Universitatea Politehnica București

Facultatea de Energetică

CONTRIBUTION TO THE ACCDIDENT MANAGEMENT IN THE NUCLEAR POWER PLANT

- SUMMARY -

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CUPRINS:

INTRODUCTION

The preparedness for a radiation emergency has often been done in isolation without the full involvement of national or local organizations responsible for conventional emergencies response, such as fires, floods or storms. However, these organizations play a key role during a nuclear or radiological emergency. Moreover, an emergency may involve criminal activities, such as terrorism, illicit trafficking or theft, in which case the emergency response must be made with the support of the designated Public Prosecutor's Office and in conjunction with the provisions of specific plans, protocols and provisions the level of the National System of Defense, Public Order and National Security.

Finally, there are misperceptions about the risks of radiation exposure and these perceptions can lead to decisions to make public measures and actions that do more harm than good. In order to ensure an effective response in the event of a radiological and / or nuclear accident and to avoid confusion and conflicting information during the management of response actions, it is mandatory to define an integrated response system that includes all responsible authorities and institutions.

1. ELEMENT OF ROMANIAN EMERGENCY MANAGEMENT SYSTEM

The purpose of emergency planning and preparedness is to ensure adequate organizational capacity, to provide available resources and to act in a prompt and efficient manner at local, regional, national and, where appropriate at international level, in the event of a nuclear or radiological emergency for an integrated set of infrastructure elements which include, but are not limited to: authority and responsibilities; organization and staff; coordination; plans and procedures; tools, equipment and facilities; training and exercises.

The National Emergency Management System (SNMSU) is organized according to the legislation in force on all three levels: national, county and local and is composed of decision-making structures, executive structures and operational structures.

The National Committee for Emergency Situations under the coordination of the Prime Minister and is an inter-ministerial body composed of ministers and leaders of central public institutions, depending on the types of risk managed or support functions distributed within the National Emergency Management System.

The General Inspectorate for Emergency Situations is organized and functions as an executive structure at national level, as a specialized body subordinated to the Ministry of Internal Affairs which ensures the unitary and permanent coordination of the activities of prevention, intervention and management of emergency situations.

As operational structures are organized the National Center for Coordination of Intervention within the Ministry of Internal Affairs and Emergency Operations Centers with the role of ensuring the decision-making support of CNSU and in coordination with all operational and operational centers established within ministries and public institutions (Romaniei, HG 557/2016 privind managementul tipurilor de risc, 2016).

At the county level, County Committees for Emergency Situations are set up under the management of the prefects. The professional community public services for emergency situations, function as county inspectorates and ensure in the areas of competence the coordination, guidance and control of the activities of prevention and management of emergency situations.

At the level of municipalities, cities, sectors of Bucharest, as well as communes are set up, under the management of the mayor Local Committees for Emergency Situations.

All applicants / holders of CNCAN authorization in Romania must submit in order to obtain the operating license from CNCAN, the arrangements for planning emergency preparedness and response. One of the conditions of authorization is the obligation of the applicant for authorization to establish and maintain his own response system for radiological or nuclear emergencies in accordance with SNMSU.

The operator of a nuclear / radiological installation carrying out activities with sources is primarily responsible for limiting the consequences of a nuclear accident or radiological emergency. It will notify the authorities and provide the first recommendations on actions to protect the population and the environment. The operator also has the obligation to take all measures to limit the consequences in case of a nuclear accident or radiological emergency in order to protect the population, the environment, personnel and property. The operator of a nuclear installation participates in the intervention by implementing on-site mitigatory actions and protection measures also making available to the national authorities its own forces and means of intervention when is requested.

The national authorities, components of SNMSU, participate in the intervention outside the location of nuclear installations by implementing protection measures and providing all the forces and means declared for responding to emergencies in their areas of competence and support the operator of the installation where the event occurred in implementing of mitigatory actions.

2. OPERATIONAL CALCULATION OF THE STRUCTURES DEFINING SEVERE ACCIDENT MANAGEMENT SYSTEMS

2.1. Genaral Aspects

Defining the method of evaluating the interfaces of the component systems of a system that describes the management of the emergency situation.

Emergency management can be considered as a complex system, consisting of elements of the following main categories:

- the system that defines the management of a severe accident and the limitation / elimination of its consequences (SY_MAN);
- the system that defines the security culture of those who have to implement the SY_MAN system (SY_SC);
- the system that defines the ability to ensure adequate leadership of the other two systems SY_MAN and SY_SC “leadership” (SY_LEAD) (MIN & Serbanescu,

Systematic Approach on Human and Organizational Factors in the Nuclear Power Plants Emergency Management, 2017).

Each of these systems has very different characteristics

- SY_MAN has technical components, resulting from analyzes using as criteria functions such as Risk but managed according to a system of procedures and interfaces very clearly defined;
- SY_SC has qualitative components and reflects the real degree of training of the team members implementing SY_MAN to manage accident situations;
- SY_LEAD has an even more subjective character, often predominantly psychological and of skills of those who lead processes in SY_MAN and who are able to generate positive SY_SC states and obtain the expected results. (Min Petre, 2017)

2.2. Modeling complex systems

A management system can be described by using specific methods of systems theory. One of the components of this approach is the description of the structural and interaction parts of the management system in matrix form.

Thus the matrix [Mij] describes a management system having two categories of components:

- Components that describe the part of constituent elements (those marked with index «i») as in the figure and components that describe the processes and integrations between elements (those marked with indexes «j») in figure 1. Structure of a management system
- The use of systems theory by using matrix calculus leads to fast, repeatable and verifiable results with many advantages over multicriteria decisions and expert analyzes.

For a nuclear management system characteristics i and j derive from the descriptions and requirements of the standards in force.

2.3. Specific aspects of the systems considered into the management of nuclear safety

The main purpose of the management system is to achieve and increase the nuclear safety of the installation, so that to ensure the following objectives:

(i) Meeting all the management requirements of the organization in a consistent manner;
(ii) A description of the planned and systematic actions needed to ensure adequate confidence that all these requirements are met;
(iii) Ensuring that health, environmental protection, quality and economic requirements are not considered separately, but together with the requirements of nuclear safety. Nuclear safety will be considered paramount in the management system.

3. METHOD OF ANALYSIS OF THE MANAGEMENT SYSTEM, SECURITY CULTURE AND LEADERSHIP

A management system can be described by using specific methods of systems theory. One of the components of this approach is the description of the structural and interaction parts of the management system in matrix form.

The analysis of emergency management, considered as a complex system is done considering that it consists of a system defining the management of a severe accident and limiting / eliminating its consequences (SY_MAN), a system defining safety culture of those who must implement the system SY_MAN management system (SY_SC) and a system defining the ability to ensure proper leadership of the other two systems ("leadership") SY_LEAD.

The chosen method of analysis is a systemic one, which deals with the interaction of the component parts in order to define the sensitive elements, the weak links, which require more attention in order to improve them.

4. SYSTEMIN MODEL

Starting from the organization of the national emergency management system and the use of the analysis method presented in Chapter 3, the analysis of severe accident management, it was considered that a complex system consists of the following systems:

(i) A system representing the regulation and control of the nuclear field (level 0)

(ii) A system for managing the emergency response at the level of the economic operator operating the installation (level 1),

(iii) An off-site management system at local, county and national level (level 2), and

(iv) A system that defines hypothetical emergencies (disruption) and would activate the other three systems.

The systemic approach is reflected in the fact that these systems are described in the form of matrices, defining their structure (MIN, Key Factors of the National Emergency Management System, 2019). Their interaction is described by the composition of these structures presented in matrix form, according to the rules of operational calculation. Similarly, external perturbations are described by vectors, and their impact on structures is described mathematically by the composition of vectors and structure matrices.

Using the systemic approach, namely the definition of the elements of the structure matrices and the perturbation vector, the matrix calculation is defined:

Step 1: $MS_{level0} \text{ X } V_{perturbation} = V_{input1}$

Step 2: $MS_{level1} \text{ X } V_{input1} = V_{input2}$

Step 3: $MS_{level2} \text{ X } V_{input2} = V_{input3}$

The structure matrix of the shape shown in formula (1) is defined and the input which is a vector called the perturbation vector hereinafter VIN are defined by the formula (2)

$$(MS) = \begin{pmatrix} m_{11} & m_{12} & \dots & m_{1n} \\ m_{21} & m_{22} & \dots & m_{2n} \\ m_{m1} & m_{m2} & \dots & m_{mn} \end{pmatrix} \tag{1}$$

$$(VIN) = \begin{pmatrix} vin1 \\ vin2 \\ vin3 \\ vin4 \\ vin5 \\ vin6 \end{pmatrix} \tag{2}$$

The structure matrix for level 0 describes the system that represents the regulatory and control body of nuclear activities, with role and attributions on all areas of the emergency management system, namely both for the prevention of emergencies and the response to situations emergency.

This role and responsibilities are implemented through two mechanisms. The first involves the establishment and application of a control mechanism in order to maintain nuclear safety standards (IAEA, The management System for Nuclear Installations, 2009). The second mechanism involves the establishment and application of an emergency response system, a mechanism aimed at controlling the on-site response, ensuring the transition from on-site response to off-site response and decision support for off-site protection measures.

The structure matrix MS0 consists of the combination of the elements describing the prevention mechanism and the elements describing the response mechanism as presented in formula (3), with "r" the response elements are denoted and with "p" the prevention elements.

$$(Ms_{level\ 0}) = \begin{pmatrix} r1p1 & r1p2 & r1p3 & r1p4 & r1p5 & r1p6 \\ r2p1 & r2p2 & r2p3 & r2p4 & r2p5 & r2p6 \\ r3p1 & r3p2 & r3p3 & r3p4 & r3p5 & r3p6 \\ r4p1 & r4p2 & r4p3 & r4p4 & r4p5 & r4p6 \\ r5p1 & r5p2 & r5p3 & r5p4 & r5p5 & r5p6 \\ r6p1 & r6p2 & r6p3 & r6p4 & r6p5 & r6p6 \end{pmatrix} \tag{3}$$

The result of composing MS0 și Vperturbation is V for level 1 shown in the formula (4).

$$Vlevel\ 1 = \begin{pmatrix} r1p1 & r1p2 & r1p3 & r1p4 & r1p5 & r1p6 \\ r2p1 & r2p2 & r2p3 & r2p4 & r2p5 & r2p6 \\ r3p1 & r3p2 & r3p3 & r3p4 & r3p5 & r3p6 \\ r4p1 & r4p2 & r4p3 & r4p4 & r4p5 & r4p6 \\ r5p1 & r5p2 & r5p3 & r5p4 & r5p5 & r5p6 \\ r6p1 & r6p2 & r6p3 & r6p4 & r6p5 & r6p6 \end{pmatrix} X \begin{pmatrix} v01 \\ v02 \\ v03 \\ v04 \\ v05 \\ v06 \end{pmatrix} = \begin{pmatrix} v11 \\ v12 \\ v13 \\ v14 \\ v15 \\ v16 \end{pmatrix} \tag{4}$$

The structure matrix for level 1, namely the location of the nuclear installation is defined by the composition of elements representing the site emergency response organization marked with “o” and the elements of the site emergency response plan marked with “p”, the matrix of MCR as shown in the formula (5) (MIN, Key Factors of the National Emergency Management System, 2019) and by composing the elements representing the on-site emergency response organization and the elements representing the on-site resources noted by “r”, the second intermediate matrix for level 1 MCA as presented in the formula results (6) (MIN, Key Factors of the National Emergency Management System, 2019). The composition of the two intermediate matrices will result in the structure matrix MS1 presented in the formula (7).

$$\begin{pmatrix} o1p1 & o1p2 & o1p3 & o1p4 & o1p5 & o1p6 \\ o2p1 & o2p2 & o2p3 & o2p4 & o2p5 & o2p6 \\ o3p1 & o3p2 & o3p3 & o3p4 & o3p5 & o3p6 \\ o4p1 & o4p2 & o4p3 & o4p4 & o4p5 & o4p6 \\ o5p1 & o5p2 & o5p3 & o5p4 & o5p5 & o5p6 \\ o6p1 & o6p2 & o6p3 & o6p4 & o6p5 & o6p6 \end{pmatrix} = \mathrm{MCR} \tag{5}$$

$$\begin{pmatrix} o1r1 & o1r2 & o1r3 & o1r4 & o1r5 & o1r6 \\ o2r1 & o2r2 & o2r3 & o2r4 & o2r5 & o2r6 \\ o3r1 & o3r2 & o3r3 & o3r4 & o3r5 & o3r6 \\ o4r1 & o4r2 & o4r3 & o4r4 & o4r5 & o4r6 \\ o5r1 & o5r2 & o5r3 & o5r4 & o5r5 & o5r6 \\ o6r1 & o6r2 & o6r3 & o6r4 & o6r5 & o6r6 \end{pmatrix} = \mathrm{MCA} \tag{6}$$

$$(Ms_{level\ 1}) = \mathrm{MCRxMCA} = \begin{pmatrix} o1s1 & o1s2 & o1s3 & o1s4 & o1s5 & o1s6 \\ o2s1 & o2s2 & o2s3 & o2s4 & o2s5 & o2s6 \\ o3s1 & o3s2 & o3s3 & o3s4 & o3s5 & o3s6 \\ o4s1 & o4s2 & o4s3 & o4s4 & o4s5 & o4s6 \\ o5s1 & o5s2 & o5s3 & o5s4 & o5s5 & o5s6 \\ o6s1 & o6s2 & o6s3 & o6s4 & o6s5 & o6s6 \end{pmatrix} \tag{7}$$

By composing the structure matrix for level 1 described by the formula (7) and the input vector for level 1 described in formula (4) we obtain the input vector for level 2 described by the formula (8) the vector for the next level.

$$(Vnivel\ 1)\ X\ (Ms_{nivel\ 1}) = (Vnivel\ 2) \tag{8}$$

$$Vnivel\ 2 = \begin{pmatrix} v21 \\ v22 \\ v23 \\ v24 \\ v25 \\ v26 \end{pmatrix} \tag{9}$$

The system defining the off-site response, level 2, contains the following aspects:

- The elements that define the main components of SNMSU denoted by “c
- Elements that define the necessary SNMSU resources marked with "r"
- Elements defining the off-site response plan marked with "a"

The first intermediate matrix for level 2, $MI_{1\ level\ 2}$, is defined by composition of main componets of SNMSU și resources of *SNMSU*. The matrix $MI_{1\ level\ 2}$ is shown in the formula (10) (MIN, Key Factors of the National Emergency Management System, 2019).

$$(MI_{1\ level\ 2}) = \begin{pmatrix} c1r1 & c1r2 & c1r3 & c1r4 & c1r5 & c1r6 \\ c2r1 & c2r2 & c2r3 & c2r4 & c2r5 & c2r6 \\ c3r1 & c3r2 & c3r3 & c3r4 & c3r5 & c3r6 \\ c4r1 & c4r2 & c4r3 & c4r4 & c4r5 & c4r6 \\ c5r1 & c5r2 & c5r3 & c5r4 & c5r5 & c5r6 \\ c6r1 & c6r2 & c6r3 & c6r4 & c6r5 & c6r6 \end{pmatrix} \qquad (10)$$

The second intermidiate matrix for level 2, $MI_{2\ nivel\ 2}$, is defined by composition of the main componets of *SNMSU* and elements of the off site nuclear emergency response plan. The matrix $MI_{2\ level\ 2}$ is shown in the formula (11) (MIN, Key Factors of the National Emergency Management System, 2019).

$$(MI_2 level\ 2) = \begin{pmatrix} c1a1 & c1a2 & c1a3 & c1a4 & c1a5 & c1a6 \\ c2a1 & c2a2 & c2a3 & c2a4 & c2a5 & c2a6 \\ c3a1 & c3a2 & c3a3 & c3a4 & c3a5 & c3a6 \\ c4a1 & c4a2 & c4a3 & c4a4 & c4a5 & c4a6 \\ c5a & c5a2 & c5a3 & c5a4 & c5a5 & c5a6 \\ c6a1 & c6a2 & c6a3 & c6a4 & c6a5 & c6a6 \end{pmatrix} \qquad (11)$$

The structure matrix for level 2 is defind by composition of the firt intermediat matrix for level 2, $MI_{1\ nvel\ 2}$ and the second intermidiate matrix for level 2, $MI_{2\ level\ 2}$, the rezultats is shown in the formula (12) (MIN, Key Factors of the National Emergency Management System, 2019).

$$MI_1 \text{ X } MI_2 = \begin{pmatrix} s11 & s12 & s13 & s14 & s15 & s16 \\ s21 & s22 & s23 & s24 & s25 & s26 \\ s31 & s32 & s33 & s34 & s35 & s36 \\ s41 & s42 & s43 & s44 & s45 & s46 \\ s51 & s52 & s53 & s54 & s55 & s56 \\ s61 & s62 & s63 & s64 & s65 & s66 \end{pmatrix} = \text{MSlevel 2} \qquad (12)$$

The final vector is optaind by composition of the structure matrix for level 2 and the input vector for level 2 as is shown in a formulei (13) .

$$\begin{pmatrix} s11 & s12 & s13 & s14 & s15 & s16 \\ s21 & s22 & s23 & s24 & s25 & s26 \\ s31 & s32 & s33 & s34 & s35 & s36 \\ s41 & s42 & s43 & s44 & s45 & s46 \\ s51 & s52 & s53 & s54 & s55 & s56 \\ s61 & s62 & s63 & s64 & s65 & s66 \end{pmatrix} \text{X} \begin{pmatrix} V21 \\ V22 \\ V23 \\ V24 \\ V25 \\ V26 \end{pmatrix} = \begin{pmatrix} V31 \\ V32 \\ V33 \\ V34 \\ V35 \\ V36 \end{pmatrix} = V_{final} \qquad (25)$$

Furthermore, using the systemic model described in this chapter, it is proposed to study the links between the elements described at all levels in relation to the final vector and to perform sensitivity analyzes. The aim of the study is to demonstrate that the systemic model works and can be used to identify sensitive elements and especially to optimize processes.

5. ANALYSIS USING THE SYSTEMIC MODEL

This chapter is dedicated to the study of the behavior of the variabil system which is defined by the hypotetical emergencies.

For this research, in order to easily perform the calculations to be performed to study the behavior of the elements according to perturbation, the Code "SNMSU_NUMERIC" was developed. The code uses matrix calculation and is written in the MATLAB program.

Using this code SNMSU_NUMERIC three type of analysis were accomplished:

a) **basic calibration:** in the study of the established cases (scenarios) it was taken into account the evaluation of the maximum margins of variation without considering the meaning of some structural changes that have a certain significance for the study - strictly mathematical maximum / minimum possible variation).

Basic calibration involves evaluating the maximum margins of variation without considering the meaning of structural changes that have a certain significance for the study shows - strictly mathematically possible minimum-maximum variationMarja de variație a rezultatelor arată că:

The method works mathematically and

(i) the results make sense as calculation operations

(ii) the method gives stable results

(iii)the coordinated variations of some categories of criteria (an entire column for example) have a smaller impact than a mosaic variation of the characteristics in the table

The variations have a very wide range and cases that have a physical meaning must be chosen in order to be able to draw conclusions related to situations close to the real ones.

b) **reference cases:** involves the evaluation of variations in the situations considered the most credible - the variation is not strictly mathematical but shows the impact of structures in case of disturbances considered the most credible

The variation margin of the results confirms the general conclusions from the type I running cases (basic calibration) and shows that:

(i) By choosing meaningful cases (cases 1 and 2) the results confirm that:

- o The influence of MS0 elements at the site level is important and can reduce the negative impact, especially as the disturbances on the system (initiating events) are more severe.

- o The impact of MS0 actions is smaller in the case of disturbances that require off-site reactions.

(ii) The most unfavorable situations, such as the low efficiency of the MS0 action, are those in which the structure is not necessarily very bad for a single category of criteria, but when it has weaknesses of various natures (the structure is of the svaiter type) and higher than in standard cases

c) **sensitivity analysis:** involves assessing the impact of complex changes in variations in the situations considered most credible. It is shown that the results of the sensitivity analyzes confirm the conclusion from category II, the reference cases and confirm it for any configuration / structure in which we have many weaknesses of various natures, for various criteria that lead to the worst situations of negative impact on management control. emergency.

6. DEVELOPING A CODE REGARDING THE CALCULATION OF THE SYSTEMIC MODEL USING THE EVOLUTIONARY ALGORITHM

The code named evolve2_prod_v.1.05.py was developed as an application in PYTHON code using array operations and running on a Linux platform on which the Python programming language is installed.

The application was developed using the concept of evolutionary computation for the systemic model developed in Chapter 4 in order to obtain an optimization mechanism in order to identify the best solutions for certain given conditions of the systems described in the complex system.

Evolutionary computing is a sub-branch of Artificial Intelligence that includes the soft-computing paradigm for solving problems in areas such as machine learning, designing complex systems and optimization. These evolutionary algorithms are probabilistic algorithms mainly in biology and have in common the following elements:

- Maintain a population of *candidate solution* representations
- Which evolves over *generations* / iterations
- I'm in control of a *fitness function* that measures individual merit

The terminology and concepts regarding evolutionary calculation elements were taken from the specialized documentation (Eiben), (Back, 1996).

7. USE OF THE CODE ”evolve2_prod_v.1.05.py”

The research did not consider running a specific scenario but demonstrating the functionality of this code, the main goal being to optimize the management of planning, preparedness and emergency response on the site but also to optimize planning, preparation and emergency response off the site to obtain the benefit maximum for given conditions. Random qualifying were assigned for the elements describing the level 0 structure matrices and the perturbation vector. The intermediate matrices at level 1 and 2 are determined by the program.

After running the code, 5 generations were selected starting with the first generation that satisfied the threshold condition, namely the first 20 scores to be below the established threshold (15%).

It should be noted that the program identified a multitude of generations that met the condition but the first 5 were chosen to see if the method works mathematically, using this code. From the analysis of the results it can be seen that the method gives stable results. Using this approach, a faster convergence of the algorithm to those solutions that meet the established threshold condition is ensured.

In addition to the speed of finding optimization solutions, this program can find quick solutions for situations where certain elements of the structure matrices cannot be changed in a positive way. Another major conclusion is that this program also offers optimization solutions for situations where the elements can be modified only in a single structure matrix or in combinations of two structure matrices, as well as for multiple event situations or combinations of events.

8. OPTIMIZING THE PLANNING AND PREPARATION PROCESS FOR NUCLEAR ACCIDENT MANAGEMENT

Taking into account the conducted research and the conclusion that the systemic model works and can be used, the model developed using evolutionary algorithms aims to support the decisions underlying the process of controlling accidents within the limits of the project, handling severe accidents, minimizing radioactivity and minimizing consequences radiological.

Assuming that this model establishes a method/mode of analysis that deals with the interaction of components at all levels of the management system in order to define sensitive elements, weak links that require more attention in order to improve them, I believe that the model would be used in the operation of a nuclear installation to ensure and demonstrate nuclear safety and security in application of the levels 3, 4 and 5 Protection In-depth concept.

The use of the systemic model, in order to apply the optimization principle, aims to identify the best solutions for preparation, planning and implementation of the response to nuclear accidents and reduction of radiological consequences both on site and off site. By running the code we look for the best solution, optimized, in terms of organization, resources, actions that define the planning and preparation both on site and off site of the nuclear installation.

8.1. Description of the scenario

From the technic documentation, namely, probabilistic analyzes of CNE, for the study, the proposed scenario is a severe accident resulting in the exposure of a person outside the exclusion zone of a CANDU nuclear installation to values higher than the reference levels established in the Romanian legislation, for the probability of occurrence of deterministic and stochastic effects. This scenario is relevant for planning/preparing for a severe accident response.

Scenario contains the following assumptions:

- The initiating event is the loss of coolant in the moderator (INCLUDE)
- Tire insulation is lost for 24 hours. It is assumed an opening of the equipment lock of 0.03m
- Active zone failure cooling system (ECC) available for high stage (HPECC) and medium pressure (MPECC)

8.2. Optimization calculation

In order to achieve the optimization, the program was run by randomly choosing the threshold that would satisfy the acceptance conditions. Initially the code was run with a threshold set at 10% and it was found that after running, the code generated a single optimization variant to meet the threshold condition.

For the 15% threshold, the code generated over 200 variants, various combinations for the elements of the matrices that make up MS_{nivel1} şi MS_{nivel2}.

8.3. Optimization and conclusions

The 10% threshold was not taken into account because a single variant represents a limitation for optimization. If certain elements of the matrices defining the structure matrices MSnivel1 and MSnivel2, cannot satisfy the established conditions, it results that this variant cannot be applicable. A single optimization variant does not lead to implementation solutions.

The variant chosen to optimize the preparation, planning and response both on site and off site in the event of the worst severe accident, was the best variant generated by the code with a threshold of 15% response.

The following must be considered in order to achieve optimization:

- The elements regarding the on-site emergency response organization, Shift Supervizor DST, on-site Emergency Response Team ERU and the Physical Protection Unit UPF are key elements in implementing the on-site response. Both DSTs and ERUs cannot be replaced/supported by other resources, so it must be considered that the human resources program and the dedicated ERU and DST training program shall be developed to a highest standard. Also, the resources used by them must be very high.
- The elements regarding the on-site emergency response organization, UCC Command and Control Unit and the GST Technical Support Group are the minor elements, it can be seen that the weakness of these elements is compensated by the key elements. It should be taken into account that only one of the two elements can have an unsatisfactory level so that compensation can be ensured.
- The elements regarding the on-site emergency response organization The Emergency Director DU is not a dominant element for on-site mitigation actions but may be a dominant element in coordinating with off-site response. Therefore, the development of dedicated training programs for DU, especially for on-site and off-site emergency

response, is necessary to achieve optimization. Resources in this case must be at a high level.

- The elements describing the implementation of the off-site response plan must be stable, this means that the legislation is not changed very often. Any change leads to the variation of these elements. To this end, a long-term regulatory strategy must be agreed and approved at the level of the regulatory body.
- The elements that describe the components of SNMSU are dominated elements, it is necessary to consider the development of training programs at higher standards and the provision of resources to the institutions that provide these components. Security culture programs are mandatory to be implemented in these involved institutions.

As a perspective, the study initiated in this doctoral thesis can be extended by:

- Developing a program code to be used in the decision-making process during emergencies, applying an optimization process to identify the best decision solution taking into account the elements that define the emergency situation and various uncertainties.

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