Crisis organization and severe accident management: Contribution of ergonomic considerations in the definition of Severe Accident Management Guidelines (SAMG)

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Abstract: This document presents an ergonomic action led in the framework of the definition of the organizational reaction to a crisis and the associated technical and documentary supports, defined for the design of a new nuclear plant.
In the event of an incidental or accidental situation occurring in a functioning plant, the risk management approach is based on a local and corporate crisis management organization, the objective being to ensure that the situation at the plant is under control and to protect people endangered by the situation. The more specific case of a severe accident is defined as a state of functioning with deterioration and possible loss of the plant and the probability of this type of accident occurring is extremely low. Nevertheless, these cases are taken into account in the design stage and emergency simulation drills are organized to help prepare the staff to manage these situations.
The first part of this document presents the crisis organization and the associated documentary supports (the SAMG) designed to manage a severe accident. The second part describes the ergonomic approach to the design of the SAMG and concludes with the value of such an approach in preparing the teams to manage a crisis in a complex and high risk social and technical system.

Keywords: design, ergonomics, crisis organization, severe accident management guidelines,

1. GUIDES TO REACTING TO A SEVERE ACCIDENT IN A CRISIS SITUATION

1.1. What is a crisis situation?

A severe accident, leading to the loss of the plant and potential external impacts (on people, the environment, etc.), would place the entire company in a crisis situation. Consulting existing literature on this subject, mainly in the fields of risk science and psychology, provides elements that can help to define this type of situation [1], [2], [3], [4].

- A crisis is a threat which can lead to catastrophes or disasters. A crisis is defined by the enormity of the original fault and its multiple consequences. It creates severe constraints, difficult environmental conditions and deteriorated working conditions. It is a step into the unknown resulting in a clear difference between 'before' and 'after' the crisis. It involves many risks and huge organizational, economic, environmental and political stakes.
- A crisis creates a very specific temporal reality characterised by a continued situation of instability, unpredictability and surprise. Crisis situations evolve at different speeds but often in a non-linear manner. Another characteristic of a crisis is absolute urgency demanding the implementation of pertinent actions in very short spaces of time. In this context, teams have very little time to establish a diagnosis and to predict how the situation will evolve, in order to coordinate, decide upon and implement the chosen actions. Moreover, a crisis situation can last for a very long time.
- From a psychological standpoint, a crisis is characterised by exceeding (cognitive) resources [5]. In these situations, events are hard to apprehend and understand. A crisis arises "*when a system is confronted with an event, generally unforeseen, the consequences of which develop rapidly producing significant risks, and the management of which exceeds the pre-existing resources in terms of actions and people*" [4].

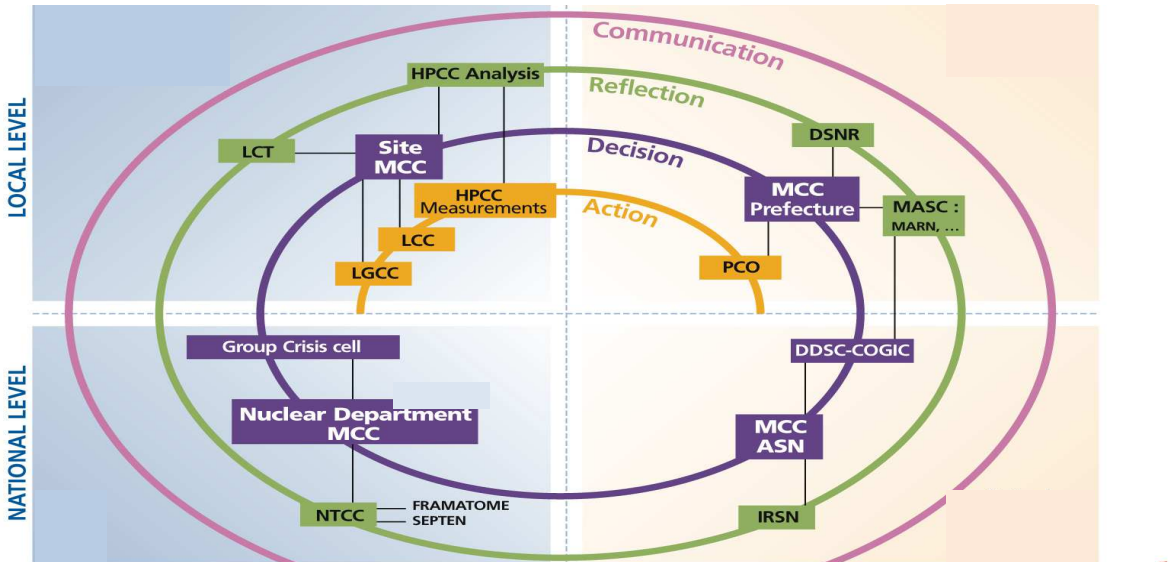
- Lastly, a crisis is a stressful situation for those responsible for managing it due to the following contradiction: they must be capable of bringing rapid and pertinent responses to a complex and fast-moving situation which at least partially escapes their understanding. Furthermore, a context of uncertainty and extreme conditions of intervention add to the stress felt by the teams.

This brief list of characteristics give an idea of the situation that the teams would find themselves in if a severe accident were to occur (which nevertheless remains very hypothetical). To prepare ourselves to manage crises in general, and specific cases in particular, the company has designed a local and corporate organization which is presented in the following paragraph.

1.2. A crisis organization to lead the response to a severe accident

At the new plant, the management of a severe accident is part of the company's general crisis organization defined to manage other facilities, with adaptations at the local and corporate levels. This organization is consistent with the standards of the mechanisms designed to manage these situations [2, 6]. The functions typically attributed to crisis organization concern: expertise, decision-making, logistics and communication. The implementation of these functions relies on competent and trained teams in the different work groups at the local and centralised level. Furthermore, technical, documentary and communication supports help in the management of these situations.
The following diagram shows the four functions of the crisis organization defined for the company.

Figure 1: Overall crisis organization diagram



This organization is implemented in order to control the situation at the plant, minimize the environmental consequences, and protect people.

Specialists in crisis management [1, 6] insist upon certain points to distinguish crisis organization from organization in a normal situation. In particular, they identify:

- The scope of the players concerned by the crisis which goes beyond the scope encountered in a normal operating situation (public authorities, surrounding populations, media, etc.),
- The need to call upon internal experts and external experts who are not available within the company,
- Requirements in terms of extra equipment,
- The stakes linked to in-house and external communication.

To manage a crisis situation as defined in paragraph 1.1 and for which we point out the similarity with a severe accident situation, the organization proposed, and concisely presented in this paragraph, must allow the teams to bring adapted responses to the situation encountered. On this subject, the approaches proposed in HRO (High Reliability Organizations) and resilience engineering [7, 8, 9] are interesting because they have considered how best to organize the activity of the teams so that the organization as a whole is capable of dealing with unexpected critical or threatening events [3]. Concerning how to manage a severe accident, several points caught our attention.
Firstly, crisis situations demand the combination of a process of anticipation and a process of adaptation. The process of anticipation refers to the preparation of methods of coordination and action within the teams, backed by instructive supports and preparative drills. The process of adaptation concerns the way in which the methods of coordination and action adjust according to events.
Secondly, we retain the fact that crisis organization must allow for changes in the configurations of the plant over time. Therefore it must be sufficiently flexible to give the teams optimal understanding and control of events. There must also be appropriate communication and information exchange capacities to allow the emergency response team, comprising people dispersed in different places, to have a clear overview of the state of the plant and the actions led. In these conditions, the emergency response team is able to adapt its actions at every stage of the evolution of the crisis. This clearly requires an organized method of coordination even if the deteriorated situation may cause communication difficulties.

Following on from the organizational approaches mentioned above, ergonomic psychology, which is mainly focused on the capacities of individuals to deal with situations, also insists upon the notion of adaptation [3, 4]. Adaptation appears as a response to the extraordinary nature of the situation which exceeds the ordinary (cognitive)[1] resources called upon by individuals. When circumstances go beyond a certain point, individuals and groups need extra resources to prevent them from losing control of the situation and to allow them to try to regain control. Extra resources are needed to allow the (short-term) adaptation process to be implemented in a pertinent manner. "*Short-term adaptation refers to the processes by which an individual (or group or organization) modifies or regulates its activity to respond to variations in its external or internal environment with the aim of maximising the appropriateness of its responses to the difficulties encountered*" [4].

This concise presentation of elements taken from studies on the subject of crisis organization gives a good insight into what is required to manage these often complex situations, known for their deteriorated contexts and the unpredictability of their evolution, requiring actions to be implemented rapidly and obviously stressful for those in charge of managing them. The crisis organization put in place must allow the teams to bring adapted responses to the rapidly-changing situations encountered. In this context, one of the main aims of the organization is to allow anticipation and adaptation. This means offering teams a precise framework for analysing and exchanging information about the situations, and making it possible to periodically assess these situations and implement the associated adjustments. All this requires organized modalities of coordination between the members of the emergency response team.

In the framework of its crisis organization, to manage severe accidents, which, to reiterate, lead to the loss of the plant and the probability of which is very low, the company has created a specific

[1] In the domain of psychology, these are the cognitive resources called upon by an individual, as opposed to resources in the sense of 'human resources' (i.e. staff).

organizational mechanism reinforced by documents called Severe Accident Management Guidelines (SAMG). These documents are presented in the following paragraph.

1.3. SAMG as supports for managing a severe accident

Management of a severe accident begins only once a technical threshold of plant deterioration has been reached. At that moment, and only after validation from the site's senior management, the approach changes from 'incidental/accidental' management to the status of a 'severe accident', the consequence of which is the loss of the plant and the beginning of a crisis requiring long-term management. The decision to use the SAMG changes the configuration of the crisis organization already in place to manage the 'incidental/accidental' situation. The SAMG provide the different people concerned with an operational support in the form of Operating Strategies for Severe Accident (OSSA). One of the particularities of the SAMG is that they transfer the responsibility of operating the plant from the control room to the site's senior management division, which decides upon the action to take with the help of a network of local and centralised experts both within and outside of the company.

Seven SAMG documents are made available to each of the members of the emergency response team in charge of operating the plant in a severe accident situation and can be found in four areas on the site (Control Room, Emergency Technical Centre, Local Management Command Centre) and in the company's centralised department (Corporate Technical Emergency Response Team). The SAMG cover three circles of the overall crisis organization diagram (figure 1): expertise, decision and action. The SAMG offer precise indications concerning the actions of each user, according to their mission in the crisis organization, but avoids directing the team members down excessively restrictive paths of action which could prove to be inappropriate in the long-term. This enables them to be adapted to the situations encountered in order to allow users to react to the unforeseen events and surprises mentioned in paragraph 1.1. The SAMG also contain periodic written messages concerning the state of the plant and documents guiding the emergency response teams in their analysis, diagnosis and predictions concerning the situation.

The SAMG designed for the new nuclear plant contain two major innovations for the experts in the emergency response teams, compared to those existing for the other plants:

1. A 'looped' approach which regularly poses the question of the state of the plant to provoke a diagnosis of the three main safety functions which are: control of radioactivity release, the confinement of the plant, and the cooling of the core.
2. A decisional aid matrix which defines, depending on the degree of deterioration of the three safety functions, the priority mitigation actions to conduct on the plant.

As soon as the plant's senior management division has decided that the situation has reached 'severe accident' status, the teams are faced with an emergency situation which necessitates immediate actions which do not require prior analysis. The operating team works autonomously in the control room to implement these initial actions which do not require direct external expertise. Guided by the SAMG and thanks to the organized communication points in the guide as well as specific messages about the state of the plant, the other work groups involved in the crisis organization can follow the performance of these immediate actions.

After performing the immediate actions, application of the SAMG allows the local and corporate emergency response teams to continue to supervise the state of the plant (by monitoring certain parameters) and to perform periodic diagnoses of the damaged unit; to suggest, decide and implement appropriate actions according to the situation in order to limit the consequences of the severe accident. The SAMG also provides guidance for predicting the future state of the plant. At the crisis organization level, the circle of experts is particularly solicited at this point. The second phase of the response to a severe accident is surveillance and potentially the implementation of pre-established counter measures (amongst other mechanisms) according to the faults encountered during the evolution of the plant, hour after hour and day after day. This phase is characterised by successive

adaptations by the emergency response teams to take actions adapted to the rapidly-changing and uncertain situations encountered. These adaptations are made possible thanks to communication between the members of the emergency response team, with each individual sharing their understanding of the situation and the actions suggested. The SAMG, in their capacity as documentary supports, have been designed to facilitate and optimise the reliability of coordination and synchronisation between the different work groups involved in managing a severe accident (consistency of vocabulary, formalisation of important coordination measures, traceability of the actions led, etc.).

Finally, the temporal specificities of a severe accident have been taken into account in the design of the plant. These guides are designed for long-term management of the plant and integrate the temporal aspect of severe accident management by offering the possibility of suggesting actions to be led over time. They also take into consideration the fact that, for this type of accident, the dynamics of the plant are not entirely foreseeable at the moment of designing the process (by a regular diagnosis of the state of the plant and an associated diagnosis, potentially completed by suggestions of actions validated by the plant' Senior Management).

In this first part of the present document, based on the characteristics of crisis situations, we have addressed the modalities that shape crisis organization, the objective of which is to allow the teams to come up with responses that are adapted to the complex and often unforeseeable situations that they encounter. Bearing this in mind, the management of a severe accident is guided by documentary supports designed so that their use will allow teams to adapt to the situations encountered throughout the crisis period. Following on from this, the second part of this document presents the ergonomic approach to the design of the SAMG, created from 2009 to assist in the management of a severe accident at the new nuclear plant.

2. CONTRIBUTION OF ERGONOMICS IN THE DESIGN OF THE SAMG

2.1. Characteristics of the ergonomic[2] approach in documentary design

An ergonomic approach integrated into the SAMG design project

The ergonomic approach applied to the design of the SAMG is just one aspect of an overall industrial project to design a new nuclear plant. This large-scale project depends on many different spheres of competence found in the company's different divisions (engineering, future operator, R&D). A 'Human Factor' engineering program structures the actions led in this design project. The human factor contribution of Research & Development consists in providing ergonomic markers for the design of the management means and associated organizations, and for evaluation campaigns.

The project to design the SAMG documents, launched in 2009, has been underway for several years and will end before the industrial start-up of the new plant. This project depends on different players: the authors of the SAMG, engineers specialising in severe accidents, the future operators, the company's experts in ergonomics from Research and Development, etc. Experts in the 'human factor' have been involved from the very start of the project and intervene throughout the process, the aim being to act while there is still sufficient room for manoeuver in order to detect as early as possible (and therefore resolve at a low cost) any use and performance problems in the mechanism being designed [10].

In this project, the ergonomists' role is to help the authors of the SAMG to compile documentary supports that will, in the event of a severe accident, facilitate and maximise the reliability of the emergency response teams' different missions comprised in the circles of expertise, decision and action of the crisis organization presented in paragraph 1.2. To reiterate what has been said in part 1, the ergonomists' contribution is to help the authors of the SAMG to design documentary supports

[2] In the company, the ergonomics and 'human factor' engineering approaches cover the same scope.

which will reinforce the approaches of anticipation and adaptation allowing the team to come up with responses adapted to the complex, uncertain and stressful situations encountered.

The priority is to design documents that are easy to use and that reinforce the coordination and synchronisation of the emergency response team members

The ergonomists focus on two main aspects. Firstly, they offer their expertise to ensure that the documents can be used without difficulty. In this framework, the documentary ergonomic requirements are suggested for the project and ergonomic evaluations are conducted. Several ergonomic requirements need to be considered. They concern [10]:

- Usability: the SAMG documents must be easy to use from the very first time they are followed;
- Guidance: the SAMG should offer clear guidance for the users;
- Coherence/uniformity of the documentary design elements (graphic design and presentation of the information) ;
- The comprehensibility of the information (syntax, vocabulary, and use of abbreviations);
- The quantity and density of information;
- The coherence between the SAMG and the other supports used when following them (Man-Machine interface, other documentary supports, communication supports, and technical supports).

Following on from this, ergonomic evaluations [12, 13, 14] ensure the quality of the documents by considering, depending on the experts, two or three fundamental aspects. Some experts [15] focus above all on the pertinence of the document, i.e. *"its capacity to respond to the user's needs in terms of information"* and its usability i.e. *"its capacity to be used and understood easily and to give access to the pertinent information that it contains"*. Other experts [15] focus more on a third aspect which is its acceptability, in other words the extent to which the design of the documents encourages people to use them. Given the stakes, complexity and infrequent use the SAMG, which are designed to be used solely in the event of a severe accident, the acceptability aspect is very limited in these evaluations.

Secondly, the ergonomists help the authors to produce SAMG documents which will be supports that facilitate coordination and synchronisation between the team members applying these guides. In addition to the elements presented in paragraphs 1.2 and 1.3, temporal coordination and synchronisation between the team members help them to better understand and control situations. Thanks to the communication and information-sharing means, the teams should be able to get an overview of the state of the plant and the actions led. In the SAMG design project, the ergonomists are very careful to integrate this organizational aspect into the documentation.
In addition to evaluations concerning the usability of the documentation, the aspect relative to the possibilities for coordination and synchronisation offered by the SAMG is also evaluated. The evaluation procedure is an important part of the ergonomic documentary design approach and deserves some explanation here.

Successive ergonomic evaluations throughout the SAMG design process

The ergonomists conduct several documentary evaluations throughout the SAMG design process. These evaluations involve a representative panel of future users of the SAMG. They are participative evaluations [15, 17, 18]. They are evolutive; in other words they contain specificities determined according to the degree of completion of the documents (evaluation by an expert, 'static' evaluation with representatives of the future users, 'dynamic' overall evaluation in the framework of mini crisis drills). The evaluations are iterative: they encourage teamwork between the designers of the SAMG, the representatives of future users and the ergonomists. However, the final analysis of the results of the evaluation is performed independently by the ergonomists.

Each ergonomic evaluation is subject to an analysis of user difficulties, the results of which are then presented to the designers of the SAMG as a series of recommendations. In compliance with the

method of this documentary design process, these recommendations are used when compiling updated versions of the SAMG through until the industrial start-up of the plant.

In the following paragraph, the presentation of key points concerning the modalities of the last 'dynamic' evaluation conducted shows the contribution of the ergonomic approach in the SAMG design process. It also reveals findings concerning training in the management of crisis situations in the context of the implementation of a specially-dedicated organization.

2.2. Evaluating the SAMG by simulating the management of crisis situations with maximum realism

Framework and objective of the 'dynamic' evaluation of the SAMG

The ergonomic evaluation approach is part of the SAMG design project and is therefore a participative and iterative process between designers, evaluators (ergonomists) and representatives of future users. These players find themselves in an environment which is in the process of being designed, as close as possible to the design stage considered but different from the framework of the use of the documentation in a real situation (at several levels: technical, documentary, organisational, in terms of team skills, etc.). Despite the differences between the situation during the design phase and a real operating situation, this evaluation method, because it is a key aspect of the design process, helps to identify the main difficulties that the users could encounter in real situations (in terms of the usability of the documents, comprehensibility of the messages, and effectiveness of the document as a support for analysis, action, and coordination between the different work groups involved in managing a severe accident). This is the framework of the 'dynamic' evaluation process presented in this paragraph.

Its objective was to analyse the usability of the SAMG documentation in the context of the most realistic simulation possible, at this stage of the design of the crisis organization and the associated human and logistic resources. To satisfy this objective, the evaluation involved the different team members contributing to the management of a severe accident. They applied the SAMG in a coordinated and synchronised manner, in the different work groups at the future plant (operating simulator, local emergency response team, management command post) and at the centralised emergency response centre (corporate emergency response team). For this, 'mini' crisis drills were organized based on severe accident scenarios. The three selected scenarios were chosen to ensure that the SAMG could be used in different ways and very varied cases. The simulator was specially prepared to improve the representativeness of the management and use of the SAMG in the control room. Finally estimated performance times of local actions, taking into account the availability of field operators, were integrated into the scenarios.

The evaluation lasted three days with a different scenario each day from 8-12am. The afternoons were devoted to debriefings, firstly in separate work groups and then with all four participating work groups.
Based on the analysis of the usability of the SAMG, the aim was to make the designers of the documents aware of changes to integrate into the next series of documents.

The ergonomic evaluation method

The people involved in the evaluation:

- Representatives of the future users: The ergonomic approach to documentary evaluation is a participative approach. Therefore this type of evaluation is conducted on a representative panel of future users. In the present case, the user panel covered all the work stations applying the SAMG. In order to be able to apply the SAMG, the representatives of the future users and all those participating in the evaluation followed a short training session to familiarize themselves with the SAMG, the associated supports and the crisis organization. We should add that the participative evaluation concerns the ergonomics of the document and its

usability. It does not concern the competence of the users or their technical knowledge of severe accidents.

- The independent Human Performances (HP) evaluation team: The evaluation team was present in each work group comprising users of the SAMG and gathered data during the simulation drills and the debriefings that followed the drills. The HP team then analysed the data. A technical support team assisted the HP evaluation team, notably by giving their opinions concerning the achievement of the technical objectives.
- The instructor-pilot of the simulator (from the training department) and the severe accident operating engineer: During the several months spent preparing the evaluation and until it was launched, this duo defined the drill scenarios, made the necessary technical preparations for the scenarios and compiled the technical information to be communicated to the users. During the evaluation, these two individuals supervised the progress of the scenarios and operated the simulator.

NB: The SAMG designers are not involved in the evaluation. Their role was nonetheless important because they had to produce all the documentation required for the evaluation in time.

Representativeness and limits of the evaluation:

It is important to address the representativeness and the limits of the evaluation. This allows us to analyse the risks of the evaluation to identify potential counter measures to ensure the pertinence of the data gathered.

In the case discussed, the representativeness had been improved compared to the previous 'static' evaluation (improvement of the representativeness of the work stations thanks to specific use of the operating simulator and the national emergency response resources; the scenarios lasted several hours which is a more realistic simulation of the temporal conditions of a severe accident, particularly in terms of coordination and synchronisation between the different work groups; the documents were all at a more advanced state than for the previous evaluation).

Various limits in terms of representativeness have been identified and taken into account in the analysis. The fact that the same team participated in the scenarios for three days, despite the differences in the scenarios, produced an effect of repetition that caused the individuals to become relatively 'practised' in the exercise. For logistic reasons, it was not possible to simulate the entire crisis organization and only the users of the SAMG participated in the evaluation; this undoubtedly had an impact insofar as the real management of a severe accident would be part of an overall crisis organization involving more interfaces to deal with. In the end, the limits identified did not prevent the collection of instructive and pertinent information.

Study hypotheses to satisfy the aim of the evaluation and guide the analysis:

In order to evaluate the usability and the capacity of the SAMG to facilitate coordination and synchronisation between team members, as defined in paragraph 2.1, the following general hypotheses, developed into detailed hypotheses, have been suggested;

1. The structure of the SAMG and the associated documentary ergonomics allow each of the team member-users of the SAMG to diagnose/appraise, decide, act and monitor what their mission demands of them;
2. The supports associated with the SAMG (operating resources, traceability supports and communication means) enable each user to apply the guidelines relative to their mission.
3. The SAMG and associated supports reinforce coordination and synchronisation between the team members called upon to manage a severe accident.

<u>Analysis of the data and main results</u>

Using methodological data collection and analysis tools, the data analysis is performed as follows:

- Firstly, the data analysis provided insights into study hypotheses based on:
    - The opinion of technical support specialists on the achievement of the safety objectives of the crisis simulation drills;
    - The data gathered during the scenarios and debriefings ;
    - The overall reconstitution of how the users reacted during the scenarios;

- Individual feedback from the users of the SAMG.

- Secondly, the data analysis according to the study hypotheses led to the formulation of HF recommendations for the SAMG and the associated supports.

In terms of results, the main safety objectives associated with the different scenarios were achieved. The analysis produced recommendations for optimisation concerning the documentary supports, the operating resources, the crisis management activities and the missions of certain posts of responsibility in the control room. These recommendations will be taken into account in the compilation of the future version of the SAMG which will in turn be subject to a final evaluation before the industrial start-up of the plant.

The presentation of this documentary ergonomics evaluation describes how the evaluation and data analysis was conducted, primarily in order to produce HF recommendations for the authors of the SAMG. From the perspective of the industrial start-up of the plant, the aim is to propose SAMG documents that are easy to use and that optimise coordination and synchronisation between the team members applying the SAMG.
For this new plant, the performance of this first 'dynamic' documentary evaluation simulating crisis situations and activating the associated organization has also helped to train the different players at the new plant in the management of complex, uncertain and stressful crisis situations [6, 18].
This type of evaluation can also encourage experience feedback about the capacities of the organizational set-up and the teams to manage these situations and about the ways of conducting this type of crisis simulation drill.

CONCLUSION

The definition of elements characterising crisis situations, and the concise presentation of elements taken from studies on the subject of crisis organization, provide a good insight into what is required to manage these often complex situations, known for their deteriorated contexts and the unpredictability of their evolution, requiring actions to be implemented rapidly and obviously stressful for those in charge of managing them. This type of organization must enable the teams to bring adapted responses to the rapidly-changing situations encountered. In this context, one of the main aims of the organization is to allow anticipation and adaptation. This means offering teams a precise framework for analysing and discussing the situations, and making it possible to periodically assess these situations and to support the associated adjustments. All this requires organized modalities of coordination between the members of the emergency response team. At the new plant, the management of a severe accident has been taken into account as of the design phase. The documentary supports (the SAMG) have been designed and evaluated to ensure that those called upon to use them can adapt to the situations encountered throughout the duration of the crisis.

The ergonomic approach to the documentary design applied to the SAMG, and initiated from the outset of their design, guides the designers to help them to create documents that are easy to use and that optimise coordination and synchronisation between emergency response team members. Along the same lines, the modalities of documentary evaluation proposed by the ergonomic approach, thanks notably to the simulations of crisis situations, help to prepare the teams at the new plant to manage crisis situations and encourage experience feedback on this subject at the corporate level.

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