Fire PSA and insights

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Abstract: IRSN (TSO of French Nuclear Safety Authority) develops simplified Fire Level 1 probabilistic safety assessments (PSAs) for nuclear power plants (NPPs) in order to establish his own independent opinion on the assumptions and results of the licensee Fire PSAs (EDF). IRSN Fire PSAs are extensions of the IRSN in-house developed NPP Level 1 PSAs for internal events.
The licensee and IRSN studies are similar in scope; however the objectives and some main assumptions may be different. The licensee objectives are to answer to the Safety Authority requests to perform complete PSA studies as a complementary approach of the deterministic studies of the fire risks. The IRSN study objectives are to provide an independent verification of the licensee study and also to allow further PSA applications in the framework of technical instruction of safety issues. In particular, IRSN main goal is to focus on the most critical equipment and compartments in terms of fire-related risks.
The paper gives two examples of specifics insights obtained regarding the licensee PSAs in the field of Fire.
The first example is related to the ongoing third periodic safety review of 1300MWe NPPs. The second example deals with IRSN review of the licensee Fire PSA for the commissioning of the French EPR reactor (at Flamanville 3).

Keywords: Fire PSA, Periodic Safety Review.

1. INTRODUCTION

The periodic safety review procedure is a periodic process implemented for every reactor. In France, the periodic safety reviews occur every ten years and concern all reactors of a given serie (e.g. 900 MWe or 1300 MWe or 1450 MWe reactors).
In that context, IRSN, the French Institute for Radiological Protection and Nuclear Safety, which is the technical support of the French Nuclear Safety Authority (ASN), develops his own PSA to assess the PSA developed by the licensee.
IRSN began to develop and use level 1 probabilistic safety assessment (PSA) for French Nuclear Power Plants in the 90's. In the frame of its missions, the in-house development of PSA allowed gaining valuable knowledge on nuclear safety. In the same time, a deep independent analysis of the PSAs developed by the licensee (EDF) was performed. Since 2002 [2], PSA review became an important part of the periodic safety reviews of the operating plants.
PSA development program is still in progress at IRSN and at the licensee. These developments aim to introduce new knowledge and to extend their scope, in order to increase the possible fields of applications. Both organizations are working in parallel on PSA developments. The licensee objective is to establish reference PSAs for each plant series. IRSN objective is to obtain independent insights, precious to evaluate and point out needs for further developments. Comparisons between these two independent PSAs highly contribute to the quality of the studies.

In the context of the third decennial visit for the French 1300MWe nuclear power plants, IRSN developed a fire level 1 PSA for 1300MWe reactors. IRSN main goals were to gain knowledge in order to be able to evaluate assumptions and results of the licensee Fire PSA. The study is an extension of IRSN in-house 1300MWe NPPs Level 1 PSA, for internal events. The development of a Fire PSA is necessary due to the importance of fire on the risk of core damage.
A lot of information was exchanged between the licensee and IRSN during the development of the project. The licensee and IRSN studies are similar in scope and use the same principles; however the

objectives and the main assumptions may be different (for example: damage temperature considered for the equipment, fire source characteristics…). In particular, IRSN main goal is to identify and to quantify preponderant accident sequences leading to core melt. The study will therefore focus on the most critical equipment and compartments in terms of fire-related risks. IRSN objectives are also to provide an independent verification of the licensee study and to use Fire PSA applications in the framework of technical instruction on specific safety issues.

IRSN also reviewed the licensee Fire PSA for EPR reactor commissioning (at Flamanville 3). The assessment of the EPR Fire PSA was very particular. Especially because EPR is currently under construction and a lot of data are still missing: this is the case of railway cables and several components which are not localized in fire areas. Moreover, fire action procedures for operator are not developed yet. However the method used for the Fire PSA is globally the same as the one used for 1300MWe NPPs.

2. FRENCH SPECIFIC CONTEXT

Regarding nuclear industry, France represents a unique situation with a rather large fleet of Nuclear Power Plants (58 in operating, 1 in construction) which are all built by the same manufacturer (AREVA) and operated by the same licensee (EDF). This nuclear fleet is standardized in 3 PWR series - soon 4 with EPR – (900MWe: 34 plants, 1300MWe with two types of plants named P4 and P'4: 20 plants, 1450MWe: 4 plants; EPR: 1 plant). The plants of each PWR serie are almost identical in design and operation, excepted EPR. The standardized series has real advantages in terms of experience feedback. In the specific field of PSA, the situation is particularly favorable for data collection, and moreover a single PSA (at least for level 1 PSA and internal initiating events) is sufficient for a whole PWR serie of plants. In fact, three PSAs - 4 with EPR - are sufficient to cover all operating plants, for internal events analysis; for Fire PSA only three Fire PSAs - soon 4 with EPR - are sufficient to cover all operating plants. Since few years, IRSN has begun to develop also PSA for internal hazards in order to increase its capability to assess similar studies developed by the licensee and because those studies are important for safety. Regarding PSA for external events, developments are still ongoing especially for seismic hazards and other external hazards inducing long term loss of offsite power and heat sink.

Concerning IRSN Fire PSA, two models have been developed. The first development of Fire PSA started in the 90's and concerned French 900MWe. This study was achieved in 2007. It was a very complete study, developed as recommended in the international practice [1]. It will be updated in 2014 to take into account new data and new experience feedbacks. Moreover, the model will be completely reviewed and implemented with Risk Spectrum tool® in order to facilitate sensitivity studies.
The second development of Fire PSA started in 2005 and concerned French 1300MWe reactors. The general method adopted by IRSN for his 1300MWe Fire PSA is similar to the one used for 900MWe reactors Fire PSA. Nevertheless, the lessons learned from the development of the 900MWe reactors Fire PSA as well as the progress in computer tools have led to some improvements, such as the selection of critical compartment (the most critical compartments for the 900MWe NPPs, were essentially localized in the electrical building) and the development of the study only with RiskSpectrum® tool by linking events trees (event trees of fire scenarios and internal event level 1 event trees).

3. PERIODIC SAFETY REVIEW

3.1. Generality

The periodic safety review procedure is a periodic process implemented for a given reactor type, which in order to take into account operating experience and updated knowledge. For PSA, the review is mainly divided in 2 steps.
In the first step, the periodic safety review procedure aims to demonstrate the conformity of the "*reference plant situation*" with the "*safety reference system*". The "safety reference system" consists

of all the safety rules, criteria and specifications applicable to a reactor type resulting from the safety analysis report. The "reference plant situation" consists of the state of the installation and its operating conditions. Any observed deviations are corrected or justified.
In application of the general procedure, PSAs are used during the periodic safety review to assess the core damage frequency and its change compared with the assessment made at the end of the previous review, including the analysis of the potential changes in system characteristics and in operating practices.
In addition, the identification and the analysis of the main contributors to the core damage frequency (for example analysis of the predominant functional sequences) are achieved in order to highlight potential weak points for which design and operation changes should be studied. They can be ranked using PSA results to define priorities. In particular, the analysis must take into account the frequency of the sequences, possible consequences on containment integrity and uncertainties.
During the first step of the periodic safety review, the reference PSA is updated, with the most recent operating experience (identification of frequency of initiating events, equipment reliability data, plant operating states…), updated plant design and operation. It also includes new knowledge about the plant behavior, obtained from the most recent studies.
After the review of all conservative assumptions of the PSA, this analysis results either in a status quo or in an indication of the usefulness or the needs of implementing design or operational modifications.
Following the periodic safety review, a new version of the reference PSA is produced taking into account the plant changes or modeling improvements decided during the review process.

The use of PSA for periodic safety review is done accordingly with the French PSA Basic Safety Rule [2].

Regarding Fire PSA, the periodic safety review or the anticipated safety review for commissioning of EPR is divided into two phases based on the two steps described above with specificities for Fire PSA.
During the first phase, the licensee develops a Fire PSA and, then, IRSN compare this PSA with his own study. The objective of the Fire PSA development is to allow gaining valuable knowledge on risks due to fire on nuclear plant and to identify main contributors, risk of fire in different compartments… IRSN Fire PSA leads to several requests of changes from French Safety Authority (ASN) to the licensee. For the requests, endorsed by ASN, the licensee should propose solutions (design or operational improvements) at the end of the first phase of the periodic safety review.
In the second phase (after the licensee solutions proposal), the licensee study is updated, as IRSN Fire PSA, and is finally used to verify the improvement associated to the changes decided.

3.2. IRSN PSA Development for Periodic Safety Review

For the third periodic safety review of the 1300MWe French plants, the licensee updated his Internal Events PSA and also developed a Fire PSA, an Internal Flooding PSA and a Fuel Pool PSA. In order to prepare the review of the licensee studies, IRSN updated his own 1300MWe internal events PSA and developed a 1300MWe Fire PSA.

The paragraph 5.1. describes the Fire PSA use in the frame of the third periodic safety review of 1300MWe plants.

4. THE ANTICIPATED SAFETY REVIEW OF EPR

The anticipated safety review for the EPR for the commissioning is particular because the review is divided into several steps depending on the deadline of the commissioning application.
Some requests proposed by IRSN will be taken into account by EDF for commissioning application and other will be achieved for another deadline corresponding to end of the commissioning tests report; the deadline is decided regarding the potential effect of the request on core damage frequency.

For the anticipated safety review of EPR for its commissioning, the licensee developed an Internal Events PSA a Fire PSA, an Internal Flooding PSA and an Explosion PSA. In order to prepare the review of the licensee studies, IRSN only developed an Internal Events PSA.
The paragraph 5.2. presents the IRSN assessment of the Fire PSA for the anticipated safety review of EPR for its commissioning.

5. IRSN ASSESSMENT

5.1. The third Periodic Safety Review for the 1300MWe NPPs

For The third Periodic Safety Review for the 1300MWe NPPs, IRSN firstly, as a preparatory work, developed his own Fire PSAs, which consist of two different models for the two types of 1300MWe plants, in order to be able to better distinguish the specificities of each design. For P'4 type plant, an adapted method of the international practice was implemented by IRSN: the "*qualitative screening*" [1] was reduced at the selection of compartments containing important safety equipment which are the most important contributors to the core damage frequency (estimated by importance calculation with Risk Spectrum® tool [3]) or at the selection of compartments which are adjacent to a compartment containing equipment important to safety. For one compartment, only one type of component was taken into account for the source fire characteristics. For P4 type plant, a very simplified model was developed by IRSN for few fire areas, based on the conclusion of the P'4 plant Fire PSA. Fire areas, taken into account, were selected considering the results of the type P'4 in terms of core damage frequency (CDF) due to a fire.

The licensee presented a "reference" Fire PSA which is common for the two types of 1300MWe plants (P4 and P'4). IRSN considers that the two types of 1,300MWe NPP are different due to compartment geometries, different types of component contained into the compartments, localization of compartments in the buildings and different types of adjacent compartments. The fire areas are not the same too. For Fire PSA, those elements have consequences on the result for fire simulation and on the list of components lost after a fire. If the compartments are different due to dimension, geometry and due to the combustible they contain, the failure time could be different. All these reasons led IRSN to ask the licensee to develop two Fire PSAs: one by type of 1,300 MWe plant. This conclusion of the periodic safety review was approved by ASN who asked to the licensee to develop a fire PSA for the 1,300MWe reactor type P4 for the second step of the periodic safety review.

The reference study performed by the licensee pointed out the need to change the type of the manual command on the Main Control Room (MCR) of the pressurizer safety valves to avoid the spurious signal leading to their opening in case of the failure of I&C cabinet due to fire.
A first conclusion of IRSN assessment was that during the first step of Fire PSA development, hypothesis more or less conservative, as well as parameters values with various uncertainties are used: it's very important to analyze the effects of those choices on the PSA results and to identify the possible cliff-edge effects and the needs for R&D.
IRSN estimated that the use of Fire PSA approach proposed by the licensee was acceptable and consistent with requirements of the French basic safety rules for PSA. Regarding the licensee conclusions, a particularly deep verification of the Fire PSA developed by the licensee was performed by IRSN, based mainly on the use of the IRSN Fire PSA models. The licensee and IRSN studies were developed by using the same computer code Risk Spectrum®. Some differences exist between the two studies. They include, among others, the following aspects:

- reliability data about fire damper and fire door,
- characterization of fire,
- damage temperature,
- fire spreading between fire areas which contains components of the two electrical trains,
- human reliability analysis (HRA); IRSN and the licensee didn't use the same method,
- departure of fire on the current part of cable,

- development of two Fire PSA for IRSN: one by type of 1,300MWe NPPs.

Those differences led to several recommendations due to the potential impact on the core damage frequency, obtained at the end of the first step of the periodic safety review.

The licensee proposed to take into account most of the recommendations, in the updated model of his Fire PSA developed for the second step of the periodic safety review, but he maintained his position for the damage temperatures.

The damage criteria are important parameters of Fire PSAs. These criteria correspond to the failure of equipment. In case of fire, these criteria should be linked to temperature, smoke concentration, humidity, etc. In the licensee Fire PSA, the damage criteria taken into account are associated to a temperature threshold defined for each component.

The licensee considered the value of damage temperature equal to 95°C for electronic equipment (only I&C cabinet) and 137°C for electrical component including all electrical cabinets.

IRSN considered that the value considered for electrical cabinet was not acceptable because (i) electrical cabinet contain electronic cards and (ii) the value considered is not the recommended value of damage temperature in international practices [1].

Regarding international R&D, different values of damage temperature are proposed but there is a lack of knowledge on electronic and electric cards contained in electrical cabinets. For that reason, IRSN decided to set up specific R&D programs in this area: the objective was to quantify the damage temperature and to investigate the impact of the smoke on the components. Three components of electrical cabinet were tested: two electronic devices (named “electronic card”) and one circuit breaker (IRSN considered that they are potentially the most affected components of electrical cabinet). Two experimental programs were defined [3].

The first experimental program, called “CATHODE”, took place in an experimental small-scale compartment named SIROCCO. The objective of those tests was to define the empirical temperatures of the three components. The results were not sufficient to conclude because the experimental program was not in real condition of fire. For example, there was not soot taken into account. To confirm the results, it was necessary to pursue the experimental program to test components in real conditions of fire.

The second experimental program, called “CATHODE Suies” (“Suies” stands for soot), was performed in a real-scale experimental compartment. The objective of the tests was to obtain elements of answer concerning the damage criteria of component of electrical cabinets in real conditions of fire: first, in terms of temperature and second, in terms of soot concentration. The effect of soot was particularly studied. Four tests were performed between June 18 and October 8, 2009 in the DIVA facility. One type of component of the first SIROCCO experiment was tested in DIVA facility: the electronic cards. They were placed at two different heights (two tests at 1.80 meters and two tests at 0.55 meter) in the compartment containing the electrical cabinet, in a fire. The electronic cards were lost when they were positioned at a height of 1.80 meters but were still operating at 0.55 meter. The first analysis of the tests showed that the electronic cards were lost at a value of temperature lower than the value of temperature found in the first SIROCCO experimental program (upper than 100°C): the value of the damage temperature, obtained in DIVA facility, was superior or equal to 65°C. Another conclusion was that the electronic cards did not work temporarily when some conditions on temperature and soot are reached: a combination of values of two “damage criteria” (temperature and soot) could cause the relay’s malfunction. At the beginning of 2014, new series of experiments will be performed to check this assumption and to quantify the values of temperature and soot for which the components are lost.

Considering the results of the experimental programs, IRSN considered a damage criteria of 65°C in his Fire PSA for electrical and I&C cabinet. This value corresponds to the temperature of an area with hot smoke which leads at the failure of components.

The damage criteria were used in fire simulation to estimate the time at which the component fails called the “failure time”. It occurs when the area around the component reaches the damage criteria.

For fire simulation, IRSN relies on SYLVIA code (a two-zones fire model), a software system for simulating fire, ventilation and aerosol contamination phenomena developed at IRSN. SYLVIA code estimates pressure, temperature and concentration in carbon which allow to estimate the failure time

for various safety related components, in the critical compartment. It also gives similar information in the adjacent compartment, in case of fire spreading.
To estimate if a component is lost during the fire scenario a comparison is done between the failure time and the duration of fire. If the failure time is lower than the fire duration and if damage criteria are reached: the component is lost. In the other case, the component is available. This method gives the list of components or cables which are lost.
Then, a sensitivity study is performed, taking into account two different values for the damage temperature, to evaluate their effects on core damage frequency:

- for the reference study, the value of damage temperature of electrical cabinets is equal to 65°C, it is assumed to be conservative,
- for the sensitivity study, the value of damage temperature of electrical cabinets is equal to 95°C (value taken by the licensee).

Experimental results and sensitivity studies were presented to the licensee. A conclusion was: If the damage temperature increases of 30°C, less component are lost in the fire compartment and in the adjacent compartment. The increase of damage temperature has an important impact on core damage frequency as less initiating events are induced and less equipment important for safety are lost.
In conclusion of the periodic safety review, ASN asked the licensee to change the damage temperature or to perform a sensitivity study on the damage temperature in his Fire PSA for electrical cabinet.

5.2. The Anticipated Safety Review for EPR for commissioning

For EPR reactors, the safety demonstration was significantly improved. EPR design is based on the "technical guidelines for the conception and the construction of the next generation of nuclear reactors with pressurized water", established in 2000, after the French-German experts assessment of EPR safety options. These guidelines mentioned in particular that "the demonstration of safety for the nuclear power plant of the next generation must be made in a determinist way, completed by probability methods and works of research and development suited".
They also mention that "a significant reduction of the global frequency of core damage must be obtained for the nuclear power plant of the next generation. The implementation of improvements of the in-depth defense of these NPP should lead to the obtaining of a global frequency of core damage lower than 10^{-5} per reactor year (/r.y.) by taking into account uncertainties and all the types of failures and hazards. "

Within the framework of the reactor EPR-FA3 commissioning, the licensee achieved a level 1 PSA relative to internal fire. IRSN did the assessment of this Fire PSA.
The Fire PSA results are consistent with the general safety objectives (especially to obtain a global frequency of core damage lower than 10^{-5}/r.y.). For IRSN, this result supports the EPR design regarding fire risks, in particular the separation of electrical train in four different buildings (one by electrical train and fire areas within every building).
IRSN considers that the method, the main assumptions and the data used by the licensee are suitable. Nevertheless, IRSN highlights that the study does not take into account electrical cables and piping of hydrogen, neither as ignition equipment nor as potential targets.
As the reactor is under construction, the localization of cables was unknown when Fire PSA was developed by the licensee. Additional work is then needed to consider the risk due to cables and the study will be completed by the end of the commissioning application. This study concerns fire risks in the containment annulus and, more generally in all compartments with cables of different electrical train.

Furthermore, IRSN identified needs of further development concerning spurious orders in case of fire and evaluation of frequencies for fire departures.
The licensee committed himself to updating his Fire PSA for the end of the commissioning tests report, by taking into account these aspects.

More specifically, during its assessment, IRSN pointed out that the licensee first based his EPR Fire PSA on deterministic principle (fire barriers are always fire-resistant: the spreading of the fire is not possible). For example, a fire door is considered to resist to any fire. Therefore, the licensee didn't take into account, in his fire PSA, the probability of the failure of the fire door during a fire. These assumptions will be checked by IRSN during the deterministic studies assessment.

5. CONCLUSION

It is important to note that a PSA development program is still in progress at IRSN and at the licensee. The developments aim to improve PSA quality and to extend their scope, in order to increase the field of applications. Both organizations are working in parallel on PSA developments. These two independent works, which could be considered as a particularly deep external review, highly contribute to the quality of the studies.

The third periodic safety review for the French 1300MWe nuclear power reactors is performing with the particularity to extend PSA to internal hazards like fire and flooding. The development of an IRSN Fire PSA made it possible to conduct in-depth analysis of the licensee study. IRSN estimated that the use of Fire PSA approach proposed by the licensee was acceptable and consistent with requirements of the French basic safety rules for PSA. Some plant improvements were identified. They concerned the change of the type of the manual command on the Main Control Room (MCR) of the pressurizer safety valves to avoid the spurious signal leading to their opening in case of the failure of I&C cabinet due to fire. The conclusion of the periodic safety review led ASN to ask the licensee to develop a fire PSA for the 1,300MWe reactor type P4 because some elements, important for a Fire PSA, are different between the two types of 1,300MWe plant (geometry, fire barriers, localization of component…) and to change the damage temperature or to do a sensitivity study on the damage temperature in his Fire PSA for electrical cabinet. The study, performed by IRSN, highlighted the importance of the values of the damage criteria considered in Fire PSA and the need to perform experimental programs in this field.

Concerning EPR, the Fire PSA results are consistent with the general safety objectives. These results support EPR design against fire risks, in particular the separation of electrical train in four different buildings (one by electrical train) and the measures of separation into fire area within every building. Additional studies will be performed by the license by the end of the commissioning application, especially to take into account risks associated to fires in compartments including cables of different electrical train.

References

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