Protection of facilities against sabotage
General approaches and studies in France

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Abstract:

In addition to the measures taken in the frame of the nuclear safety demonstration, the French nuclear facilities are subjected to a specific verification approach concerning the risk resulting from a malevolent action that may cause a release of radioactive materials in the environment. This approach aims at determining the protection level for facilities, based on predefined threats and the provisions to be set, if necessary, to ensure a satisfactory protection. The approach presented in this paper basically consists of a sensitivity analysis followed by a vulnerability analysis. In the French national control system also shortly described in the paper, the Competent Authority asks the operator to present a demonstration based on the approach and IRSN is charged with the technical assessment of the dossier. Because these analyses are generally based on specific tools, particularly in the case of vulnerability assessment, IRSN has raised a program to collect a set of methods and data on this subject, presented in the second part of this paper. It must be pointed out that no quantitative results or detailed examples will be given in the paper due to the sensitivity of the subject and the confidentiality measures applying.

1 LEGISLATIVE AND REGULATORY FRAMEWORK

The French regulatory framework meets a set of fundamentals principles endorsed by the board of Governors of the IAEA in his meeting of 15 August 2001 (GOV/2001/41); namely the following principles:

1.1 Responsibility of the State - (See fundamental principle A)

The responsibility for the establishment, implementation and maintenance of a physical protection regime within a State rests entirely with the State

1.2 Regulatory framework - (See fundamental principle C)

The French “Ordinance” 58-1371 of 29 December 1958, is intended to strengthen the protection for the facilities of vital importance, for which the unavailability might considerably reduce the war potential or economical potential, the safety or survival of the French nation with regard to any sabotage action. These requirements may be extended to facilities for which the destruction or failure of some parts would seriously endanger the population. These regulations define general protection principles that are applicable, irrespective of the type of installations.

Destructions or failures that raise consequences in terms of operating loss, industrial tool loss, media impact, brand image weakening etc. are not included in the scope of these regulations. The operator is fully responsible for this type of consequences.

Specific ministerial instructions detail the arrangements defined for nuclear facilities. The latest is a ministerial instruction dated 16 May 2000 upgrading older documents.

1.3 Implementation of the competent authorities - (See fundamental principle D)

The function of the Competent Authority has been devoted in France to the ministry in charge of industry, and more precisely to the High Civil Servant for defence and a specialised division: the Division for “Sécurité des Infrastructures Economiques et Nucléaires”. As concerns the protection of nuclear facilities against sabotage, the link with safety issues is materialised via a two-headed authority, shared with the safety authority.

1.4 Responsibilities of the entities involved - (See fundamental principle E)

In France, the responsibility for implementing the various elements of physical protection is clearly identified. The Competent Authority states that the prime responsibility for implementation of physical protection of nuclear material or of nuclear facilities rests with the holders of the relevant licenses. Three different entities are involved in the French national control System: the Competent Authority mentioned previously, its technical support body (namely the Institut de Radioprotection et de Sûreté Nucléaire) and the Operators. The organization clearly defines the roles and responsibilities between these entities.

It is important to note that such an organization closely involves together the authorities and the operators and allows a profitable dialogue between them. The technical exchanges between the operators and IRSN based on the operators’ studies are easied by the development, inside IRSN and for its own use, of specific tools described later in the paper.

1.5 Design basis threat - (See fundamental principle G)

Concerning malevolent action, several types of threats are taken into account in the French DBT. As examples, the following could be mentionned:

- Internal threats involving actions taken by insiders acting alone or not,
- External threats involving actions by small groups of adversaries. Two assumptions are made when testing the ability of protection systems to counter aggressions of this type. The first one involves a small team of adversaries with limited resources, and the second one takes into account a larger team with more sophisticated resources.

Assumptions are also made about the type of actions that could be taken by malevolent workers in sensitive zones and possible aggravating factors to be considered. As an example the loss of the offsite power supply could be taken into account.

Emphasis has to be paid on the fact that the internal and the external threats are of completely different natures and neither one can be considered as an envelope of the other.

2 METHOD

The approach to be followed can be summed up as follows:

1. The sensitivity of each zone of the facility is determined; this can be characterised by the level of the radiological consequences resulting from a malevolent action. Sensitivity is determined by taking into account:
    - the radioactive product inventory,
    - possible accident situations,
    - an estimate of the consequences of these accidents.

2. The vulnerability of the various zones to each type of aggression is estimated, in other words, an estimate is made for the extent to which it is difficult to carry out a malevolent action in the zone in question.

3. If need be, counter-measures are taken to protect zones for which the consequences would be unacceptable compared to the force of the aggression. Counter-measures are intended both to minimise sensitivity, to make it more difficult to carry out the aggression envisaged, and to mitigate the consequences of the aggression.

2.1 Determining sensitivity

Analysis of the sensitivity of a facility involves using safety analyses to identify potential accident sequences, which, if they occurred, would have significant consequences for workers, the public or the environment.

An accident sequence is taken to mean a series of events resulting from one or more initiating events (the failure of one or more components or functions, or human error) and which put the facility into a degraded situation with the possibility of radiological consequences, despite the engineered safety systems and mitigation devices installed in it. Safety analyses are performed to study these sequences and the counter-measures to be taken, mainly by using a standard incident and accident list taken into consideration at the facility design stage.

However, sabotage is not taken into account in the safety demonstration. As an example : the simultaneous failure of the redundant equipment of a safety related system as the pumps of an emergency cooling system cannot be considered as probable in the safety analysis if there is no common failure risks. And yet, this failure caused by an action of sabotage can lead to an incident or an accident with radiological consequences. As an other example : the failure of a tank which is not under pressure could be considered with a low probability in the safety analysis. But this tank can be seriously damaged by use of explosive in the case of an action of sabotage and the dispersion of the radioactive content has to be assessed.

Facility sensitivity analysis deals firstly with components, systems or functions which are important for the safety of the facility and identifies those that would lead to a degraded situation if they were lost or caused to fail by a malevolent action.

Specific initiating events leading to degraded situations caused by malevolent actions also have to be considered. To this end, a study is made of the particular cases of failure resulting from malevolent actions with possible losses of functions or equipment not taken into account in the safety case.

Thus the method put forward allows to identify the most sensitive elements in the facility (components, systems or functions) and therefore the zones in which they are located ; there are three types of zone depending on the gravity of the consequences of a malevolent action in the zone:

- Risk zones or systems, when an action is not serious enough to lead to radiological consequences; to cause a significant accident, at least two risk zones or systems have to be affected,
- Critical zones or systems, when an action leads to radiological consequences deemed acceptable from a safety point of view.
- Vital zones or systems, when an action leads to more serious radiological consequences than those taken into account in the safety case.

The study of measures permitting to decrease the sensitivity of vital or critical zone must be performed. When it is feasible these measures have to be implemented, as an example by limiting the quantity of radioactive materials contained in a capacity.

For the zones in which sensitivity cannot be reduced, the vulnerability is examined systematically for vital zones, or on a case-by-case basis for critical zones.

2.2 Assessing vulnerability

The vulnerability assessment of the zones and systems identified previously can be broken down into two parts :

- the estimate of the resources required to destroy or sufficiently damage a system or function (for example, the quantity of explosives necessary),
- the qualification of the paths leading to zones or systems deemed sensitive.

The second part can be dealt with by identifying all the paths leading to sensitive zones or systems and estimating for each one the difficulties involved or, more generally, the time taken to overcome obstacles (such as fences, walls, reinforced doors,…) and the potential for detecting adversaries.

The previous approach, which has to be linked to response forces interventions, must make it possible to estimate, at least qualitatively, the vulnerability of zones and systems and the need, if any, to take additional steps to strengthen the system (design modifications, additional physical protection devices etc.). This analysis has to strike a balance between the need for adequate physical protection measures and the problems associated with facility operating conditions, nuclear safety and the mitigation of accident situations (emergency exits for workers, access for firemen,…).

The resources in the possession of the adversaries depend on the threats being considered, in accordance with the relevant DBT. A distinction is made between internal and external threats. In the case of external threats, adversaries are armed or equipped with explosives, whereas in the case of internal threats, adversaries only have access to everyday tools or perhaps more sophisticated ones if they are usually on hand in the facility. It is therefore clear that insiders have more limited resources than external aggressors; on the other hand, insiders are assumed to be familiar with the facility and they are operational immediately since they have authorised access. What is more, it may be more difficult to detect an aggression by an insider than one by an outsider. Thus it is that vulnerability assessments vary enormously depending on whether internal or external threats are being considered.

The steps to be taken to reduce the vulnerability of components, systems or functions also vary depending on the kind of threat (internal and external). Although physical protection devices installed between the area outside the facility (public area) and the identified targets effectively counter external aggressions, they are useless in the case of internal threats and other steps have to be taken. For example, poor operation of an item of equipment or wrong position of a valve have to be detected as far as possible by adding sensors for sending alarms to the control room or by making items of equipment less accessible (under lock and key if necessary) according to their sensitivity.

2.3 Criteria

Acceptable consequences are taken as being those leading to levels of radioactive releases less than, or equal to, those taken into account in the facility safety case. This implies that vital zone vulnerability be reduced to a minimum so that an excellent level of protection can be provided for these areas. In the case of critical zones, the level of protection is considered on a case-by-case basis, depending on the consequences of malevolent actions (situation not far from a threshold beyond which consequences are no more acceptable, relative easiness to perform a malevolent action,…).

3 SPECIFICITIES OF SABOTAGE ACTIONS COMPARED TO THE THEFT OF NUCLEAR MATERIALS

The protection of the facilities against the risk of sabotage has many analogies with the protection required against the risk of nuclear material theft, but it is different for a number of points. In particular:

- Concerning the theft of nuclear materials, the potential targets are in limited number, i.e. plutonium, enriched uranium, thorium, deuterium, lithium enriched with lithium 6 and tritium. On the other hand, the targets selected for a sabotage may be numerous and diverse, for example distribution switchboard, water pumping station, spent fuel pool.
- The potential targets for sabotage are spread over a whole site, while nuclear materials are stowed in a storage area or in a « process zone ».
- To counter a sabotage action, the response forces should be on site before the adversaries begin to treat the selected target, while in the event of a nuclear material theft, the response forces could recover the stolen nuclear materials just as the aggressors are leaving the site.

Unfortunately, it is impossible to know the intentions of possible adversaries, do they come to steal nuclear materials or do they come to sabotage the nuclear facility? The plans of action to counter the adversaries have to cope with both assumptions.

4 STRUCTURE RESISTANCE TO EXTREME LOADINGS

One objective of the vulnerability assessment is to estimate the resources needed to destroy voluntarily a system, or a structure that shelters this system, in order to prevent it from ensuring its function. This estimation generally requires specific tools to predict the resistance of structures submitted to extreme loadings, in particular when dealing with weapons or explosives. This section is a short description of research actions conducted to develop or evaluate various tools to help in that estimation. These tools are designed to be used as a support in the evaluation performed by IRSN of the studies presented by operators in the general framework described in section 1 of this paper.

4.1 Technical issues

In order to predict the conditions under which a structure resists or collapses facing the action of a weapon or an important explosive amount detonated, on a technical point of view it is necessary to consider the three following questions:

1. What is the loading produced by the weapon or the explosive blast on the structure?

2. In order to model correctly the interaction between the weapon or explosive blast and the target structure, is it necessary to consider a coupled or uncoupled approach or experience?

3. How to model the structure in coherence with the displacements magnitude assumed so as to determine its final damage state?

Most answers to each of these questions separately are available in open literature, for studied for a long time. Nevertheless, it seems important to emphasize that in the case of vulnerability estimation, the three questions have to be treated concurrently.

The global problem constituted by the three questions above might be particularly difficult to solve for each question is relevant from different – says distant – fields of mechanics. For instance, let us consider the case of the blast resistance of a reinforced concrete wall: first, comprehension of detonation physics of an explosive charge, the energy propagation and the shockwave produced in air is relevant to compressible unsteady fluid mechanics and thermodynamics, including discontinuities – the shock front; in second, the analysis of a reinforced concrete slab submitted to this blast loading requires the study of an heterogeneous solid – the slab constituted by concrete and reinforcement steel bars – in dynamics and non linear response in most cases.

The important and challenging feature for the estimation of vulnerability by structure resistance assessment is that it combines in a single problem questions considered very differently from a scientific point of view.

4.2 The “Structure Resistance Capability in a Malevolent Situation” program

The objective of the so-called “Structure Resistance Capability in a Malevolent Situation” program is to gather useful tools for the prediction of the damage caused to structures or attached/sheltered systems by the use of weapons or explosives.

4.2.1 Starting point

As a starting point to this particular program, we consider a terrorist group that aims at introducing and using destruction means inside a nuclear facility. In order to reduce the number of scenarios to be studied, it is assumed in this paper that the group goes through the external barrier of a facility and then starts to act. This group is part of the external threat and its means are defined in the design basis threat (DBT).

This particular scenario is used to raise the following question, motivating the program: what might be the consequences on sensitive parts of a facility of the use of a high-energy destruction device – typically several hundreds of kilograms of TNT equivalent – or assault weapons?

4.2.2 General approach

The approach used to build the “Structure Resistance Capability in a Malevolent Situation” program follows the three steps below:

- Identify every potential targets on one hand and destruction means on the other hand.
- Classify both targets and destruction means in general categories that, brought together, define generic cases to be studied.
- Define a priority order for the cases to be studied.

As previoulsy described in section 2.1, the sensitivity analysis allows to define a list of potential targets, i.e. elements and structures. A list of generic destruction means is defined in coherence with the Design Basic Threat.

All these data are synthesized in two generic lists, one for the targets and one for the weapons. These two lists define the points to be dealt with, i.e. any couple target/weapon. For any couple target/weapon a practical tool should be identified, then evaluated or developed to help in predicting the effects of the weapon on the target.

In the third step, the most important cases are identified and summarized, like in the matrix presented on Table 1. This matrix shows some generic examples of cases to be treated. It is not exhaustive since it does not includes all the targets and weapons really listed, due to sensitivity reasons.

The list of targets presented includes five categories:

- A “Generic studies” category for which are investigated tools useful for the prediction of blast wave generation and propagation in air as well as in water;
- The “Buildings” category includes two different aspects, on one hand the buildings that need to be considered globally and on the other hand the cases where one focuses on external walls, roofs or floors, likely to be treated as individual slabs;
- In the “Water tanks category” are distinguished two important classes of reservoirs, the ones with thick concrete walls, generally with a stainless steel liner, and the other ones with thin walls;
- The “Steel pipes” category calls for no special comment;
- The “Active or passive safety devices” includes all the special systems ensuring a safety function, identified as sensitive and to be studied as a particular case to determine its vulnerability.

Some of the weapons considered are gathered in three example categories:

- The “Explosive” category includes the possible use of a certain amount of explosive in three different ways, in far-field from the target and in close-field; concerning the close-field situation, we have distinguished the situation when only one device is used and when several devices detonate in different locations;
- The “Antitank weapons and others” category groups for instance the weapons constituted by a certain amount of explosive, a confinement and a liner propelled at a very high speed by the explosive to create a jet, a projectile able to penetrate or cut armour, steel, concrete, etc.
- The “Rifles, fragmentation bomb” category gathers in particular the weapons likely to produce and propel small projectiles like bullets at high speed.

The “Generic studies” category does not apply to the last two weapon categories. In addition rifles and fragmentation bombs are not designed to damage concrete structures or buildings but lighter steel structures, so the present program does not include any study on those questions.

Concerning the last two weapon categories, including antitank weapons and rifles, there is no need in this program for special developments assuming that the basic performances of the weapons in this category are well known and available. So the program developments objectives are concentrated both on the explosive detonation consequences and the studies focusing on particular safety devices (white cells in the Table 1 matrix).

4.3 Current studies

The program presented above aims at gathering two different types of tools: on one hand simple, fast and efficient tools based on analytical methods are investigated, evaluated and validated; on the other hand certain particular cases more complicated need detailed studies and the development of numerical models in commercial computational mechanics codes.

4.3.1 Analytical methods

Analytical methods are used as a base for the development of numerical tools requiring few computational resources. The main interest is their rapidity of execution thus permitting parametric studies.

The analytical methods are generally based on simple and well-tried theories available in open literature. In most cases it consists in approximate or simplified theories thus implying significant uncertainties when dealing with real cases. Meanwhile, such a method allows determining properly the order of magnitude for the quantities of interest.

In the program described above, some examples of the use of simplified methods are listed here below:

- Explosive – Far-field – Buildings – RC Slabs: In such cases, the pressure applying to the structure due to the explosive blast may be modeled via analytical formulas and parameters tables found in Kinney and Graham [1] or Baker et al [2]. Biggs's one degree of freedom method [3] is used to study the non-linear response of a concrete slab and to determine the displacement magnitude. Some improved methods derived from [4] and developed by France's "Délégation Générale à l'Armement" have been used also [5].
- Explosive – Close-field – Buildings – RC Slabs: In addition to the methods described in the previous item, a specific approach taking into account the complexity of mid-field to close-field loading has been developed [6].

Concerning these two items, the chart presented on fig. 1 illustrates the types of results obtained. On this graph is established a relation between the explosive mass considered and the distance from the slab considered. This graphs shows respectively the regions where a certain amount of explosive (mass) at a certain distance leads to resistance, fracture or collapse.

- Explosive – Far-field – Water tanks – Thick concrete walls: An analytical approach coupled with a Finite Element code is described in ref. [7].

4.3.2 Numerical models

Studies conducted with numerical models come in complement to those conducted with analytical approaches: numerical simulations allow greater accuracy of the results, the inclusion of complex non linear material behavior models and the determination of local quantities evolutions. Some illustrations of such developments may be found in references [8,9].

5 REFERENCES

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Target \ Weapon		Explosive			Antitank weapons and others		Rifles, frag--mentation bomb
		Far-field	Close-field (1 device)	Close-field (> 1 device)	Shaped or formed charge	Cutting charge	
Generic studies	Aerial propagation			Results deduced from 1pt close-field studies	No study necessary		No study necessary
	Underwater propagation						
Buildings	Particular building				No development needed. Use of weapons basic performance characteristics		
	RC Slab						
Water tanks	Thick concrete walls						
	Thin walls						
Steel pipes							
Active or passive safety device							

Table 1. Synthesis matrix of cases to be treated in the program

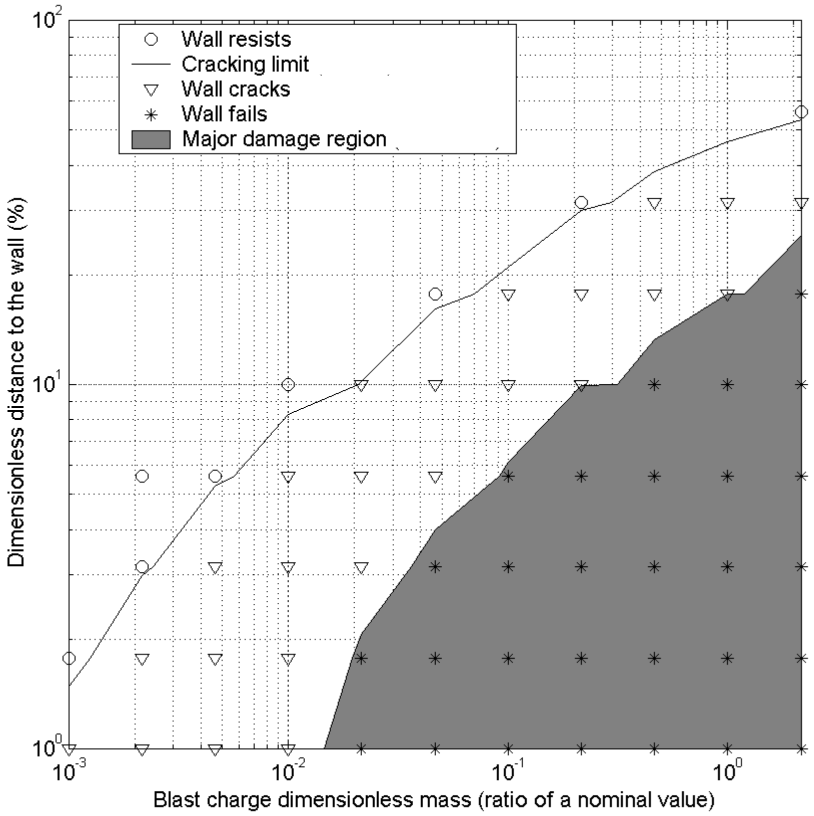

Fig. 1. Dimensionless distance-mass diagram established from several analytical calculations.