Data collection in Fire PSA

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IRSN (as French Nuclear Safety Authority TSO) develops level 1 Fire probabilistic safety assessments (FPSAs) in order to consolidate its own independent opinion on the assumptions and results of the Fire PSA that are conducted by EDF which is the Licensee of French NPPs. IRSN Fire PSAs are extensions of the IRSN in-house developed NPP Level 1 PSAs for internal events.
The FPSAs developed by IRSN focuses on few compartments which contains important safety components. But for each compartment selected a detailed study is done. Thereby, IRSN needs a large amount of data, mainly for the fire scenarios modeling and for conducting fire simulations as a support of PSA. The objective of this article is to present how the necessary data are collected by IRSN and how they are used in the frame of FPSA.
Data are collected by the analysis of the fire incidents occurred in French NPP and by walkdown on the studied NPP to complement the design and operational information provided by the Licensee.
The collected data are then stored by IRSN in databases. One of them contains all the fires occurred in French NPP since the commissioning. The information collected to establish the Database covers the period from April 21, 1975 to December 31, 2014. It represents more than 900 fire events for more than 1600 reactor.years. Another Database contains the description of the compartments studied in the Fire PSA with their detailed description (geometry, size, openings, equipment, cables and automatic system of detection and extinction inside), their adjacent compartments and what they contains in terms of equipment and cables. The data collected concern also flowrate and pressure measurement in ventilation conduct and at fire doors to take the ventilation system into account in fire simulation.
These data are important to quantify the frequency of fire scenario. Data are used to develop statistical parameters like fire frequency of equipment, failure rate of fire protection systems (e.g. fire dampers), human actions and intervention delays of different teams to extinguish fire (e.g. operating team, firefighting team, etc.) or to define fire scenario. Data are also used as input of the IRSN SYLVIA code (a two-zone fire model) which is employed to simulate the fire effects in the frame of IRSN fire PSA. The objective of fire simulation is to estimate the consequences of fire in terms of failure of equipment and cables.

I. Context

In preparation of the NPPs decennial safety review, IRSN develops Level 1 Fire probabilistic safety assessment (FPSA) in order to establish its own independent analysis on the assumptions and results of the Fire PSA that is conducted by EDF which is the plant's operator. The study is an extension of the IRSN in-house developed level 1 PSA for internal events.
The IRSN FPSA needs a large amount of data mainly for the fire scenarios modeling and for conducting fire simulations as a support of FPSA. IRSN developed a focused Fire PSA on few compartments in which contains important safety components. But for each compartment selected a detailed study is done.

The following paragraphs present how these data are used in IRSN Fire PSA and how they are collected. A particular attention is given to the ventilation system data because of the in-house IRSN code named SYLVIA (a two-zone fire model) which models precisely the ventilation systems.

II. Using data in Fire PSA

II.A. IRSN Fire PSA

The general method adopted by IRSN for its FPSA follows the international state of art. IRSN main goal is to identify and to quantify the preponderant accident sequences leading to core damage. The study therefore focuses on the most critical equipment and compartments in terms of fire-related risks. The method to develop the IRSN FPSA is detailed in the reference 1.

The following picture shows a scheme of the IRSN FPSA's architecture.

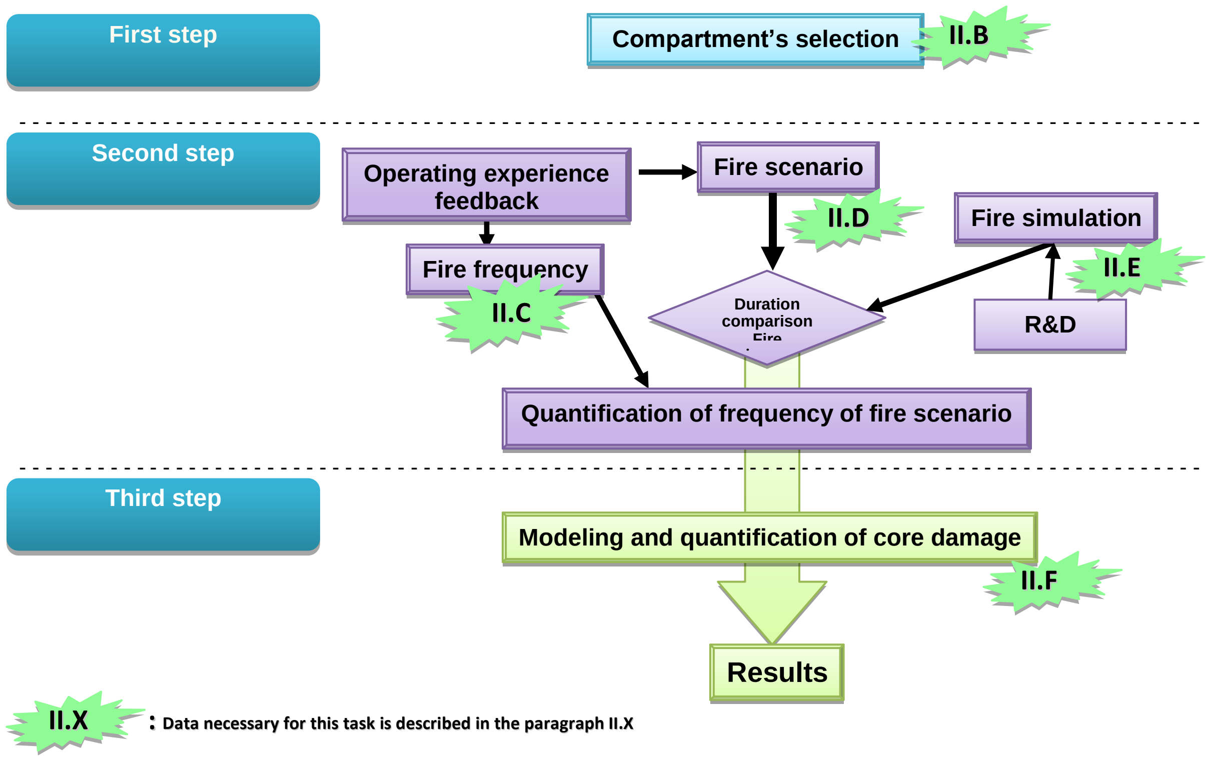

Fig. 1. This is the IRSN FPSA's architecture.

The first step's goal is to select a small number of compartments which contributes significantly to the RFC. This selection was not carried out by a systematic analysis of all the NPP's compartments but on the basis of:

- importance calculations performed using the "internal events" level 1 PSA,
- experience feedback from the development of IRSN Fire PSA.

These analyses highlighted components which are critical for the internal events level 1 PSA, and allowed identifying the fire compartments containing these components.

The second step is the elaboration and the quantification of fire scenario. A large amount of data is needed for this step, mainly for the identifying the fire scenarios and performing fire simulations.

The objective of the third step is to quantify the core damage frequency induced by a fire. The model is based on the existing "internal events" level 1 PSA. Event trees, to which an initiating event is generated after a fire, are adapted in order to incorporate the firefighting features and the specific accidental procedures which are implemented in case of fire.

The description of Data used in different steps of the Fire PSA is described in the next paragraphs. The description of data necessary for the "internal events" level 1 PSA is not included here.

II.B. Compartment's selection

For the IRSN FPSA, as a focused study was intended, the chosen method to select compartments is based on the identification of the critical targets. A target is an important safety component or a mitigation component whose failure leads to an initiating core damage event or a mitigation system failure. To identify the target contributing to the core damage frequency, importance calculation with the RiskSpectrum® PSA model for the level 1 PSA was done. The identification of target allows selecting "critical" compartment. A "critical" compartment contains targets or is adjacent to a compartment containing targets for whose failure leads to the loss of targets.

Data needed to carry out this task are, for component and cables:

- The list of component and cable in all the compartments of the NPP,
- Their safety impact in the NPP,
- Their protection against fire.

The information concerning the components and cables is given by Licensee documentation and by walkdown on the studied NPP to complement the design and operational information provided by the licensee.

II.C. Fire frequency

The compartment's fire frequency is estimated by the sum of the fire frequency by type of component included in the compartment and the frequency of transient component.

The data needed to carry out this task is:

- number of components,
- number of cable section,
- type of each component and cable in each compartment,
- number of departure of fire on each type of component,
- number of fire ignition sources on transient components in the building,
- number of rooms in the building,
- total duration of operating experience feedback.

The total duration of operating experience feedback, for the quantification of the fire frequency, is about sixteen hundred reactor years. Data is obtained by documentation and walkdown and the analysis of the experience feedback of departure of fire to identify fire with a real impact on core damage.

II.D. Fire scenario event tree and quantification

In the fire scenario event trees, the reliability of automatic fire detection and extinguishing systems has to be assessed by fault trees using failure rates derived either from analysis of French plant operating experience feedback, from the reliability data provided by the licensee, or from the international data (as for example Refs 2, 3, and 4). The failure of the compartmentalization by fire doors or fire dampers or ventilation being stopped is quantified also with FT. Data necessary to quantify those failure are obtained from fire events or from experience feedback during inspection. In particular, the failure of the compartment's fire dampers takes into account the failure of the closing mechanism and fuse failure. The failure of human action is important too. For example, the operator error to follow the fire data sheet, in which it's asked the operator to press a button in order to close some fire dampers which enable to stop fans or some fire doors, is taken into account too.

An average duration of a fire scenario is estimated, as the result of operating experience and the detection and the extinguishing configuration. The duration of the detection and the different level of extinction (by the staff, field operator intervention, plant firefighting team, or the external fire brigade) are estimated by analyzing French fire events and the duration indicated in a guideline developed by the licensee for the fire intervention which described the maximum value of delay for each level of extinction.

The data needed to carry out this task is:

- duration to perform human action (the time necessary to detect and extinguish the fire),
- failure of human action in detection and extinction (from fire event analysis).

II.E. Fire simulation

For each fire scenario, the consequences of the fire are established. The consequence is the list of the components and the electrical cables lost, in the fire compartment and, due to the fire spreading, in the adjacent compartments. To establish this list, fire simulations are necessary. IRSN develops a two-zone fire model, called SYLVIA code. It's a software system simulating fire, ventilation and aerosol contamination phenomena. The SYLVIA code allows to estimate the failure time (time when the components fail) of various components in the fire compartment and in the adjacent compartments in case of fire spreading. Fire simulation objective is to evaluate the failure time at which the components or cables fail. A large amount of information is necessary to realize fire simulations, in particular, about:

- characteristic of the ignition source: data needed for modeling ignition source is defined by using IRSN R&D (see below),
- damage criteria, defined by using IRSN R&D (see below),
- characteristics of components and cables:
    - cables (location in the compartment, characteristics, number of connectors, components to which the cable is connected, all the compartments in which the cable goes through),
    - components located inside compartment (structure, electrical trains A or B, location in the compartment),
    - specific data about panels and control desks of Control Compartment,
- compartment characteristics:
    - compartment geometry including size, openings and their location in the compartment, as soot and hot gas can be transferred by door or hole...),
    - firefighting and protection devices (fire dampers, fire extinguishing system, automatic detection),
    - fire barriers (location and characteristics),
    - component and cables inside the compartment,
- ventilation systems configuration:
    - static pressure and the flowrate inside the ducts at the main points of the ventilation system,
    - pressure inside the rooms where fire is supposed to occur and inside their adjacent rooms,
    - flowrate trough the leaks of the rooms (mainly the doors),
    - characteristics of the fans.

Data are collected by walkdown on the studied NPP to complete the design and operational information provided by the licensee. Databases were developed for describing compartments, cables and components inside compartments with their characteristics.

II.F. Quantification of core damage frequency

To quantify the core damage frequency induced by a fire event, the "internal events" level 1 PSA is adapted to take into account new functional analysis (initiating events, failure of safety and support system, spurious alarms…) and adapted probabilities for human errors (to take into account the stress due to fire situation and the accessibility to the compartment, the lack of visibility due to the smoke and the accessibility difficulties inside affected compartments).

Data to carry out this task is:

- cables (Electrical trains A or B, characteristics, number of connectors, components to which the cable is connected),
- components (electrical trains A or B, location in the compartment, their adjacent component),
- specific data about panels and control desks of Control Compartment and their adjacent panels or control desks,
- functional impact of failed components and cables due to fire,
- fire dedicated procedures for operator actions in the main control room or for local actions.

Data is provided by the licensee.

III. DATA COLLECTION

Data is collected mainly by the licensee for the studied NPP (the study was done for one NPP in particular). It's completed by IRSN with the analysis of fire events and with a plant walkdown. For specific technical information, IRSN perform dedicated R&D activities. The different means to collect Data are listed in the chapters below.

III.A. Documentation

The chapter gives a list of documentations used in FPSA.

- documentation provided by the Licensee:
  - specific documentation on elementary systems (detailed and scheme about mechanical system, and electric distribution system),
  - specific documentation on ventilation system: mainly the plans of the ventilation system and the technical documentation of the fans,
  - plan documentation and partitioning (configuration of building, fire door implementation, localization of equipment and cable, …),
  - procedures in case of fire (for example, the “FAIOp procedure” allows to do the cut-off of one electrical file failed by the fire, “FAI rondier” describes the local human action in case of fire: to verify the closure of fire door, to open extinction system valve…):
- international documentation: NUREG guidelines (probability of failure of fire doors, fire dampers, functional analysis regarding spurious alarm, fire frequency) and AIEA guidelines.

In general, IRSN uses the data provided by the Licensee. But the documentation provided by the Licensee is compared with IRSN own data and international data, Refs 2, 3, and 4.

III.B. Fire event analysis

To analyze fire events, IRSN creates a database which contains all the fires occurred in French NPP since the commissioning. The information collected to establish the Database covers the period from April 21, 1975 to December 31, 2014. It represents more than 900 fire events for 1600 years reactor. To develop the IRSN Fire PSA, 500 initiating fires are studied. The self-extinguished fire event, in others words, fire events without human actions are not selected. Data available includes the origin of the fire, the type of detection, the chronology of events, the intervention time for each level of detection and extinction, the impact on equipment and the potential consequences on safety.

The Database is used to develop statistical parameters like fire frequency of equipment, cables and transient combustible, failure rate of fire protection systems (e.g. fire dampers), the delay of the intervention teams to extinguish fire and human factors (e.g. operating, intervention, …).

III.C. IRSN R&D

IRSN investigates in fire R&D as a support of the Fire PSA. In particular, the modeling of the ignition source and the establishment of damage criteria and the pressure resistance of the compartmentalization elements are based on R&D done in IRSN.

<u>Fire modeling</u>

In FPSA, two types of ignition source are taken into account. These are the ignition sources called “cable” and “electrical cabinet”.

The modeling of “electrical cabinet” is based on experimental program leaded in IRSN called “PICSEL”. The details of the experimentation are described in the references 5, 6 and 7.

The modeling of “cable” is based on the experimental programs leaded in IRSN called “PRISME” and “PRISME 2”. The details of the experimentation are described in the references 8 and 9.

<u>Damage criteria</u>

The damage criterion is an important data of the Fire PSA. In fire simulation it allows to estimate the failure time of component and cables and to establish the consequences on NPP caused by fire.

The damage criteria of cables is established with the experimental program leaded in IRSN called “PEPSI”. The experimental program studied the short circuit on several types of cables.

The damage criterion of components was established with two experimental programs performed by IRSN. The first experimental program, called “CATHODE”, took place in a convective oven, capable of reaching temperatures of the order of 250 °C, named SIROCCO. It was only dedicated to the thermal malfunction of component. The objective of those tests was to measure critical malfunction temperatures by testing three components. The three components chosen were two relays and one circuit breaker which are, from IRSN point of view, the components of electrical cabinets the most affected by the temperature effect.

The second experiment program, called "CATHODE Suies", was performed in an experimental compartment at real-scale. The objective of the tests was to obtain elements concerning the malfunction of component of electrical cabinets in real conditions of fire. The damage by effect of soot is first and foremost searched. Four tests were performed between June 18 and October 8, 2009 in the DIVA facility, with only one type of component tested in the first experiment (the relay). The relay was positioned at two different heights (two tests at 1.80 meters and two tests at 0.55 meter) in the real compartment containing the electrical cabinet in a fire. The first analysis shows that the relay is lost at a value of temperature less conservative than the value of temperature found in the first experimental program. Another conclusion is that the relay doesn't work temporarily when some condition on temperature and some condition on soot are reached. A combination of values of two damage criteria (temperature and soot) could cause the relay's malfunction.

News series experiments, called "DANAIDE" are going on. Their objective is to verify this assumption and to quantify the values of temperature and the values of soot which components are lost.

<u>Overpressure resistance</u>

At the beginning of the ignition phase of a fire and at its extinction, an overpressure can occur. This overpressure could cause damage (or the opening) on fire dampers and fire doors. An experimental program, called "STARMANIA", was leaded in IRSN to establish the resistance criteria, in terms of overpressure, of the fire doors and fire dampers. The details of the experimentation are described in the reference 10.

III.D. Walkdown

The objective of the walkdown on the NPP was to confirm or complete the list of necessary data to develop the different steps of the Fire PSA. It allows IRSN to decide whether or not to keep a given room as a critical room. For example, the visiting of the two rooms containing the components "cooling water pumps" for trains A and B enables to show that rooms are not risky in regards to loss of the two electrical trains (A and B) for component "cooling water pumps" if the fire spreads into those rooms. The walkdown allows too to complete the collection of Data and confirming Data provided by the Licensee. This chapter gives a presentation of the walkdown done by IRSN to collect data in 21 compartments for fire simulation and it gives details about the data collected to take into account the spreading of the fire by the doors and the ventilation system.

The following table presents Data collected during the walkdown by compartment. Data are collected for each compartment, each component and each cable.

TABLE I. Data collected during the walkdown by compartment

Compartment's name	Ventilation	communication between compartment	Automatic detection et extinction system	Electrical cabinet	Other Material
Building	**Extraction**	**Doors**	**Detector**	Name	Name
Fire zone name	Width (m)	Name	Name	Type	Type
Characteristics/type of material	Height (m)	Type	Type	Ventilation	composition
Temperature (°C)	X coordinate (m)	Characteristic	Characteristic	Natural or mechanical	height (m)
Humidity level (%)	Y or Z coordinate (m)	Fire resistance	Line number	Characteristic	**Position inside compartment (scheme)**
Pressure (Pa)	Flowrate (m^3/h)	Adjacent room/room in communication	Position on the wall	Flowrate (m^3/h)	X coordinate (m)
Height (m)	**Blowing**	Closure system	X coordinate (m)	Composition	Y coordinate (m)
Wall	width (m)	Opening direction	Y or Z coordinate (m)		Z coordinate (m)
Number on the scheme ([1])	Height (m)	Flowrate (m3/h)	**Smoke exhaust system**	Weight (kg)	**Dimensions**
Thickness (m)	X coordinate (m)	Manufacturer reference	Name	Combustible weight	Width (m)
Composition	Z coordinate (m)	Dimensions	Type	Volume	Height (m)
Length (m)	Flowrate (m^3/h)	Width (m)	Hourly renewal rates (vol/h)	Number of component inside	Length (m)

Height (m)
Adjacent comportment
Name
Name of Fire zone

([1]) a compartment's scheme must be drawn to go with this data

Fire damper
Name
Identification
Type
Fire resistance
Manufacturer reference
Compartment
Extraction / blowing
Name of wall
Length (m)
width (m)
Position on the wall (name)
X coordinate (m)
Y or Z coordinate (m)

Height (m)
number of the wall containing the door
Position of door on the wall
X or Y coordinate (m)
Z coordinate (m)
Hopper
Type
Characteristic
Flowrate (m^3/h)
Name of the wall
Dimensions
Height (m)
length (m)
Position on the wall (name)t
X coordinate (m)
Y or Z coordinate (m)
Opening
Type
Characteristic
Flowrate (m^3/h)
Dimensions
Height (m)
Length (m)
Position on the wall (name)
X coordinate (m)
Y or Z coordinate (m)

Dimensions
Width (m)
Height (m)
Position on the wall
X-coordinate (m)
Y or Z coordinate (m)
Automatic extinction system
Type
Characteristic
Position on the wall (name)
X-coordinate (m)
Y-coordinate (m)
Z-coordinate (m)

Panelwiring
Terminal block
Raceway
Other component inside
Opening's dimension
Number of opening
Opening's area
Fire protection
Localization of opening
X-coordinate (m)
height (m)
Separation between two openings (m) with
Name of opening 1
Name of opening 2
Position inside the compartment
X coordinate (m)
Y coordinate (m)
Z coordinate (m)
Dimensions
Height (m)
Length (m)
Width (m)

Cable tray
Name
width (m)
Height (m)
length (m)
Position inside compartment (scheme)
X coordinate (m)
Y coordinate (m)
Z coordinate (m)
Cables
Name of cables
Cable tray reference
Fire Protection
Reference
Cable's Type (electrical support, control, measurement)
Composition
Electric tension (V)
Dimensions
Diameter (m)
Length (m)

5 persons, during 4 days, were necessary to collect all those data. 3 additional persons were dedicated to collect ventilation Data. Data concerning ventilation is used only by IRSN because the fire simulations are done with Sylvia tool in which the ventilation system is modeled as it built. Aeraulic data is necessary to model correctly this system. To remember, IRSN developed a focused Fire PSA on few compartments in which there are important safety components. But for each compartment selected a detailed study is done. Thereby, IRSN needs many data mainly for the fire scenarios modeling and for conducting fire simulations as a support of PSA.

The measurements in the ventilation system were made in several strategic locations with a pitot tube. This latter, is connected to a pressure gauge and then inserted through a small hole in the duct. Thus, for each location, flow velocity is determined in several points distributed over the cross section of the duct which allows to compute the flowrate. The static pressure is also determined by pitot tube.

To determine the leakage flowrate a hot wire anemometer was used: the flow velocity profile trough each leak (mainly the door) was determined and the leakage flowrate was computed by multiplying the average velocity by the area of the leak.

Finally, the walkdown allows to note the pressure inside the rooms concerned by the Fire PSA as well.

IV. CONCLUSIONS

In preparation of NPP decennial safety review, IRSN develops a Level 1 FPSA in order to establish its own independent opinion on the assumptions and results of the Fire PSA that is conducted by EDF which is the plant's operator.

IRSN developed a focused Fire PSA on few compartments which contains important safety components. But for each compartment selected a detailed study is done. Thereby, IRSN needs large amount of data mainly for the fire scenarios modeling and for conducting fire simulations as a support of PSA.

The objective of this article was to present how data is used in its Fire PSA and how data is collected by IRSN and how they. A particular attention is made in this article on the ventilation data because of the SYLVIA tool allows to model precisely the ventilation system as it is built. Data are collected by the analysis of the fire incidents occurred in French NPP and by walkdown on the studied NPP to complement the design and operational information provided by the Licensee.

The important quantity of data and the specificity of the data due to fire increase the difficulty to collect all data needed to develop this focused but detailed Fire PSA.

ACKNOWLEDGMENTS

Many thanks to M. Laurent AUDOUIN and M. Sylvain SUARD for their contribution to write this article.

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