it to a controlled state following a severe accident involving core damage. Early on, it was recognized that SAMG deal with a situation far outside the plant design basis, and as such, any available means to mitigate the situation would be considered and included in the guidance, even if equipment was used outside it intended use.

In the US, SAMG development was performed as an industry initiative in the early nineties. A Technical Basis Report (TBR) was developed by EPRI[1] [1] , and the various utility owners groups developed generic guidelines packages, based on the technical state of the art provided in the TBR. Individual utilities then used the generic guidelines to develop plant specific guidelines.

The original WOG approach to PWR SAMG, which is briefly outlined below, has also been extensively used to develop plant specific SAMG in plants outside the US, including many PWR plants, but also plants of differing design including VVER and CANDU reactors.

2 WOG SAMG OVERVIEW

The original generic WOG SAMG were developed during 1991 to 1994 with the aim of providing a basis for individual PWR plant owners to implement plant specific guidance material. The goals for severe accident management that form the foundation of the WOG SAMG are:

1. Terminate any release of radioactivity to the environment;
2. Prevent the failure of any containment fission product boundary as a result of the further progression of a core damage accident, and
3. Return the plant to a controlled stable condition where containment fission product boundaries would not be threatened in the long term.

In reaching these goals, the release of radioactivity to the environment must be minimized, and the availability of equipment and instrumentation must be maximized.

The WOG SAMG Revision 0 [2] provides severe accident management guidelines based on a structured decision making process, and use of step-wise structured guidelines and flowcharts. This approach minimises training requirements and provides a tool that is easy to use under the potentially high stress conditions of a severe accident. The structured process includes:

- Assess plant conditions by monitoring key plant parameters
- Prioritize response
- Assess equipment availability – and prioritize recovery actions for unavailable equipment
- Identify and assess negative impacts of potential actions
- Determine whether to implement available equipment
- Determine whether implemented actions are effective
- Identify long term concerns for implemented strategies

The applicable accident management actions are independent of the details of the severe accident phenomena and/or the progression of severe accidents. The principal actions contained in the guidelines are:

[1] The original EPRI TBR was a proprietary document. The TBR was subsequently updated following the Fukushima accident (EPRI2012), and is no longer proprietary. It is available at : http://my.epri.com/portal/server.pt?Abstract_id=000000000001025295

1. Fill the steam generators
2. Depressurize the reactor system.
3. Inject water into the reactor system to cool the core
4. Inject water into the containment
5. Depressurise the containment
6. Reduce the containment hydrogen concentration

The generic WOG SAMG is contained in two control room guidelines (implemented by the operations staff in the main control room), a diagnostic flow chart and a severe challenge status tree (the primary diagnostic tools for severe accident management), and fourteen Severe Accident Management Guidelines which provide a structured evaluation for implementing severe accident management strategies.

The diagnostic tools and the guidelines are intended primarily for use by the on-site Technical Support Centre (TSC). TSC organization and staff training in the use of new SAMG are therefore important issues which must be addressed during plant specific implementation..

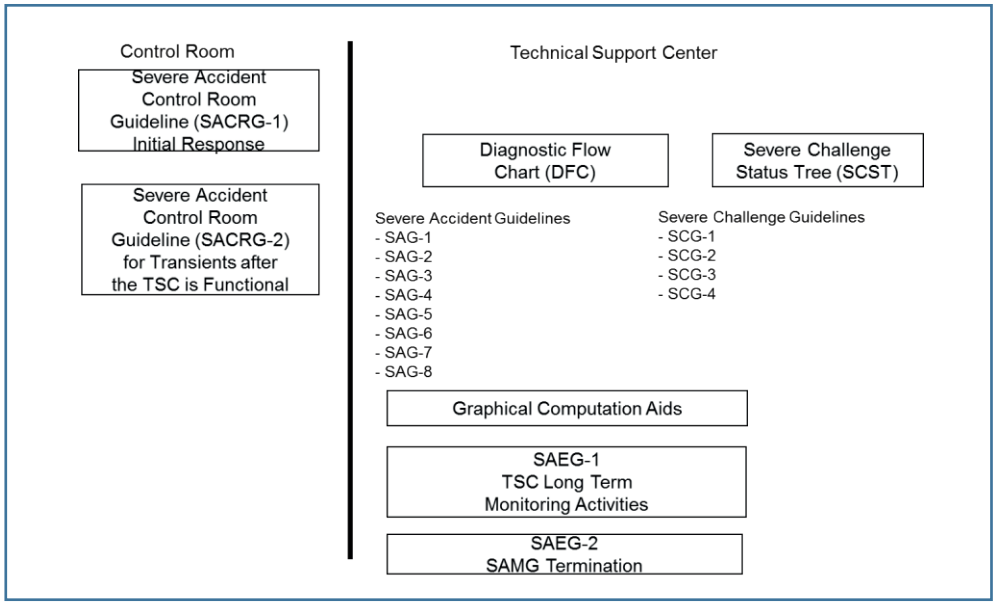

Figure 1: WOG SAMG Rev. 0 - Components

3 REVISIONS AND DEVELOPMENT OF THE WOG SAMG

Revisions to the generic guidance were performed when improvements were made to the understanding of severe accident phenomena, plant modifications were introduced to facilitate mitigation of severe accidents, and lessons were learned from implementation and performance of drills and exercises.

Revision 1 of the WOG SAMG was issued in 2001 [3], and incorporated many detailed changes/modifications to the generic WOG SAMG which had been accumulated from several years of experience with training, validation and exercises of plant specific guidelines.

Revision 2 was issued for implementation in December 2012 [4], following the Fukushima accident. This revision was intended to address short term post-Fukushima modifications to the SAMG. Since the development of consolidated PWROG SAMG was ongoing in parallel (see

below), this revision addressed only specific issues raised by the revised TBR [1], mainly in the following areas:

- Spent Fuel Pool
- Auxiliary Building Ventilation
- Containment Venting
- Use of Raw Water (e.g., sea water, brackish water, river water)
- External cooling of the reactor vessel lower head

PWROG consolidated SAMG: Driven mainly by the desire in the US to consolidate the three original Owners Group SAMG approaches into a single approach applicable to all PWRs, the PWR Owners Group has performed a major revision of the generic SAMG which is intended to be applicable for Westinghouse, Combustion Engineering and B&W PWRs, and which can also be adapted (as was the original WOG SAMG) to other designs. This development drew on the strong features of the individual SAMG approaches, on the various revisions described above, and on the lessons learned from the Fukushima accident, to provide a restructured an improved SAMG package. The basic structure and components of the PWROG consolidated SAMG are shown in Figure 2. The PWROG SAMG was finalized in early 2016 after undergoing validation. Utilities are expected to start implementing revised plant-specific SAMG based on the new approach during 2016.

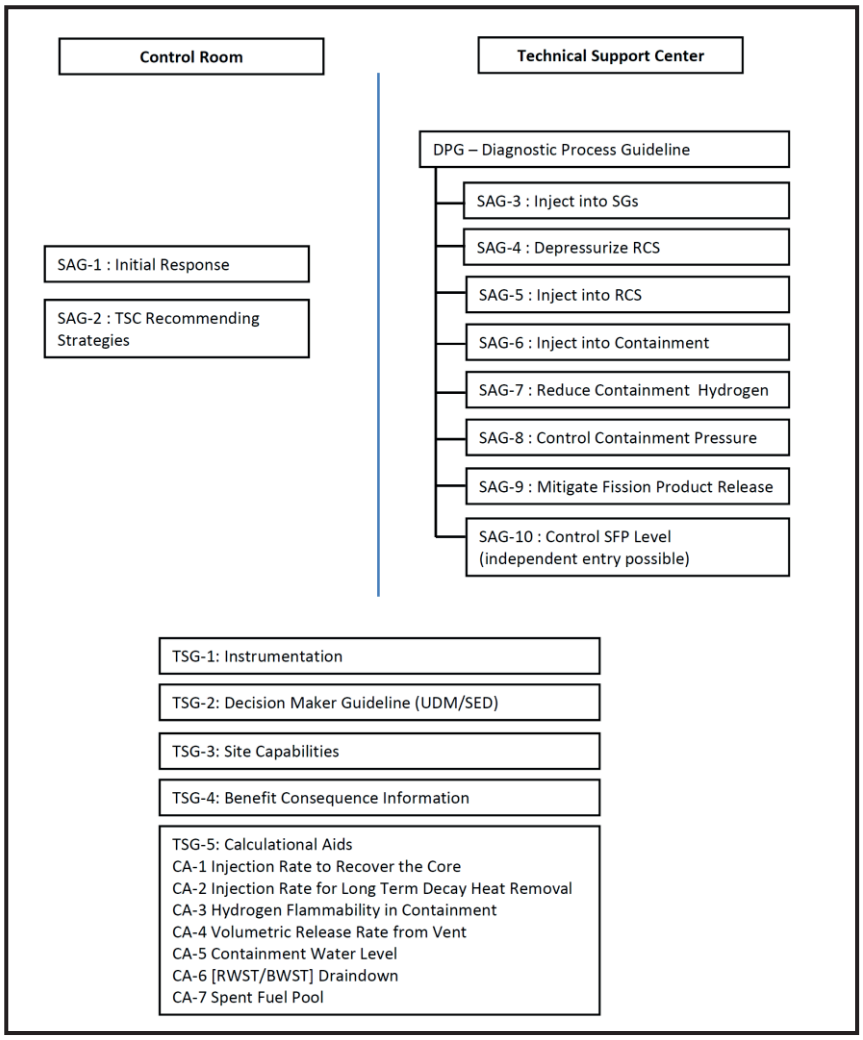

Figure 2: Structure and Components of the PWROG Consolidated SAMG

European work / revisions for international plants: Many plants in Europe and elsewhere (but outside the US) have implemented systems upgrades and backfits to enhance severe accident mitigation. In addition, certain issues (such as severe accidents occurring from shutdown initial plant states) have always received more attention in Europe than in the US. This has led to specific needs for international plants implementing SAMG which were originally developed in the US. To address some of these issues, in the period following the Fukushima accident, a European PWROG project was performed in 2012-2013, which complemented the development efforts ongoing in the US. The project provided international plants with:

- Modifications to SAMG for plants with PAR-based hydrogen control systems
- Modifications to SAMG for plants with severe accident filtered vent system
- Modifications to SAMG for plants without containment hydrogen monitoring system
- A specific procedure for severe accident combined with loss of all D.C./Instrumentation
- A review of the benefits and disadvantages of diagnosing reactor vessel failure in SAMG
- Extension of SAMG to cover shutdown initial plant states
- Review of multiple unit issues for SAMG (consideration of simultaneous severe accidents in multiple units)
- Interfaces with US development programs to ensure consistency.

4 EXAMPLE OF NEW FEATURES: TSGS

TSGs are a new feature of the PWROG SAMG. "TSG" is consistent with the BWROG terminology for additional SAMG tools used by the TSC. They address different areas of severe accident response, and may be used by both control room and Technical Support Center. The generic PWROG SAMG contains five TSGs:

TSG-1: Instrumentation: This TSG provides guidance for evaluating the accuracy and reliability of plant instrumentation, contains instrumentation information (design limits, calibration details, operation details, calculated biases), guidance on cross-checking of indications with other instruments, obtaining local readings. It covers loss of all DC as well as loss of individual instrumentation

TSG-2: Decision Maker Guideline (UDM/SED): This TSG provides the ERO Ultimate Decision Maker with guidance related to SAMG actions and potential conflicts. TSG-2 is discussed in more detail below.

TSG-3: Site Capabilities TSG-3: This TSG contains details of site mitigation equipment, both installed and portable equipment (e.g. air compressors, electrical generators and d.c. power sources). Details are pre-filled by the plant for equipment availability and location, capacity, operating requirements, etc. Site water resources and fuel resources are also be tracked.

TSG-4: Benefit Consequence Information: Benefit consequence evaluation has been simplified in the new SAMG by including the recommended action for most likely plant conditions directly in the SAGs. This TSG provides additional information regarding benefit/consequences of strategies.

TSG-5: Calculational Aids: Calculational aids are grouped together in TSG-5.

5 DECISION MAKER GUIDELINE: TSG-2

The ultimate decision making regarding a SAM strategy recommended by the TSC often lies with the Site Emergency Director (SED). The SED is the only member of the emergency response organization (ERO) with a sufficiently broad understanding of the situation to be able to evaluate the overall potential impacts of a proposed strategy. However, in the past there was no guidance from within the SAMG to assist the SED in this role. This has been addressed within the PWROG consolidated SAMG by the provision of a specific Technical Support Guideline for use by the SED. TSG-2 provides the ultimate decision maker (the SED) with a tool that provides information that may be beyond TSC recommended strategies (use not required), and helps him to evaluate the appropriateness of proposed strategies in the context of:

- personnel safety
- physical plant damage
- site resources
- nuclear safety (single and multi-unit decisions)
- regional impacts
- regaining mitigation capability.

6 ADDRESSING FUKUSHIMA LESSONS LEARNED

The way in which the new developments described above address some of the major lessons learned from the Fukushima accident is summarized below.It should be noted that addressing these issues relies on a fully integrated and self-consistent set of guidelines and procedures, of which SAMG form a part.

Extended Station Blackout:

- Implementation of FLEX (or equivalent) equipment and capabilities;
- Implementing the corresponding FLEX Support Guidelines (FSG) (or associated operating procedures);
- Ensuring consistent links between procedures and guidelines (including EOPs, SAMGs, EDMGs, and FSGs).

Loss of instrumentation and control

- FSG-7 and SACRG-0.0 for loss of d.c.;,
- Instrumentation Technical Support Guideline TSG-1.

Severe accident occurring from shutdown initial condition:

- Extension of generic SAMG to cover shutdown states (PSC-1081)

Loss of Spent Fuel Pool cooling:

- FSG and FLEX equipment to makeup to SFP
- Extension of generic SAMG to cover spent fuel pool accidents

Use of seawater – potential precipitation issues:

- EPRI TBR update and WOG SAMG rev. 2 guidance

Multi-unit severe accident:

- TSGs for Decision Maker
- N+1 FLEX equipment

Site disruption – TSC unavailable/late :

- Restructuring of control room SAGs – some actions systematic by operators
- EDMG for loss of command and control

7 PSC-1413 AND THE WAY AHEAD

As described, there have been many developments since the first SAMG of the mid-nineties, both pre- and post-Fukushima. But what is important to plant owners is to have a single applicable set of generic SAMG that can be used to develop plant specific guidelines and which incorporate all the development TD since the original SAMG were developed.

The development of the new PWROG SAMG in the US has incorporated all these developments, but was also driven by a US desire to "consolidate" the three PWR owners' groups (W, CE and B and W) approaches into a single approach usable by all US PWRs.

In Europe, many plants implemented WOG type SAMG. (The WOG SAMG have been used as the basis for plant specific SAMG in Westinghouse PWRs (eg Beznau, Ringhals, Asco, Vandellos, Almaraz, Tihange and others), at Framatome/AREVA plants (eg Koeberg), at Siemens/AREVA plants (eg Borssele) and in VVER reactors in Central Europe (Bohunice, Mochovce, Temelin, Dukovany). However, the approach to systems upgrades for the mitigation of severe accidents has differed between the U.S. and Europe, with European plants generally opting to backfit mitigation systems such as passive hydrogen control and filtered containment vents. Also, plant features are often different and regulation though generally consistent has produced some differences in expected scope/expectations (NRC/NEI vs IAEA/WENRA) (for a review of the regulatory and industry response to the Fukushima accident in U.S. and in Europe, see [6]). These differences can have a major impact on SAMG, and have meant that developing and maintaining plant specific SAMG based on U.S. generic reference guidelines has become more and more complex for European plants. In addition, the motivation to consolidate different U.S. owners groups' SAMG mainly did not exist in many European plants, which often followed the WOG approach, though of course new technical developments/enhancements need to be included. While the international PWROG project PSC-1081 described above addressed many of these differences, it did not produce a new dedicated set of generic guidelines for plants with additional SA mitigation features.

To address this, PWROG authorised a currently ongoing project specifically for international plants which uses a reference plant design typical in Europe (with large dry containment, PARs, filtered vent, etc). The project will deliver an updated set of generic SAMG applicable to the reference plant, and taking maximum benefit of the enhancements resulting from the previous development projects described earlier in this paper. This project, PSC-1413, is currently underway and is scheduled to complete in the second half of 2016.

This results in two sets of generic PWROG SAMG - one for US reference plant and one for European. The two resulting sets are fully consistent but are tailored to enable utilities in both the US and Europe to adapt more easily their applicable generic set to their plant.

Thus in the US, during 2016/2017 plants are expected to begin implementing plant specific SAMG upgrades based on the consolidated PWROG SAMG. And in Europe, the generic guideline set from PSC-1413 can be used from mid 2016 as a basis for developing or updating plant specific SAMG.

8 CONCLUSIONS

There is wide experience in implementing plant specific SAMG based on the original WOG severe accident management guidelines. While generic SAMG were revised periodically, the Fukushima accident revealed additional areas requiring attention.

Following Fukushima, PWROG programs were launched to address these areas, to integrate PWR SAMG (in US) and to provide specific guidance for International Plants.

Integrating revised SAMG with other plant specific guidance and procedures (including EOP, FSG and EDMG) provides for a comprehensive accident management capability, and special effort has gone into ensuring such integration.

During 2016, new generic SAMG will be available for both U.S. and European reference PWR plant designs which can form the basis of plant specific SAMG upgrades which will take full advantage of the extensive developments since Fukushima.

9 ABBREVIATIONS

B&W	Babcock and Wilcox
BWROG	Boiling Water Reactor Owners Group
CA	Computational Aid
CE(OG)	Combustion Engineering (Owners Group)
DPG	Diagnostic Process Guideline
EDMG	Extensive Damage Mitigation Guideline
EOP	Emergency Operating Procedure
EPRI	Electric Power Research Institute
FSG	FLEX Support Guideline
FLEX	Diverse and Flexible Coping Strategies
IAEA	International Atomic Energy Agency
NRC	Nuclear Regulatory Commission
NEI	Nuclear Energy Institute
PWROG	Pressurized Water Reactor Owners Group
TBR	Technical Basis Report
TSC	Technical Support Center
TSG	Technical Support Guideline
SACRG	Severe Accident Control Room Guideline
SAG	Severe Accident Guideline
SAMG	Severe Accident Management Guideline(s)
SED	Site Emergency Director
SFP	Spent Fuel Pool
UDM	Ultimate Decision Maker
WENRA	Western European Regulators Association
WOG	Westinghouse Owners Group

10 REFERENCES

[1] EPRI2012 “Severe Accident Management Guidance Technical Basis Report,” Volumes 1 & 2, Prepared for EPRI, Fauske & Associates Inc., October 2012, http://my.epri.com/portal/server.pt?Abstract_id=000000000001025295

[2] (Proprietary) “The Westinghouse Owners Group Severe Accident Management Guidance, revision 0", June 1994 (3 volumes).

[3] (Proprietary). Westinghouse Owners Group, Severe Accident Management Guidance, Revision 1, October 2001.

[4] (Proprietary). Pressurized Water Reactor Owners Group, LTR-RAM-I-12-065, Rev. B, “Severe Accident Management Guidance – Westinghouse Plant SAMG, Second Addendum”, December 4, 2012.

[5] (Proprietary). PWROG-15015-P Revision 0, “PWROG Severe Accident Management Guidelines”, February 2016.

[6] Lutz, R. J., and Prior, R., “Comparison of the Fukushima Response in the United States and Europe”, accepted for presentation at the 24th International Conference on Nuclear Engineering, ICONE24, June 26-30, 2016, Charlotte, North Carolina, USA. (Paper ICONE24-60101).

11 ACKNOWLEDGEMENTS

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