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Severe Accident Management Guidance: Lessons Still to be Learned after Fukushima - The Need for an Industrial Standard

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Abstract

After the accidents in Three Mile Island (TMI) and Chernobyl, many countries decided to develop and implement guidelines specifically directed to mitigate accidents with core damage, so-called severe accidents. The guidelines are usually named Severe Accident Management Guidelines (SAMG). In the USA, all operating plants had these guidelines in place at the end of 1998. Most other countries followed later, but today, it can be said that many nuclear power plants in the world have such guidelines in place.

Typically, however, the guidelines were constructed under the assumption that many plant systems still will be available, i.e. there will be DC to feed the instruments, AC to feed equipment and water to restore cooling to the core. Typically, this was basically the situation at TMI: most equipment was functional, only the insight of what had happened had been lost and operators did not know how to respond.

At Fukushima-Daiichi, a Site Disruptive Accident (SDA) occurred and it appeared that the situation was much more complex: much of the needed supportive equipment needed was unavailable, which greatly complicated the handling of the event.

In this paper, the major shortcomings of the present existing SAMG are discussed, both from a technical, and an organisational viewpoint. It is concluded that, where proper regulation still is missing, the development of an industrial standard is recommended to define adequate tools and guidelines to mitigate severe accidents, including SDAs.

Keywords

management of severe accidents, Fukushima-accident, industry standard

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1.0 Introduction

Since the accidents at Three Mile Island (TMI, 1979) and Chernobyl (1986) a series of guidelines have been developed for operating plants to mitigate severe accidents, i.e. accidents where the fuel in the core and/or in the spent fuel pool may melt and large releases may occur. The guidelines are commonly known under their acronym SAMG: Severe Accident Management Guidelines (or Severe Accident Management Guidance).

In a number of countries also major hardware modifications have been implemented, such as a filtered containment vent or a set of passive autocatalytic recombiners (PARs). The filtered vent should prevent large releases from high pressure events in the containment. The PARs should prevent hydrogen explosions in the containment. A vivid expression of such explo-

sions – but outside the containment - were the explosions of reactor buildings in the Fukushima-Daiichi nuclear power plant (NPP) in March 2011, well captured on television.

The TMI and Chernobyl accidents triggered large scale research world-wide to study the phenomena which occur during a severe accident, and so formed a technical basis from which the guidelines could be developed. Yet, neither these insights nor the extensive guidelines available were capable to prevent the Fukushima-Daiichi releases. The question arises whether the SAMG developed indeed has the capability to mitigate severe accidents and reduce risk. Remarkably, few research papers have been published which study the potential risk reduction of a package of SAMG; an example is given by Lutz and Lucci [1]. Even today, SAMG is not commonly a well-integrated part of most probabilistic safety assessments (PSA), even where industrial standards call for their inclusion, see e.g. ANS/ASME RA-Sa-2009, [2], p. 98.

A closer look to the various SAMG packages as they exist today reveal that they are typical mitigation measures derived from the TMI-accident. I.e., all systems were available to mitigate the accident, only the insight was missing what had happened and what could be done.

With the advanced Emergency Operating Procedures (EOPs) as they have been developed after the TMI accident, the loss of such insights should not lead anymore to a severe nuclear accident, as EOPs do not any longer require proper diagnosis of the event and cover often also a number of beyond-design basis events. Today, severe accidents are more likely the consequence of extreme external events, multiple internal events, hidden common cause failures, severe operator errors, and terrorist attacks. It appears, however, that SAMG packages do not typically cover such events. In addition, it appears that in a number of cases SAMG packages either lack proper tools or do not have been implemented properly. In a number of SAMG reviews which the author has conducted, severe shortcomings were detected which one even would not expect at well-designed and well-operated plants.

It should be said that developments have been made in a number of countries to develop guidance to mitigate large site accidents which destroy buildings and infrastructure (e.g. caused by an air plane crash), so-called Site Disruptive Accidents (SDAs), as Fukushima-Daiichi was, Vayssier [3]. Notably in the USA a number of so-called Extensive Damage Mitigation Guidelines (EDMGs) have been developed. They support plant staff in restoring command and control, should it have been lost, plus indicate a number of actions to stabilise the reactor, notably with a number of manual actions. For some actions, additional – portable – equipment is needed, which has been procured and stored remotely on the site. The EDMG are, however, not (yet) integrated in most current SAMG. Very few countries have developed such guidelines, as the underlying document NEI 06-12 [4] was originally held back due to security reasons (they were initially developed in response to terrorist attacks, after the 9/11 attacks in the US). After the Fukushima-Daiichi, the US NRC made the underlying documents publicly available, but this has not yet led to substantial initiatives in the development of EDMG in the various other countries.

2.0 Major changes in accident management after the Fukushima-Daiichi accident

A number of studies and measures in accident management have been taken after the Fukushima-Daiichi accident. Examples are the consideration of additional portable equipment to support plant staff in the case of an extended loss of AC power or the loss of the ultimate heat

sink. This approach has been taken up in the US under the name of FLEX, NEI 12-06 [5]. It includes the procurement and storage of portable equipment also off-site. In the US, there are two centres where such portable equipment is located and can be flown to the stricken site. Similarly, such a centre has been created at a central location in Switzerland. In France, a Rapid Deployment Force (French acronym: FARN) has been created which can bring needed experts and equipment to the stricken site, Vidard [6]. Some other countries rely on their bunkered decay heat removal systems, and do not plan to use portable equipment.

The capability of this support, if implemented, includes simultaneous damage to plants at multi-unit sites, as a SDA affects in principle all units on a site.

A stress test has been performed at the European plants, coordinated by the European Commission [7]. One of the topics was the existence and capability of the various SAMG programs at European nuclear sites. This has also led to a series of improvements, including both hardware and procedures/guidelines

Also the Technical Basis of SAMG programs has been updated. A major effort here was the update of the EPRI Technical Basis Report (TBR, [8]), as the basis of the US SAMG programs. Even more that the document was now made publicly available, after the versions before were only available as licensable material for a substantial fee. Typical additions were:

- consideration of the spent fuel pool;
- cooling with all available water sources (for example: including sea water); and
- consideration of leakage of gases from the containment to other buildings (for example: hydrogen that leaks to an adjacent compartment, as happened in Fukushima-Daiichi).

3.0 Problems in the development of the current SAMG programs

Although a number of improvements in the current SAMG programs have been developed or are still underway (Williamson et al., [9], Prior [10], Reed LaBarge et al. [16]), it still is questionable how much they indeed are capable of supporting plant staff in an actual event. The reason may be that the SAMG developers still have an unrealistic picture of what an actual severe accident is, the immense chaos which may go with it (as we have seen in Chernobyl and Fukushima), the stress to which the main players are exposed, the large scale failures of equipment, the breakdown of communications, the fear that the staff has for its own safety as well as for that of their relatives. SAMG programs are designed at the engineer´s office, in all quietness of his or her daily activities, with no fear for the outcome of any of the proposed actions on his- or herself, no concerns about anybody´s safety in the office. To replace one-self in the chaos of an ongoing severe accident may be too difficult a task for a technician, thinking about the pumps he may need to start and the valves he should manipulate.

The trainings of severe accident management guidelines are not much better: very few plants have severe accident simulators that at least remotely can simulate the chaos that goes with such an accident.

The underlying cause may be that the SAMG developers and their clients, the utilities, do not really believe that their plant(s) once may be subject to the accident for the mitigation of which the guidelines are intended. This is also observed if one studies the effects on other plants if somewhere an accident occurs: the first reaction of a utility is mostly that its own

plant is much different, or operates in another cultural setting, or has better training of staff, so the accident would not happen there. Where appropriate safety culture would demand the opposite: one should primarily not look for the *differences*, but for the *similarities*, IAEA [11]. Even fully improper arguments surface. Example: it is widely believed and said that the Chernobyl accident went so badly because the reactor had no containment. The suggestion is that the Western reactors would be much better off, because of their containment. But this ignores the fact that these ´Western` containments by far not have been designed to contain a superprompt-critical event or the steam explosion that is believed to have destroyed the Chernobyl reactor building.

The often perfect operating history of many NPPs does not help either: if one enters the control room day after day and year after year and never sees anything disturbing, one starts to disbelieve in accidents. From the human engineering point of view, it is almost impossible to ask a plant operator to be a perfect manager of a severe nuclear accident, if he/she never has seen any significant plant disturbance during his/her whole career.

And then, NPPs are not designed to produce and sell safety, they are designed to produce and sell electric power. And often they must do so in a competing economic environment. The consequence is that plant staff may worry more whether their job will be still there tomorrow, rather than that the guidelines to mitigate a hypothetical accident have been properly designed. Budget controllers fear they might possibly not make ends meet – who then dares to speak about a budget for a tool to mitigate a highly improbable event?

In many regulatory environments, SAMG is not subject to regulation, which will mean a minimum involvement of the regulator. So there is also limited – if any at all – pressure from this side to develop trustworthy and applicable SAMG.

Finally, the physics of a severe accident and its evolution are extremely complex – few people (if any) have a proper understanding of all phenomena and their effect on the plant. Subjects are still under study, such as the ex-vessel steam explosion or the exact risk from a hydrogen explosion. And there are still quite extensive research programs going on to better understand the phenomena. In this field of uncertainty, development of proper SAMG (by the plant owner) as well as its assessment (by the regulator) seem heuristic tasks.

All these factors have resulted in the observation that there are still substantial shortcomings in current SAMG programs, which will be treated in subsequent sections. They are not intentional – it is just the SAMG environment as described, which causes this to be so.

4.0 Major shortcomings of current SAMG programs

The author has visited a number of plants and assessed their SAMG, either in so-called RAMP missions by the IAEA on the basis of SVS-9 [12], or in missions under a bilateral contract, which was with the plant concerned or its regulator. Plants were extremely cooperative: plant staff spent much time to discuss the various items, showed their efforts in all openness.

Besides, the author has followed various courses and seminars on SAMG packages, discussed features with the developers and utilities, and attended a number of SAMG exercises. From

the material studied and the personal information obtained, the following observations have been made (in arbitrary sequence):

1. A number of plants depart from a generic SAMG program, such as the one by the Westinghouse Owners Group (WOG), the Combustion Engineering Owners Group (CEOG), or the Boiling Water Reactor Owners Group (BWROG). This program then must be adapted to the specific plant at hand. However, it was sometimes noted that the utility had misunderstood the essence of the generic approach or had not adapted the data to its own plant and just used the generic plant data one-to-one. For example, the WOG approach has a very specific structure to search for challenged fission product boundaries – but the challenges of fission product boundaries are very plant unique and must be investigated separately for each plant.

2. Execution of SAMG leads to actions, such as pumping water from point A to point B, upon reading the instruments C and D. But very few programs (if any) tell the people what to do if instruments have failed or are lacking (i.e. no C and D), and no AC power and/or water to pump from A to B.

3. It is often recommended in the guides that the cause of failure of needed equipment should be found and the system restored. But it is mostly not indicated how this should be done, notably not during the stress of the event. Some approaches use a system dependency matrix, which indicates how front line systems (e.g., ECCS) depend on supporting systems and thereby indicate how complex a repair action might be. A recommendation could be that one should primarily search for systems with few dependencies, as these are the easiest ones to be repaired. Such guidance is, however, by far not common.

4. One of the most essential tasks is reading and interpreting instruments, as they contain the clue of what is going on and they tell the operators when they have reached the threshold for the initiation of certain SAMG actions (the set points of SAMG). Current SAMG approaches often contain information on how the instrument behaves under abnormal – i.e. severe accidents – conditions in their guidelines. But some plants simply overlook or ignore this effect. In addition, DC is needed to read the instruments. But there is usually no guidance how the instrument can be read without DC, for example by improvised means: car batteries, like in Fukushima-Daiichi, plus a calibrator to translate measured voltages into kPa, K, other. Besides, such actions require training – no such training was ever observed.

5. Portable equipment is the help if the dedicated or assigned equipment fails. Yet, few SAMG approaches (if any) specify the use of such equipment *in the mitigative domain* (it is as FLEX or similar often available in the preventive domain, i.e. in the EOPs). In addition, portable equipment must be transported to the location where it is needed and then hooked on. Few – if any – approaches tell the operator how much time he has available to perform all these actions. Such hooking-on is, however, seldom trained in practice. The applicable SAMG does not indicate any time window for the actions concerned.

6. A very typical SAMG action which I saw in many approaches is the priority for injection into the core. A remarkable matter, as we are in a severe accident just because we were *unable* to inject into the core already for quite some time. Again, this seems to be the heritage of TMI: all is there, except for the insight what went wrong. Only few SAMG approaches (in fact, I know only one [1]) recognised this and placed priority of actions on protecting remaining

[1] I observed this clearly in the Westinghouse Owners Group SAMG approach, Dessars [13].

intact fission product boundaries. I believe this matter is the *cornerstone of SAMG: protect fission product boundaries*. I believe it cannot be emphasized enough that SAMG is there to protect remaining intact fission product boundaries (and to mitigate releases), not to save the core – the core is damaged beyond repair.

7. Another remarkable item is that few (I know only one [2]) SAMG approaches direct the plant staff to remove the decay (and other) heat to an ultimate heat sink. As it must be evident to all that the decay heat (plus any chemical heat, such as heat from the water-Zr reaction) must be brought somewhere. Where SAMG approaches place this function on a containment vent, the vent should be analysed for such function, which is far outside its design basis.

8. Most SAMG approaches include venting the containment if the pressure otherwise would rise beyond the design pressure or, if there is sufficient margin, to a higher pressure. However, this always includes a high load on fission products and, hence, contamination of the environment. Many accidents already give rise to containment pressurisation before the fission products escape from the fuel. It may be prudent to vent the containment already at this stage – and then close the vents again – to create more margin to the later venting which goes with a high release. Notably this seems prudent if there are no or not sufficient supporting systems (AC, DC, water) available. Such SAMG is called ´black SAMG`, i.e. what still can be done if no supporting systems are available. None of the current approaches contains such a ´black SAMG`.

Remarkably, as venting or leaking may on the long term lead to containment sub-atmospheric pressure, very few SAMG contain any guidance here – where the containment negative design pressure is usually very low, thereby easily inflicting a containment failure in such condition.

9. The SAMG programs are all of the guidance type, i.e. they give recommendations, not instructions. Such in contrast to most EOPs, which are binding upon the operators. The obvious reason is that there are quite some uncertainties: about the instrumentation, available equipment and available resources. However, when and how plant staff may deviate from the guidance, is not indicated in any SAMG program. Consequently, most SAMG exercises which I observed treated the SAMG as instructions, like the EOPs.

10. Many SAMG programs place cautions on the actions to be performed, as some may have negative consequences. For example, using sprays in a containment may indeed result in the intended pressure decrease, but also to de-inertisation of an initially inert steam-hydrogen mixture and, hence, result in an explosion. Injecting water on an overheated core may result in a large hydrogen source, which may increase the hydrogen concentration in the containment through open safety relief valves (SRVs). Flooding debris on the basemat may result in a pressure spike in the containment, Lutz and Lucci [1]. I did not see any SAMG program where such negative consequences were quantified. I.e., the operating staff must estimate them on the fly, which probably is impossible under the stress of the ongoing accident. Which environment is also totally unsuitable to perform complex calculations. The potential negative effects of the SAMG actions should have been compiled in the plant-specific Technical Basis of the SAMG (developed from the EPRI TBR [8], from PSA-studies, or other work) – example in IAEA SRS-32 [15], Table 1 – but such Technical Basis is not always available, or has not been properly adapted from the generic one to the plant-specific one.

[2] The Areva OSSA approach, Sauvage [14]. Note: the reference does not contain the developments since 2011.

11. As severe accidents can result in large releases, proper mitigation can only be managed from rooms and buildings which have proper protection against radiation. Many plants, however, do not have such protected centres, which makes their SAMG programs virtually non-existent in a real case. A good practice is to have an alternate centre further away from the site. However, to transfer command and control in the mid of an accident to a remote centre requires training and exercise. In the exercises which I attended this was never tried.

12. Apart from the protection against radiation, the command centre should also have an independent power source, which is so robust that a damaging site event does not make the power source ineffective. Nevertheless, I saw such centres which do not have this. The staff which was following the ongoing exercise with their laptops would soon lose all information.

13. Most SAMG programs assume the command and control structure remains intact. I.e., there is a functioning Emergency Response Organisation (ERO) and operating communication means. Large site events can, however, result in a loss of the control room, the emergency control room and damage the communication infrastructure. Ways should be available to restore command and control. Such methods are available in the EDMGs, Vayssier [3], but these are only implemented in a limited number of plants.

13. Most SAMG programs place authority for evaluation and decision making during a severe accident outside the main control room to a Technical Support Centre (TSC), which includes experts in severe accident phenomena. Final decision making can be placed at a higher level, e.g. the Site Emergency Director. Usually, such a TSC is functional in about one hour after the initiation of the accident. However, in a large SDA, people may have difficulty to reach the site or unable to reach the site at all. Most current SAMG programs are, however, not shaped to be executed by plant staff without outside (= TSC) support. In some new SAMG developments, delayed activation of the TSC is explicitly considered (example in Reed LaBarge et al. [16]).

14. Where the TSC is functional, no restraint is placed or recognised on the time they spend in deliberations. Which easily may not be in line with the accident evolution. I recall an exercise where the crew spent much time to try to fill the empty steam generator (which was there the prime severe accident guideline), as equipment had to be restored back to service – where after that time the accident had progressed to a state where filling of the steam generator had lost its meaning.

15. Training programs are mostly limited to the default guidelines. However, during a severe accident, severe complications may arise. For example, suddenly all information is lost, lights go out, communication breaks down. Seldom such complications are trained in exercises. Even if no such complications arise, the default guidance may not longer be applicable, due to the evolution of the accident. I seldom (in fact: never) saw TSC staff questioning the validity of the default logic diagrams and the associated default guidelines during the evolution of the accident.

16. Many SAMG programs are set up such that they can be executed by plant staff, with limited knowledge about the complex severe accident physics and phenomena. Mostly, the default guidance can be executed by plant staff, using observed parameters. However, this approach breaks down if complications arrive and/or the accident evolution deviates from an anticipated path. The trend, however, is more and more to rule based SAMG (example: Reed

LaBarge et al. [16]). Although this saves money (it simplifies training), it is counter-productive in accident management. Notably where reliable indications fail, plant staff should be able to infer a picture of what is going on by extrapolating from a known previous situation – severe accidents are no meteorites, they often have some recognised pre-phase, Vayssier [17]. In general, plant staff should have understanding of the time scale and evolution of an accident. For example, in a station blackout, they should know how long it will take to core damage and vessel failure, as it will set their time limit to mitigating actions, restoring essential functions or hooking on portable equipment.

17. If the accident develops in a more complex way than has been considered in the SAMG development, even a totally different type of accident management organisation may become necessary. Such management organisation depends less on prescribed rules and defined authorities but more on improvisation and strong leadership. This accident management is often called ´Emergency Accident Management´, in contrast to the ´Routine Accident Management`, which the present accident management largely is. Studies here have been published by the Kennedy School of Government, Harvard University, Leonard and Howitt [18]. More resilience in emergencies is needed and should be developed, as is well described by Guarnieri and Travadel [19].

18. Although the SAMG vendor delivers the package to the plant concerned, it is the utility that ultimately decides what should be implemented and what not. I saw a plant which simply did not ´like` certain guidelines (considered them superfluous) and implemented only the part it considered relevant, even against the recommendations by the vendor. This attitude I usually compare in my courses with a patient who tells his doctor what medicaments he is going to take, possibly against his doctor's recommendations. Vendors have no absolute wisdom, but changes to their SAMG packages should only be proposed by qualified engineers, well aware of the complex physics of severe accidents and the large uncertainties involved, and preferably strict within an appropriate quality assurance program.

19. Where still so much uncertainty exists on a number of severe accident phenomena and processes, I had expected a close connection and collaboration between the organisations involved in the severe accident research and the developers of the SAMG programs. However, rather the opposite seems to be the case. Even researchers of various parts in the world have limited contact with each other. For example, the revised EPRI TBR [8] nowhere mentions the extensive research done in the European Union (and some non-EU members). Neither did the EU research group (known as the SAR-NET group) report any findings regarding the EPRI TBR. Whereas this report is the Technical Basis of many SAMG programs in the world, as already said. Talking to some SAMG developers, I even heard them saying: ´no need for research, SAMG is engineering`. Such observations place sincere doubt on the products which they develop.

5.0 Additional complications in development and implementation of SAMG programs.

There are some overall characteristics that complicate the management of severe accidents. They are listed here in an arbitrary sequence.

1. There is no uniform regulation concerning severe accident management. Some countries, e.g. the US, have no regulation at all – they depend on voluntary industry initiatives, Lutz

[20] [3] – others have regulation, but it varies from country to country. Some are very detailed (such as Germany, KTA GS-81 [21]), others are more overall-type. Smaller countries may also not have sufficient staff which is qualified in severe accident phenomena and, hence, may be unable to assess the SAMG in their country appropriately.

Voluntary industry activities (such as in the US) can be effective, provided the industry maintains also an effective assessment and inspection program. This did not generally exist prior to the Fukushima-Daiichi accident, as US NRC inspections after the accident have revealed [22]. The difficulty in this approach is that minimum standards must be set and compliance checked.

Where regulations exist, there may be a tendency to comply with the minimum level in those regulations, seen the very low probability that the SAMG actually has to be applied. And where the regulators concerned may have difficulty to set this minimum level.

2. The risk from such accidents as Fukushima-Daiichi is not only a potential high dose rate on the affected population, but also a societal disruption that is the consequence of the possible threat of such large release. Governments may easily decide to evacuate a large part of the affected area, as they may fear large releases, notably if the plant management cannot reliably predict the possible release. People are told to leave their homes and possessions, possibly in the mid of the night, without knowing if and when they may return. Evacuation of hospitals may even be life-threatening, as all actions must be halted and patients moved. The possibility arises that the evacuation takes more lives than the radiation otherwise might do. There are, in my view, two actions that are urgent:

- The effect of a low dose must be better known, so that there is no unnecessary evacuation. This relates primarily to a reassessment of the assumed linear relation between dose and effect, which has not been substantiated in the low dose area.
- SAMG must include tools to estimate the consequences of the accident and the mitigative effect of the SAMG actions. Release estimates for unmitigated accidents exist (e.g., the EURANOS project, Slootman [23], Raskob et al. [24]), but the mitigating effect of SAMG actions is not yet included in such estimates. An initiative was executed as an EU-sponsored project but later implementation discontinued due to lack of funds, SAMOS [25].

3. The present nuclear safety regulation is still based on traditional postulated accidents such as the large break LOCA. Regulation that is more based on the actual risk of an NPP develops very slowly, if it is developed at all: many countries do not (yet) apply a more risk-informed type of regulation. Criteria are almost always linked to the protection of public health and safety – environmental, economical and/or societal criteria do not really exist, where the economic damage of severe accidents easily can go into billions of US dollars. Not only because of the damage to the stricken plants, but also on the effect which radiation may have on the economic activities in the country. For example, if a big harbour is contaminated – even at low levels – business there presumably will stop, with large consequences for the life in the whole country and possibly even neighbouring countries. If a car manufacturer is hit, he will not sell any cars anymore. Evacuation of big cities is in itself already an economic

[3] The application of SAMG in the US will be part of NRC´s Reactor Oversight Process, i.e. part of the NRC´s inspection processes.

disaster. Yet, cost-benefit considerations at NPPs seldom include such considerations. The benefit is just the number of lives saved due to the radiation averted.

I believe it is needed to develop nuclear safety criteria which encompass the full series of consequences of nuclear accidents for the society. This will probably also affect development and implementation of SAMG and make the SAMG programs an inherent part of the plant safety, rather than just a marginal activity, as it is often today.

6.0 The need for an industry standard on severe accident management.

As has been argued in the previous section, the present regulation in most countries does not cover the accidents that in practice dominate risk from nuclear energy, neither does the regulation consider the proper criteria, as notably the large consequences of severe nuclear accidents for the society as a whole are not considered.

International criteria as developed by the IAEA are a step forward, as they also contain acceptance criteria for accidents beyond the design basis (called ´design extension conditions`, IAEA SSR 2/1 [26]). Similarly, important work has been done by US NRC commissioner George Apostolakis, to focus more on risk, but so far this work has not been included in most regulation [27].

As consideration of severe accidents is an activity that goes beyond national borders and, hence, national regulations, a proposal has been made by a group under the lead of former US NRC Chairman Nils Diaz to develop a ´New Safety Construct`, ASME [28]. I believe this is a most valuable initiative. As the ASME Boiler and Pressure Vessel Code has unified engineers all over the world to end the large number of pressure vessel failures a century ago, a similar Code for nuclear safety could end the various severe nuclear accidents as we have seen so far.

As such an activity has huge dimensions and can necessarily only make slow progress, I believe we could make a first step to develop an industrial standard for severe accident management. I.e., a compilation of requirements on the tools, both in hardware and in software, needed to mitigate severe accidents. Such a tool does not guarantee success – as the operating NPPs have not been designed to mitigate severe accidents – but it sets a clear standard for how the SAMG should be structured so as to have best possibilities to mitigate such accidents.

Some activity of this nature has been started at the American Nuclear Society [29], but I believe more action and commitment from various countries and organisations is needed. A good starting point seems to be the IAEA Safety Guide on Severe Accident Management, NS-G-2.15 [30]. Practical, engineering starting points may be the revised SAMG packages from the various Owner Groups, vendors and larger utilities, which consider lessons learned from the Fukushima-Daiichi accident. The standard should include methods to develop and execute exercises, as training NPP staff in SAMG is of paramount importance to mitigate severe accidents. And it should include appropriate management tools, as have been described by Leonard and Howitt [18] and Guarnieri and Travadel [19]. It will also cover the open issues, described by Ciurea and Tronea in their overview of regulation on EOP and SAMG, [31].

7.0 Conclusions

Many current SAMG programs have important shortcomings, which have been caused by a variety of reasons, as has been discussed. There are human factors (´such accidents do not happen here`), historical focus (the TMI accident) as well as a large number of organisational and engineering aspects. Current SAMG have notably not been developed to cover Site Disruptive Accidents. At a number of plants, implementation of SAMG has not been done properly: command centres are not protected, instruments are believed on their face values.

Regulation is much scattered: from no regulation at all to detailed prescriptions. Where it is not clear that sufficient know-how exists about severe accidents as the basis for that detailed regulation, neither for its enforcement. Some countries depend totally on voluntary industry initiatives. In addition, the regulation is not based on the actual risk for public health and safety, neither on the large societal damage that a severe accident may inflict.

In the absence of clear and harmonised regulation, I propose to develop an industry standard which covers the development and implementation of SAMG. Such a standard could be a part of a larger standard that encompasses the whole are of nuclear safety. Countries and their organisations are encouraged to support such activities. A beginning has been made by the ANS. Use can be made of the IAEA Safety Guide on Severe Accident Management, NS-G-2.15 [30] and, as engineering starting points, the revised SAMG packages from major utilities and vendors. It should include organisational adaptations, making accident management more robust and resilient as indicated by Leonard and Howitt [18], and by Guarnieri and Travadel [19] and so also cover the open issues mentioned by Ciurea and Tronea [31].

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