Benefits and Limitations of the New Consolidated PWROG Severe Accident Management Guidance (SAMG) – A Review of Some Critical Issues

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Abstract: After Fukushima, it was decided by the Pressurised Water Reactor Owners Group (PWROG) to merge the various approaches in Severe Accident Management Guidance (SAMG) in existence and use one single type of SAMG, which departs from the Westinghouse Owners Group approach. There are a number of apparent positive features of this development, but the author believes there are also matters which may need further consideration, if not improvement. This paper discusses the elements of the new approach, as have been presented during the PSA 2013 conference in Columbia, South Carolina, USA, in September 2013. This presentation was limited to the state of development of the PWROG at that time – which is also a limitation of this review.

Keywords: New severe accident management guidance, benefits, limitations

1. Introduction

At the PSA 2013 conference, organised by the American Nuclear Society and held in Columbia, South Carolina, USA, 26 - 29 September 2013, a paper [1] was presented by R.J. Lutz Jr. of Westinghouse about the consolidated Severe Accident Management Guidance (SAMG), under development by the combined Owners Groups of reactors designed by Westinghouse, Combustion Engineering and Babcock & Wilcox, merged into the Pressurised Water Reactor Owners Group (PWROG). This new approach would replace the existing three different types of SAMG, being the Westinghouse Owners Group (WOG) SAMG, the Combustion Engineering Owners Group (CEOG) SAMG and the Babcock & Wilcox Owners Group (B&WOG) SAMG.

In principle, it is a positive development that the individual Owners Groups have decided to follow a common line and work on such a consolidated approach. The main basic vehicle of this new consolidated PWROG SAMG is the Westinghouse Owners Group SAMG (WOG SAMG), now enhanced and adapted to the new insights in the field, including the lessons learned from the Fukushima-Daiichi accident in March 2011. Also feedback from exercises/drills has been implemented, human factors considered, and benefits from other SAMG approaches considered.

As Combustion Engineering has been bought by Westinghouse (2000), a common approach will also simplify maintenance of the SAMG of the fleet of Westinghouse reactors and thereby reduce costs, a factor which may have contributed to decide on a single approach.

This paper discusses various elements of the new approach and comments them where the author believes such discussion may contribute to its value. The comments are given for items of more generic relevance in sec. 2, and items specifically for the proposed new PWROG

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1 An overview of what is inside the WOG SAMG is given in [2].

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SAMG in sec. 3. Some experiences with SAMG reviews are collected in sec. 4. Conclusions are in section 5. The actual SAMG products were not yet developed and/or were not yet available, which restricts the possibility to comment in technical detail, and some comments and conclusions might have been changed, if that material would have been available.

2. Items of Generic Nature

2.1 Functional Objectives of SAGs versus Parametric Objectives

The intention of the WOG SAMG (and various other SAMG approaches) was that the operators /Technical Support Centre (TSC) do not need to be ‘severe accident experts’ - the SAMG was designed to be a tool for plant people, not being severe accident experts. As it was written in one Westinghouse presentation: ‘Detailed knowledge of severe accident phenomena is not required for the management of the accident’, [2]. The nature of this approach is that execution of SAMG needs to follow only observed plant parameters rather than insights in the plant damage conditions. As said, this incentive was based on the wish to be able to mitigate the severe accident by available plant staff and avoid in-depth training of this staff in severe accidents phenomena. Also the license of operators then does not need to include severe accident knowledge. This intention is repeated in [1], sec. 3.3.

However, the principle to just follow plant parameters rather than insights in the plant damage conditions reflects a process behind the SAMG development that seems to be more like the thought process of developing Emergency Operating Procedures (EOPs), which totally rely on response to observed plant parameters. In EOP-domain, the situation can be well predicted and, hence, EOPs based on following plant parameters are a suitable response to the event. In severe accident domain, however, the situation is totally different. Instruments may either be not available or not reliable, plant communication means may have failed, important equipment may have failed and the event evolution may be different from what the SAMG-developers had in mind when developing the SAMG. This requires another thought process in developing SAMG.

In the literature, ‘pre-designed accident management’ is labelled as ‘Routine Accident Management’, whereas the capability to handle unforeseen events and complications is often referred to as ‘Emergency Accident Management’, [3]. Following this subdivision, the PWROG SAMG can be characterised as ‘Routine Accident Management’ rather than ‘Emergency Accident Management’. It means that the PWROG SAMG can be expected to be successful for known evolutions of severe accidents, but may fail in more complex accidents, as now will be further discussed.

In a severe accident, as said, complications may arise which have not been foreseen by the SAMG developers. In addition, there is a threat of large releases, it is unknown whether strategies can be implemented and, if implemented, whether they will be successful. Actions can also have severe negative consequences, so that only extensive deliberations by well-educated and trained experts can show the best available path to mitigate the accident. The principle expressed by some Westinghouse trainers that one only needs to follow those parameters which are needed to execute the SAMG, [4], and does not have to bother about other insights - such as whether the core will melt / has melted through the reactor vessel - is a serious underestimate of the complexity of a severe accident and is a misleading of staff to be trained in SAMG.

In the past, this approach has already brought severe complications in exercises. For example, where the first priority in the generic WOG SAMG is to fill the steam generator (SG) to prevent steam generator tube creep rupture (Severe Accident Guideline #1, SAG-1),
one crew spent much time in trying to repair the lost SG injection, thereby not taking notice that the accident evolution had not stopped and the core had landed already in the lower plenum / was about to melt through the Reactor Pressure Vessel (RPV). Further SAGs tell people to inject into the Reactor Coolant System (RCS), but this measure has a lower priority and, hence, was not pursued with the same vigilance as filling the SG.

Now, the logic behind this SAG-1 is to mitigate an early challenge to an important fission product boundary, and if an accident analysis for this scenario would have been made, it probably would have been detected that the risk for SG tube creep rupture already had disappeared due to the accident evolution or to a depressurisation while still in EOP-space. Apparently, nobody thought about the reason why SAG-1 was there, and people operated blindly according to suggested actions by the SAMG.

Sure, the SAMG are only guidelines, i.e., deviations are possible. Yet, this author never saw in any plant exercise that this actually was done. This is probably due to the fact that operators are trained not to deviate from written procedures (for EOPs), and the SAMG developers seem to carry an EOP-mind, i.e., write detailed guidance which only and totally depends on plant parameters and not on insights in the plant damage conditions.

Insight in the plant damage condition is, however, useful as the effect of the action / response of the plant to the action may be different in different plant damage conditions, as has been described in the EPRI Technical Basis Report [5], which is the basis of many SAMG-programs.

An additional advantage of having such insights is that plant staff still has the possibility to take useful actions if they lose instrumentation. For example, if a Station Black Out (SBO) has been recognised to be the initiating event, plant staff still may know what to do if they have been trained to understand the evolution of such an accident. They will then know there is a threat for SG tube creep rupture and that they may have releases of large amounts of hydrogen to the containment through the Safety / Relief Valves (SRVs). They also will know the available time for mitigating actions and will also know that their batteries will run out of power within a given time. The same conclusion applies if the initiating event has not been recognised, but it has been found that the primary pressure is and remains high. If there was no SBO but they had recognised a Large Break Loss of Coolant Accident (LBLOCA) as the initiating event, they will know there is no risk for an SG tube creep rupture, so they will skip the associated SAG. Similarly, without such knowledge, but if the primary pressure is and remains low. Had there been a Steam Generator Tube Rupture (SGTR) or an Interfacing System LOCA (ISLOCA) recognised as the initiating event, again other actions will be relevant. As many severe accidents will have a ‘pre-phase’ in EOP-domain, there is quite a chance that operators and/or the Technical Support Centre (TSC) will know where they are, even without detailed information from the - assumed failed or deviating - instrumentation.

Inights in the plant damage condition may also make it possible to anticipate fission product (FP) boundary challenges and take appropriate preventive / mitigative action. In the parameter response model, actions are only taken once a parameter has reached or exceeded a certain pre-established value. This may lead to unnecessary delays in relevant protective actions.

Hence, it is essential that operators/TSC experts have an understanding of the objectives of

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2 However, it should be noted that each diagnosis carries the possibility of an erroneous diagnosis, which may make things worse. Therefore, using insights in underlying scenarios may not be a basis for the development of SAMG itself – such guidance should not depend on the recognition of the scenario.
the SAGs which they wish to execute, and not just only follow plant parameters. If they find
that the objective of a particular SAG either has disappeared or demands other actions - which
requires insights in the evolution of the ongoing severe accident - they should take such other
actions, which could also be actions not explored in the plant specific SAMG development. A
SAMG-program that relies on only following preselected plant parameters, without such
understanding, will probably not be effective in mitigating a complex severe accident. Hence,
it is beneficial if SAGs do not only refer to the parameters that need to be satisfied, but (also)
place the objective of the guideline as the final target to be reached. That means also that the
SAG at hand is left once the objective is reached, largely irrespective of the value of the
parameter that initiated the SAG. In addition, selecting and initiating SAGs should be
consistent with the expected accident evolution, as far as such insight is available.

A consequence is that training should be such that the objectives of the SAGs are clearly
understood and are the driving forces behind initiating and completing the SAGs. Another
reason for such training is that, as said, the accident evolution may be different from what has
been analysed before and that operators/TSC should be able to understand that alternate
actions must be taken and operators/TSC are capable to find such alternate actions. The help
from off-site support in such matters may be relevant / beneficial, but such help may not be
available in due time and, hence, should not be counted upon in executing the SAGs, at least
not in the beginning. A way to train this matter is to run a drill/exercise, where plant staff is
suddenly left without instrumentation, lost plant internal communication, are told batteries
will last only 10 minutes more, or similar complications. In recent documentation, NEI 14-01,
sec. 3.2.1, such insights are also recognised as valuable, [6].

In summary:
1. Execution of a SAG should not only depend on parameter values, but on consideration
   of the fission product boundary challenge that is mitigated by this SAG, or other defined
   objective. The SAG format should be changed so that this objective is very visible to the
   plant staff. The SAG should be terminated or skipped if the threat has been managed or
   has disappeared.
2. Execution of a SAG may also be initiated if the accident evolution - if recognised - will
   indicate a future challenge to the FP boundary which the SAG is designed to protect. To
   understand the accident evolution requires skill and expertise about severe accident phe-
   nomena and their physics.
3. The consistency of proposed SAGs with the expected evolution of the accident should
   be checked, where insight in this evolution is available.
4. Skill and expertise about severe accident phenomena and their physics should also be
   available at the TSC and, to a relevant level, at the Main Control Room (MCR), to pre-
   pare for the unexpected. Off-site support in this matter may be called in, but it should be
   clear that such support may not reach the site in time.
5. SAMG developers should better recognise that SAMG is a world far different from
   EOPs and shape their SAMG accordingly. In terms of the third paragraph of this section,
   one should try to shape the SAMG as ‘Emergency Accident Management’. Note: this
   can be a second stage of SAMG development, as the tools to do this may not be readily
   /not yet available.

2.2 Need for SAMG if there is no AC power, no DC power and/or no water

SAMG considers actions that require instrumentation to determine which SAG should be
executed, plus equipment that is capable of performing the required actions. Most instrumen-
tation, however, requires DC power, and equipment to perform SAG-actions requires AC power and water. Also many valves require DC power for operation. Consequently, the present form of SAMG, plus the envisaged improvements foreseen in the PWROG SAMG as they have been reported so far, may not offer protection for Fukushima-Daiichi type of accidents.

It is recommended to develop SAMG that also will offer protection in such situations. For example, if there is no AC, no DC and no water, it may not be possible to avoid SG tube creep rupture. It may then be possible for operators to select a path through which releases may be smaller, e.g., by opening up manually the Main Steam Isolation Valves and spray upcoming condenser leaks by a fire brigade pump. This requires an analysis of the location of potential condenser failures and leak paths from the turbine building. Of course, such alternative must be studied in advance for its radiological consequences compared to an unmitigated SG tube creep rupture.

Similarly, one may decide to already vent the containment before a substantial amount of radioactive products are released to the containment atmosphere, thereby creating a margin for the anticipated pressure build-up in the core damage domain, e.g., by \( \text{H}_2 \) and by \( \text{CO}_2 \) from the molten-core concrete interaction. It should then also be considered how much sub-atmospheric pressure may arise after steam condensation. Note 1: this example and the one just mentioned are examples only - this paper does not intend to develop such SAMG - that is the task of the SAMG developers /vendors. Note 2: this issue is mentioned in [1], sec 2, last bullet, but not in the same meaning. The action to vent the containment under these conditions is not an action in the Diagnostic Process Guideline.

2.3 Role of Portable Equipment (e.g., ’FLEX’), Extensive Damage Mitigation Guidelines (EDMG), Fire Fighting Procedures

Further to sec. 2.2, one remedial action in the absence of AC, and/or DC, and/or water, is to hook on portable equipment. For example, bringing in portable batteries (to read instruments via their calibration devices), portable pumps, hoses to connect to external reservoirs, support by fire brigades, etc. Such actions, however, are not described in either present or proposed SAMG. The use of portable equipment is described in documents such as FLEX-support guidelines (FSG, [7]), also in guidelines of the type Extensive Damage Mitigation Guidelines (EDMG) [8], which are a response to large site damage by third party actions (e.g., air plane crash). Both FSG and EDMG, however, are primarily oriented to prevent core damage, i.e., they belong to the preventive domain.

For example, preventing an SG tube creep rupture - an action in SAMG domain - requires a pump that is capable to pump against SG pressure. Such pump, however, is not foreseen in either the EDMG or the FLEX. Also NEI 12-06 [7] states that FLEX has not been designed to support SAMG. Therefore, it is recommended to review both the FLEX- and EDMG-equipment and the corresponding guidelines, and to expand these to SAMG domain (1 mentions in this respect integration of the guidelines, not the equipment).

This includes another matter until now absent in SAMG, which is the time windows during which the action should be completed to at least have a reasonable chance for success. If the time window is too small, operators/TSC will understand that they must develop an alternate strategy. Best is, of course, that the SAMG developers themselves develop such alternatives - if they exist. In principle, one should **not** leave deliberations to the TSC which SAMG-
developers/engineers could have anticipated at their office desks.

Note: now the EOPs, SAMG, FSG and EDMG are sets of procedures/guidelines with independent initiation criteria. They should be integrated, so that a unique set of actions follows a unique set of plant conditions. It is understood that the PWROG SAMG program includes this, [1]. Probably to be added: integration with fire extinguishing procedures, as fire fighting may be needed in parallel to other actions. Integration has also recently been addressed in [6].

2.4 Priority always with Core Cooling

SAMG focuses on the protection of fission product boundaries. Although this is the right focus once the core is damaged and fission product release becomes a realistic threat, the attention may NEVER drift away from maintaining core/debris cooling. Irrespective the actions which are taken under any SAMG regime, core/debris cooling is to be searched for uninterruptedly. This includes repair of power sources, repair of injection capabilities, refill or repair of water sources. Not placing major efforts on core/debris cooling may later in the accident cause even more threats to fission product boundaries and cause large releases.

In various SAMG approaches, core/debris cooling is only one of the actions to be taken in the framework of the overall SAM-actions. This may give a wrong perspective to the user. Core cooling should be placed on a high priority level, in parallel to whatever actions are taken under the prevailing SAMG regime. In a way, this is recognised in [1], sec. 3.1, 3rd paragraph. The Diagnostic Process Guideline (DPG), however, does not reflect this principle.

3. Detailed Issues of the Proposed PWROG SAMG

3.1 SAGs under MCR Authority; Rule-based versus Knowledge-based Actions

For the PWROG SAMG, it has been proposed to place some actions that were before in the SAMG domain under TSC authority now under the MCR authority:

1. Inject water into the steam generators (was generic WOG SAG-1)
2. Depressurize the RCS (was generic WOG SAG-2)
3. Inject water into the RCS (was generic WOG SAG-3)
4. Inject water into containment (was generic WOG SAG-4).

In the WOG SAMG, potential negative consequences were considered before taking a decision to execute one of these SAGs. Now these are rule-based actions, i.e., such deliberation may not any longer be considered.

Changing the guidelines concerned can only be assessed fully once the SAGs are available. The first impression of this author is that the proposed change is not favourable: it touches the essence of SAMG, which is balancing pluses and minuses of proposed actions.

An example is a full depressurisation of the RCS. If, for example, the mechanical engineering department tells the TSC that they will have a diesel generator back on line in two hours, and there is at present no low-pressure injection into the RCS available, the TSC may decide not to depressurise the RCS so as not to remove the last available water in the RCS. Or, if the turbine driven auxiliary feedwater (TDAFW) pump may be restored in a not too distant future, it may also be decided to delay or inhibit RCS depressurisation, as otherwise no benefit can be taken from the TDAFW pump. Should there be no TSC, it seems to be well possible to let the shift supervisor decide such actions or no-actions. Similar observations regarding a deviating

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3 Free to Edward Frederick, operator of TMI-2 during the accident at that plant.
strategy for depressurisation (here slower) of the RCS were reported in 2009 in a Korean investigation, [9].

In the proposed scheme, the default will always be followed, i.e., depressurisation of the RCS. As early depressurisation will also result in an earlier RPV meltdown, this action should absolutely not be taken as a simple rule-based action with always positive consequences (as it is said in [1]). The proposed method is, hence, a severe drawback against the existing practice of balancing pluses and minuses. As RPV meltdown is a very severe event, which very much complicates the accident evolution, the proposed method should absolutely be declined.

Remarkably, other SAGs are not considered in this prospect of early actions:

- SAG-5 would be mitigating releases. Should operators not care about site releases if there is not (yet) a functioning TSC?
- SAG-6 mitigates containment overpressure. It is difficult to conceive this action to be necessary before the TSC can be considered to be available. However, the actions under SAG-6 are in the present WOG SAMG - not containment venting, but working with sprays and fan coolers. It is difficult to understand why operators are not considered to be able to decide on and perform these actions. Containment venting would clearly be a TSC initiative, as it involves (possibly large) releases.
- Similarly for SAG-7, controlling hydrogen, which is also a quite straightforward strategy and, hence, could also be placed in the hands of the MCR.
- SAG-8: Some plants consider also flooding up to a high level in the containment (if not yet done under SAG-4) to cover all debris, including the debris left in the RPV, which, however, will not be a short time action, so it can be placed in the hands of the TSC only.

Now, [1] states that rule-based actions will follow the completion of the first four priority actions if the TSC has not yet been activated, but it does not specify what actions are meant. Hence, assessment of these actions is at present not possible, notably not whether they contain any equivalent of the SAG-5 – SAG-8 actions just mentioned.

This author believes, however, that most or even the whole package of SAGs can be well handled by a well-trained MCR, possibly with the exception of containment venting (or other actions that may result in releases). Then there is no need for the new rule-based actions. However, the MCR may not be able to (easily) handle complications without TSC support.

Remarkably, the protection against containment sub-atmospheric pressure seems not to have been included in the Diagnostic Process Guideline, where it initially was a prominent guideline in the Severe Challenge Status Tree. It should be clarified where this challenge now is treated.

In conclusion, we can make the following observations:

1. Replacing SAGs by rule-based guidelines contrasts a main principle of SAMG, i.e., deliberating pluses and minuses of proposed actions before actions are taken.
2. It has not (yet) been explained what has been done with the potential negative consequences of the proposed rule-based actions that were considered before in the WOG SAMG as TSC initiated actions. A severe negative consequence is connected with an unnecessary early depressurisation of the RCS, as it may result in severe complications later on in the accident evolution.
3. It is not clear why SAG-5 (mitigating releases) and SAG-7 are not part of the actions that can be undertaken by a well-trained MCR. Similar for SAG-6.
4. There is no clear reason why a well-trained MCR would not be capable of treating
most or even the full package of SAGs (*i.e.*, no simplified versions), should no TSC become available.

### 3.2 Coloured scheme (‘Diagnostic Process Guideline’) to initiate SAGs and to determine their priorities.

To help setting priorities, the PWROG has developed a coloured scheme, the Diagnostic Process Guideline (DPG), which directs the TSC to specific guidelines for each critical plant parameter. In the DPG, the priorities are assigned to the guidelines following 4 colours for plant parameters: green, yellow, orange, and red - in this sequence in increasing priority. In addition, the priority decreases for lower placed guidelines. See Fig. 1.

An advantage over the former two logic diagrams is that now different priorities can be assigned to various SAGs, as they can have different colours, where their equivalents in the DFC had not such weighting.

However, this author did not see arguments why *four* different challenge levels need to be selected. At first sight, this seems overly complex. A safety function is satisfied, or it is not. If it is not satisfied, actions should be initiated to restore it. So, in principle, two levels are sufficient. There may be arguments why a third challenge level is also appropriate, and for some parameters this is done, as they indeed have three colours. A fourth level seems to only make things more complex, without added value. In part, the assignment of some colours seems even questionable: the containment integrity can have a red challenge, whereas the SG tube integrity against creep rupture has not, although the release through a ruptured SG tube can be very significant. In addition, it is an early challenge, so there is a higher probability the challenge will not be well mitigated due to human failure or to lack of timely repair of failed systems. The reason may be that one simply has integrated the SCST into the DFC and has assigned it a different colour (red). In that sense, the new DPG is largely the same as the former two logic trees, the DFC and the SCST. Replacing the two diagrams by one for reasons of human performance is then questionable, as still the same deliberations must be made (further discussion below).

As mentioned before, this SAMG development process has similarities with the EOP-development process. As the WOG EOP /FRGs have 4 colours, it probably has also been selected to follow the same approach. It could also have been derived from the Areva OSSA approach (see Appendix 1). This author believes that in the mid of the turmoil of a severe accident, it may be dangerous to spend time on differentiating between *e.g.*, orange and yellow levels of challenges.

It is also unclear what the various priority levels mean in practice. For example, one may observe a green level for core cooling, and a yellow level on containment water level. Then, if few water sources are available, the DPG may suggest to send the water to the containment rather than to the core. This could be a serious mistake. Core cooling should NEVER be interrupted or even questioned, it must be kept alive *uninterruptedly*, as far as is possible (see also[14], sec. 4.2.1). Hence, comparing between the different challenges is something like comparing apples and pears: it should not be done.

In addition, the priority ‘ladder’ of Fig. 1 may not be generally applicable. For some reactors, the occurrence of core damage may be accompanied with a massive generation of hydrogen, so that an early barrier to fail may be the containment, due to hydrogen explosion. This suggests SAG-1 to mitigate the hydrogen risk, rather then the risk of an SG tube creep

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4 FRG = Function Restoration Guideline (symptom-based scenario-independent type of EOP).
failure. The sequence of priorities as depicted in Fig. 1 must be checked for each plant, whether it conforms to the actual sequence and severity of threats to the FP boundaries. Which may be even scenario-dependent.

The various challenges in Fig. 1 are treated independently. For example, the containment pressure is a red entry when the pressure is a direct challenge to the containment integrity. However, if also a hydrogen burn must be anticipated, the containment integrity is at stake already at a lower pressure, because one should add the pressure spike of the potential hydrogen burn.

Note: by working along the hydrogen computational aid, one may be able to avoid the flammable region. However, it cannot be concluded a priori that one always will be successful in avoiding hydrogen burns. Where igniters are used to eliminate the hydrogen risk, such burns must even inherently be included.

The DPG follows the core temperature, i.e., it follows the core cooling, but it does not follow the removal of decay heat and the existence of an ultimate heat sink. In some other approaches, the decay heat removal function is one of the main functions in a DPG-equivalent diagram, even with red-orange-yellow-green colours, as it is displayed in Appendix 1. A suggestion is to include the existence of an ultimate heat sink and the heat rejection path to this heat sink in the PWROG SAMG. Alternatively, it should be included in the Handbook of Accident Management Capabilities. But as it is directly linked to the safety function of core cooling, inclusion in a SAG seems to be the proper place for this important safety function.

Note: if a once-through cooling mechanism is selected, proper attention should be given to runoff of cooling water, as such runoff otherwise may result in large releases.

As already said above, the various challenges are not independent. One could possibly group the individual challenges into the three safety functions as displayed in Appendix 1. For example, all core/debris cooling functions could be in the group ‘core/debris cooling’. This would e.g., also include flooding the containment to achieve In-Vessel Retention (IVR). Another group would be all that is connected to containment integrity, which would include SG tube protection, hydrogen mitigation, protection of the containment against overpressure and sub-atmospheric pressure. And the third group then contains all that is necessary to mitigate releases. Other grouping processes are, of course, possible. This would possibly simplify the DPG and, thereby, contribute to the success of the mitigation efforts. This author believes that one should, in principle, work on the various challenges in parallel, where the priority is assigned based on the chronology and severity of the various FP boundary challenges (note: ‘parallel’ is not ‘simultaneous’, i.e., actions are executed still at different times and with different priority, as is formulated in the guidelines and/or decided by the TSC).

In the former WOG SAMG approach a switch could occur between the two different logic diagrams (the Diagnostic Flow Chart, acronym DFC, and the Severe Challenge Status Tree, acronym SCST), which in the PWROG approach have been merged into one logic diagram for reasons of human factors, as it is said. But now there are jumps between rows, prescribed by the observed colours, which method also challenges operator performance. Hence, the merging of the two diagrams has a limited value. One could also argue the opposite: if in the former approach work in the DFC had to be interrupted for an entry into the SCST, it was very clear that an immediate challenge existed, as the SCST just dealt only with

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5 For example, the OSSA SAMG approach by Areva, (OSSA = Operator Support for Severe Accidents), see Appendix 1.
Figure 1: - PWROG SAMG Diagnostic Process Guideline (from [10])

Immediate challenges (and large releases). It changed also the handling by the TSC: balancing pluses and minuses, as is the methodology of the DFC, was not done any more, as immediate action was required. Now this fully different approach is kept in one diagram, and the difference of treatment depends on the colour. In other words, by staying in the same logic diagram, this character of urgency of the former SCST has somewhat disappeared - it is now
only visible in the colours. One could even argue that nothing really has changed, as the only threats with a red colour are the former entries of the SCST (as already said above). Note: some of these concerns may have been or will be alleviated in the ‘Rules of Usage’, which—if already existing—were not available for evaluation.

Further to this example, the containment water level becomes only relevant when either IVR is attempted or Reactor Pressure Vessel (RPV) meltthrough is anticipated, which are not immediate actions/challenges. Hence, the selection of priorities should also include a time frame/time window. For example, irrespective of the water level in the containment, the level in the SG should have priority in the beginning of a severe accident, as it concerns the prevention of an early FP boundary failure: an SG tube creep rupture, whereas it can be ignored later in the evolution of the accident, where the RCS has been depressurised or even the RPV has failed.

Hence, there are six concerns regarding the DPG:
1. The diagram does not include the timing of the various FP boundary challenges which the SAGs should mitigate but which can be relevant for determining the proper priority.
2. The diagram suggests generic applicability, whereas its actual shape is plant-specific.
3. The diagram does not include dependencies between challenges, notably it does not recognise the combined threat of containment pressure build-up and hydrogen combustion.
4. The diagram may be overly complex as there are too many different levels (too many colours).
5. The diagram does not treat possible SG tube creep rupture as a severe FP boundary challenge (i.e., with a red entry).
6. The diagram does not treat potential containment sub-atmospheric pressure (as may happen after containment venting or leakage, upon condensing of the remaining steam).

Note: defining the time frame may require some insight in the scenario. Observations of plant conditions may help in recognising main characteristics of the scenario\(^6\). This is one more reason to train the plant staff in severe accident phenomena, as already discussed in sec. 2.1 of this document.

This author does not see a major advantage of the DPG over the former DFC/SCST, not to say he tends to believe it is disadvantageous. Other approaches and improvements are possible, as have been described above.

3.3 Handbook of Accident Management Capabilities, Shift Turnover Package, other new documents

The Handbook of AM Capabilities and the Shift Turnover Package are two documents which without doubt contain valuable information and which, thereby, should enhance the SAMG execution. However, it is not clear that additional ‘paper work’ will indeed enhance in practice the execution of SAMG. It is a common practice to respond with more rules and procedures, if an accident has happened, but it also creates additional burden on plant staff: now additional documents must be created or consulted, in the mid of the turmoil of the ongoing accident. How a severe accident must be treated was shown with much courage by the pilot of the US Airways Flight 1549, which did not (could not) follow the procedure to return to a nearby airfield, but decided for a different course of action: he landed his bird-

\(^6\) In France, there are even programmes to determine the break size of the initiating event, e.g., the program ‘Brèchemètre’.
stricken aircraft safely in the Hudson River in New York. Knowledge, experience, courage, leadership - those were the ingredients of Captain Chesley Sullenberger’s character and expertise, which led to his success in the emergency, [11].

This author believes these are the ingredients we should strive for in severe accident management, rather than expanding procedures. The PWROG SAMG seems to follow an opposite course - but in this author’s view rule-based accident management (AM) cannot substitute knowledge-based AM. Priority should be with expanding training, and procedures / guidelines should have primarily a supporting role - they do not replace the human decision making process. Valuable thoughts about human decision making in accident management in this matter are expressed in the MIT-report [3], already mentioned above in sec. 2.1.

Procedures / guidelines do not replace ingenuity, courage, leadership and vigour to complete the mission. Without these qualities, we risk losing too much time in the deliberations of the TSC and may elect a wrong course of actions – this risk was exactly the reason why more rule-based methods were introduced. In this respect, one should not change the existing SAMG to more rule-based SAMG, but to more education and training of the TSC: shaping characters is more important than shaping procedures.

It appears that the success of mitigating the tsunami damage in the Fukushima-Daini plants was primarily due to these characteristics of the leadership at that site [12]: for example, there was no procedure to lay 9 kilometres of high-voltage cables within short time, but it was done and it saved the plants.

Hence, concerning the proposed new documents, it should be studied in drills/ exercises whether these indeed contribute to the success of the work, or are just an additional burden, which then even may degrade the efficiency of a well-trained crew in handling the accident.

Other new elements are provided, as depicted in [1], sec. 3.2:

1. Increased evaluation bases scope and level of detail (evaluation aid).
2. Vendor priorities and preferred methods (reduces evaluation tasks).
3. Benefit-Consequence Table (evaluation aid).
4. Rapid Decision Matrix (provided to reduce procrastination of decision making).
5. Streamlining guidance through its integration such that the guidance is contiguous without the need for flow path transfers to non-contiguous guidance (reduces human burden and its potential for error).
6. Simplified Computational Aid (CA) usage (expedites use of CAs but may also increase the potential for errors).

These elements look promising, and indeed will be a major improvement, yet, evaluation in this document was not possible, as no description was available.

It seems that one important element is missing, and that is the estimate - quantitatively - of potential negative consequences of proposed actions. However, it may be included in item 3, the Benefit-Consequence Table. Note: so far, quantitative estimates of negative consequences were not available in the WOG SAMG.

One could also have made a more extensive use of the BWR Owners Group (BWROG) TSC guidelines. These are as follows:

- control parameter assessment guideline (CPAG): to obtain and process appropriate plant data in the ERO;
- plant status assessment guideline (PSAG): to assess current conditions in various areas.

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[1] This aspect was first mentioned by Mr. Robert J. Lutz in the revision of the IAEA Safety Guide on Severe Accident Management, NS-G-2.15.
of the plant where needed instruments or equipment are located;

- system status assessment guideline (SSAG): to evaluate the availability of systems needed to implement EOPs and plant specific SAMGs;
- EPG/SAG action assessment guideline (EAAG): to prioritize system restoration and action timing as indicated by accident management strategies.

Note: it is possible that the PWROG has incorporated this in whole or in part in the above documents.

As said before, the benefit of all these new documents should be tested in the validation of the PWROG SAMG. As also said before, documents cannot replace the needed expertise of the TSC/MCR staff to handle a complex severe accident.

4. Lessons from review of SAMG programs and SAMG exercises and drills.

Although this document is mainly devoted to the new PWROG SAMG approach, it is worthwhile to also consider practical problems in the development and application of SAMG. Because even the best approach in SAMG will fail if there is no appropriate development of the plant specific SAMG and proper education and training of the teams in charge of executing the SAMG in case of a severe accident. The PWROG SAMG program should therefore include consideration of the shortcomings and problems which have been found in drills and exercises, examples of which are listed below.

This author has taken part in many exercises and drills of many different types of SAMG. These were done either in an IAEA team or in other groups of experts assigned to SAMG review at a particular plant. Many shortcomings were noted and many recommendations for improvement have been given. Major issues were the following:

1. lack of understanding or even misunderstanding of the generic product (i.e., EOP, SAMG) and absence of appropriate training by the vendor of the generic product;
2. use of a generic product without proper transition to the actual plant or group of plants;
3. incomplete or inadequate technical basis for the plant-specific procedures / guidelines;
4. improper transition from the EOP- to the SAMG-domain;
5. incomplete list of available resources for water and/or power;
6. use of equipment that has been damaged by the accident or is not qualified for the prevailing environmental conditions;
7. not considering the impact of the severe accident environmental conditions for the instruments which are read to initiate SAGs;
8. use of rooms for the TSC and the ERO that had no protection against radioactive releases from the plant;
9. use of laptops in the TSC without any provision for recharging the batteries;
10. a very limited number of accident scenarios as the basis for the total accident management program;
11. lack of indication / understanding of time windows in which the countermeasures must be completed;
12. lack of understanding what the accident management will lead to (insufficient analysis of consequences of actions);
13. lack of integration between various sets of procedures;
14. development of accident management program without proper verification and validation;

EPG = Emergency Procedures Guideline, is BWR Owners Group equivalent of EOP.
15. lack of clear command and control and, where these have been lost initially, lack of a system to restore command and control;
16. lack of description of functions in the ERO and the associated responsibilities;
17. lack of training for the ERO functions (where defined);
18. focus on tasks which are not the responsibility of the TSC and neglect of tasks which are the responsibility of the TSC;
19. lack of training for shift transfer during an accident;
20. development of accident management program without peer review by staff of sister plants;
21. plant-unique developments which deviate so much from generic products that peer review by sister plants is difficult, if not impossible;
22. lack of training to respond to sudden complications and deviations from pre-analysed paths; and
23. different regulation or lack of regulation in different domains of accident management.

The last four items are not fundamental shortcomings, but their absence complicates the development and implementation of the SAMG program.

It must be said that these items were all found in well-developed nuclear countries – they were no ‘beginners errors’.

The conclusion of all these items is that the work is not done if a generic product, such as the PWROG SAMG has been developed. There is still a long way to go once the generic product is done, before implementation at the plants can be considered successfully completed. In other words, the focus should not only be on the front end of the SAMG development - the work by the original developers, but also on the tail end – the actual implementation at the plants.

5. Main Conclusions

The PWROG SAMG results from an in-depth review and revision of the existing US SAMG approaches. It has combined these in one single approach. New tools have been created to further support both the MCR and the TSC in the complex task of mitigating a severe accident. Creating a single PWR SAMG approach is doubtless a major improvement over the former more scattered SAMG approaches. Despite this highly desirable result, a number of potential improvements still can be made.

The approach replaces in various aspects the knowledge-based decision making process by a more rule-based decision making process. Although this approach makes the implementation in an NPP more simply, it may decrease the capability of the MCR/TSC to handle complications and, in general, unforeseen and unexpected events. As such, it can be labelled ‘Routine Accident Management’ rather than ‘Emergency Accident Management’.

Although the ‘Routine Accident Management’ (RAM) type of SAMG as presented in [1] can be considered to be a first step, it should definitely be followed by a more ‘Emergency Accident Management’ (EAM) type of approach. Without a solid basis to handle the unexpected both in the SAGs and in the training program, the SAMG program cannot be considered to be complete and may not be effective in a real event.

A first step in the transition from RAM to EAM is to define the objectives of a SAG more explicitly in terms of mitigating a particular challenge of a fission product boundary, rather than meeting a threshold for a particular parameter. Insights in the evolution of the accident

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1 Time is available, as implementation by the US Nuclear Regulatory Commission is not required before 2020.
can also help to determine the right course of actions and, hence, should be strived for. The priority of individual SAGs should follow the chronology and severity of the fission product boundary challenges.

Four actions are defined that the MCR should execute if the TSC is not available. Mitigating releases is not one of those, although this probably is a primary strategy in a severe accident. The remaining SAGs seem also to be well inside the capabilities of a well-trained MCR. Hence, it should be considered whether not the whole spectrum of SAGs could be placed inside the capabilities of the MCR. This would notably mitigate the risk that the TSC cannot reach the site, caused for example by widespread damage on- and off-site, due to some large external event.

The Diagnostic Process Guideline (DPG) is at one side an improvement of the earlier Diagnostic Flow Chart (DFC) and Severe Challenge Status Tree (SCST), as it is a single diagram and eliminates the need to switch between two logic diagrams. It also has a mechanism to assign different weights to different guidelines. On the other side, it is not basically different from the earlier DFC and SCST. In addition, it is fairly complex. It possibly can be simplified in that fewer levels of priorities can be defined, and related functions can be combined. It should be noted that not all individual entries are independent, neither are the different fission product boundary challenges always comparable when selecting priorities. This may led to a wrong selection of priorities. A method that simplifies the DPG to a method that just protects the basic functions of core/debris cooling, decay heat removal and containment (see sec. 3.2) seems preferable. Core/debris cooling can never be assigned a low priority, as it is essential that such cooling must be continuously provided.

The Diagnostic Process Guideline does not address the availability of the heat removal function, neither the continuous availability of a heat sink, nor the potential challenge from a containment sub-atmospheric pressure. For one-through cooling methods, it does not address handling the run-off water.

The PWROG SAMG assumes the availability of AC, DC and water, or portable equipment where these fail. The time windows that must be observed to successfully hook on such equipment are not specified, so that the potential for success of a particular SAG is unknown. It is recommended to develop such time windows and to confirm in the validation that the particular SAG can be executed within the specified time window.

Irrespective of the time windows mentioned in sec. 2.3, SAMG should be developed if AC, DC and/or cooling water are not available and cannot be restored back to service in an appropriate time.

The benefit/drawback of the additional guidance and documentation, i.e., more voluminous paper work, should be reconsidered and the final product be tested in the validation process.

Apart from the development of an appropriate generic SAMG product, much attention should be paid to the actual plant-specific implementation.

References


George Vayssier, M.Sc., leads NSC Netherlands now 19 years to consult world-wide on guidelines and safety measures, designed to manage and control nuclear reactor accidents. He and his team work extensively with US and European nuclear industry, the IAEA, and nuclear safety authorities in US, Canada and Europe, in development of accident management guidelines and peer review at nuclear power plants.

Appendix 1 (from [13])

**Diagnostics and Severe Accident (SA) Safety Functions (OSSA)**

- Diagnosis through monitoring of three OSSA Safety Functions:
  - Fission product releases to the environment: RELEASES
  - In-containment conditions: CONTAINMENT
  - Decay heat removal: HEAT REMOVAL

- The SA Safety Functions are continuously monitored

<table>
<thead>
<tr>
<th>SA Safety Function</th>
<th>Challenge Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. RELEASES</td>
<td>(red)</td>
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<tr>
<td>2. CONTAINMENT</td>
<td>(red)</td>
</tr>
<tr>
<td>3. HEAT REMOVAL</td>
<td>(red)</td>
</tr>
</tbody>
</table>

- Two axes of priority: the color and the number