APPLICATION OF FIRE PSA IN DEFINING SYSTEM RELIABILITY CRITERIA: DETECTION AND SUPPRESSION SYSTEMS IN I&C ELECTRICAL PANEL ROOM

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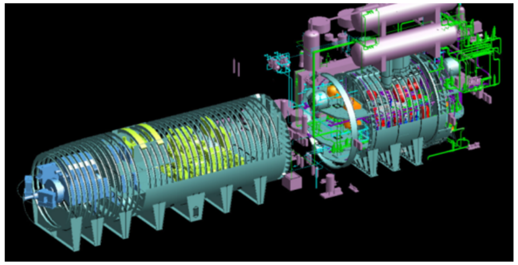
Summary

- **Motivation and goals**
- **Plant description**
- **Fire PSA methodology**
- **Development of a probabilistic model:**
  - Relevant Features of the Compartment
  - Fire Detection and Suppression Features in the Compartment
  - Fire Ignition Sources
  - Secondary Combustibles
  - Target Sets
  - Fire Scenarios
  - Fire Growth and Propagation Analysis
  - Fire Detection and Suppression Analysis
  - Suppression Probability and Scenario Frequency
- **Fire systems reliability specification**
- **Conclusions**

Motivation and goals

- **LABGENE's licensing process**
- **Presentation of a case in which PSA are used in the design process, considering a risk acceptance criteria**
- ***Estimate the risk associated to the operation:* apply the method for the detailed fire modeling presented by USNRC in NUREG/CR-6850**
- ***Definition of design requirements:* establish the reliability characteristics for the fire detection and suppression systems in two I&C electrical panel rooms**



Plant description

Table 1: CDF in the PSA Level 1

Operational Mode	Initiating Event		CDF (/yr)	Percentage of Total CDF
Full Power	Internal Events	Transients	3.99E-06	1.80%
		Loss of Coolant Accident (LOCA)	3.30E-06	1.49%
		Anticipated Transient Without SCRAM (ATWS)	3.26E-07	0.15%
		Interfacing Systems Loss of Coolant Accident (ISLOCA)	*	0.00%
	External Events	Seismic Events	*	0.00%
		Internal Fire	1.66E-04	74.75%
		Internal Flood	3.25E-06	1.46%
		Tornado	*	0.00%
		External Flood	*	0.00%
		Aircraft Crash	*	0.00%
Low Power and Shutdown	Internal Events	Shutdown	4.52E-05	20.35%
Total CDF			**2.22E-04**	**100%**

Table 2: Contribution to the CDF of Internal Fires

PAU	CDF (/yr)	Percentage of CDF for internal fires occurring in full power.
Internal Fire	**1.66E-4**	**100%**
I&C Electrical Panel Room A	8.00E-5	48.11%
I&C Electrical Panel Rooms B	8.00E-5	48.11%
Area Around Steel Containment	3.80E-6	2.29%

- **48MWth two-loop PWR (in design phase)**
- **Steel containment, surrounded by a water pool used as shielding and ultimate heat sink**
- **A confinement building houses the steel containment and a secondary system with two turbo-generators**

Fire PSA Methodology

Detailed analysis steps (NUREG/CR-6850)

Step 1: Characterize relevant features of the compartment	Step 2: Identify and characterize fire detection and suppression features	Step 3: Identify and characterize fire ignition sources	Step 4: Identify and characterize secondary combustibles	Step 5: Identify and characterize target sets
Identify the fire compartment and characterize compartment features relevant to fire propagation, target damage and operator actions; define general compartment characteristics of importance.	Identify fire detection and suppression features such as smoke and heat detectors, continuous fire watch, automatic and manual fixed suppression systems and fire brigade capabilities; characterize the operation the fire detection and suppression features in the compartment.	Identify and characterize fire ignition sources to be analyzed in terms of location within the compartment, type, size, initial intensity, growth behavior, severity/likelihood relationship, etc.; estimate frequency of ignition for the ignition source.	Identify and characterize secondary combustibles nearby fixed equipment such as cables that may be damaged by a fire in the selected ignition source.	Identify the target set relevant to each fire ignition source considered in the fire growth and damage analysis. The locations of a target set in relation to the fire ignition source, target types, failure modes, failure criteria, and other relevant information are collected.

Step 6: Define fire scenarios	Step 7: Conduct fire growth and spread analysis	Step 8: Conduct fire detection and suppression analysis	Step 9: Calculate non-suppression probability and the severity factor	Step 10: Calculate scenario frequency
Once the ignition source, secondary combustibles and targets have been identified and characterized, fire scenarios in the room can be defined, including transient and fixed ignition sources.	Select the appropriate fire modeling tool(s); analyze growth behavior of the initial fire source; analyze fire spread to secondary combustibles; analyze growth of fire in secondary combustibles; estimate the resulting adverse environmental conditions relevant to the assessment of target set damage; estimate time to target set damage.	Assess fire detection timing; assess timing, reliability, and effectiveness of fixed fire suppression systems; assess manual fire brigade response; estimate probability of fire suppression as a function of time; calculate conditional non-suppression probability for each ignition source/target set combination.	Based on the results of fire growth and spread analysis, and stochastic distributions of various input parameters of the models, the conditional probability of the fire being of the postulated severity level is established; based on the operation of the detection and suppression fire protection systems in the room, and the calculated time(s) to target damage, non-suppression probability is calculated.	Using the fire ignition frequency, non-suppression probability, and severity factor of the scenario, the overall scenario occurrence frequency can be established.

Relevant Features of the Compartment

- **The compartments to be analyzed were defined in the initial PSA – during the Fire PRA Plant Partitioning**
- **I&C Electrical Panel Rooms A and B are redundant, with identical functions (control of security systems) and characteristics (with small differences between them)**
- **These compartments were characterized with respect to:**
  - height, width and length
  - type of wall construction and thickness
  - ventilation
  - drainage
  - obstacles in the ceiling, and
  - fire detection and suppression systems

Fire Detection and Suppression Features in the Compartment

Table 4: Summary description of firefighting resources considered

Fixed fire detection and alarm system	Fixed gaseous fire suppression system	Fire brigade
• The detection and alarm system consists of photoelectric smoke detectors, manual triggers, locking switches and audio/visual indicators. • Each room has 4 detectors. • The alarm and fault information of the field elements will be sent to the central detection and alarm panel. • The central panel has an emergency power supply to maintain operation in the event of an external power failure. • The time for all control devices to be checked is less than 2 seconds and the activation time of the control modules is a maximum of 3 seconds – so the transmission time does not exceed 5 seconds (t_{sinal}). • The obscuration time required for the activation of the detector is a function of the HRR (depends on the fire evolution).	• Fixed suppression system employs the agent FK-5-1-12 – clean agent listed in NFPA 2001 [13]. • One 420-lb FK-5-1-12 cylinder will be installed for each room, plus a 250 lb cylinder for the under-floor area – being sufficient for multiple discharges. • The concentration of FK-5-1-12 used is 4.5% volumetric. • Discharge will occur after a programmable delay of up to 30 seconds (t_{delay}). • The discharge time required to achieve 95% of the minimum design concentration of the flame extinguishing agent does not exceed 10 seconds [13] ($t_{discharge}$).	• Given the success of the detection system in issuing the alarm, operators communicate the event to the brigade for manual fire fighting. • The fire brigade has its base at 1560 meters from the plant. • Operators keep brigade access clear. • The passage through the access areas and the permanence in the plant, in the event of a fire in the I&C rooms, do not cause exposure to radiation or other adverse environmental conditions besides those resulting from the burning of the materials present in the rooms. • As the plant is not in operation, for the preliminary evaluation of brigade behavior, the data of the Fire Department of the State of Sao Paulo [14] and USNRC [12][15] will be considered. Thus, the following times for the brigade response are considered: a) the communication time: 60s [14] ($t_{communication}$); b) preparation time: 90s [14] ($t_{reaction}$); c) the travel time: 140s [14] (t_{travel}), d) fire brigade effectiveness: function of the time available for combat (depends on the evolution of the fire), can be calculated by [12]: $P(success\ of\ the\ brigade) = 1 - e^{-\lambda*(time\ to\ suppress)}]$ (1) Where the suppression rate considered (λ) is given in [15] for "electrical fires", i.e., 9.80E-02 – since the equipment present in these rooms are basically cables and panels.

Fire Ignition Sources

- **Fixed sources of ignition:**
  - Panels, cables and junction boxes
  - Ignition of the panels occurs in its upper part
  - Fires that start relatively small and grow over a period of time

- **Transient sources of ignition:**
  - A solvent spillage was considered
  - It was considered a poll formation
  - Positioned next to the panels associated to the highest CCDP in each PAU
  - The frequency of ignition of transients was calculated as 5.93E-05/yr

Table 5: Peak values of HRR and their respective probabilities

Electrical panels			Transient fuels		
Peak HRR (kW)	Probability (%)	Cumulative probability (%)	Peak HRR (kW)	Probability (%)	Cumulative probability (%)
34	28.30	28.30	47	25.11	25.11
87	21.38	49.69	85	24.93	50.03
211	25.77	75.45	142	25.61	75.64
702	22.60	98.05	317	22.44	98.08
979	1.45	99.50	404	1.42	99.50
1790	0.49	99.99	650	0.49	99.99
> 1790	0.01	100.00	> 650	0.01	100.00

Table 6: Ignition frequency per panel, in year^{-1}

Description	Ignition frequency	Panels per room	Ignition frequency per panel
Self-ignited cable fires (plant wide)	3.87E-05	29	6.16E-05
Electrical panels(plant wide)	1.72E-03		
Junction Boxes(plant wide)	3.25E-05		
Ignition frequency per room	*1.79E-03*		

# Secondary Combustibles	# Target Sets

Secondary Combustibles

- Internal equipment to the electrical panels, cables and junction boxes
- Equipment internal to the panel will only combust when the fire starts inside the panel itself
- The cables inside/outside the panels are fire resistant (maintain combustion only when immersed in the flame).
- The cables outside the panels are protected by a ceramic fiber blanket, preventing contact of the cable with the flame from the burning of the electric panels and transient fuels (for a very high HRR, the propagation for all fuels in the room is considered).

Target Sets

- The PRM used to represent the behavior of the plant in the event of a fire was proposed as part of the initial Fire PSA and was not changed
- The target sets have been identified and characterized by considering the components, cables and equipment which are part of the PRM and which may fail due to the spread of the fire from the ignition sources
- The location of components and cables inside the compartments was considered

Fire Scenarios

- **The equipment associated with the initial fire source (in case of panel) is failed, independently of the reaction of the firefighting systems, at the instant of ignition**
- **The fixed gaseous suppression system, once acting, interrupts the process of fire evolution, being sufficient to reach the effective fire control**
- **The equipment affected in each scenario was defined as a function of the fire simulations (they were performed to estimate the elapsed time between the ignition and the temperature increase of the target sets, up to 65°C) – since they are affected one by one as the fire progresses.**
- **Thus, each postulated fire scenario is characterized by the position and type of the ignition source (panel or transient), by the fire intensity (defined by the HRR profile), by the group of affected equipment, and by the interval at which suppression occurs (or does not occur)**
- **CFD software: the version 5.5.3a of the Fire Dynamics Simulator (FDS) was used to model fire growth and propagation**

Fire Growth and Propagation Analysis

Figure 2: I&C Electrical Panel Rooms A – P27 ignition (after 1065s)

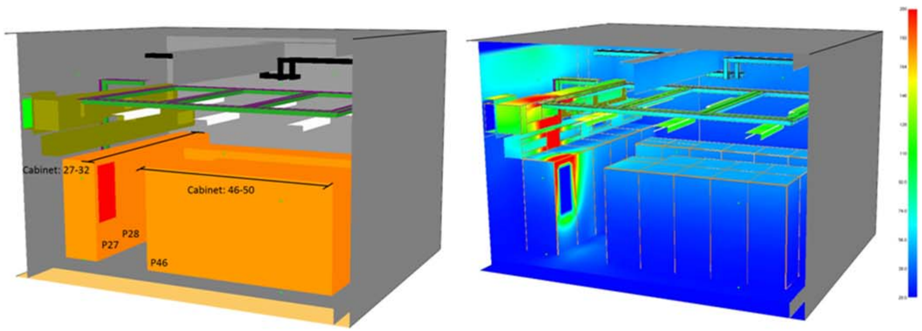


Figure 1: P27 HRR profile and oxygen concentration in the room

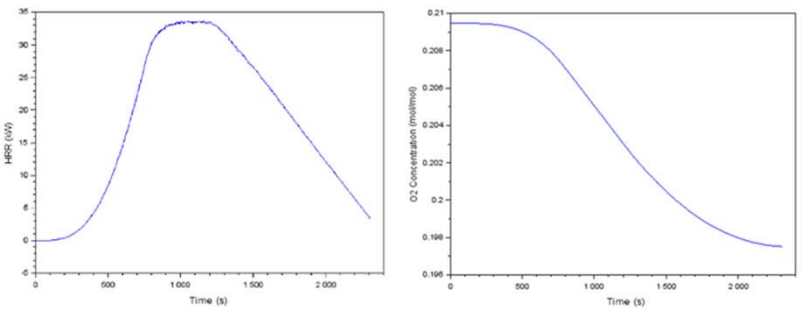


Table 7: P27 ignition – time for target sets damage

Ignition Source	Peak HRR	Time to damage (equipment reaches 65°C) [s]														Truncation*
	Cabinet	27-32			33	34	35-38	39	40	41	42-45	46-50		51	52-55	
	Panel	27	28	Other panels	33	34	Any panel	39	40	41	Any panel	46	Other panels	51	Any panel	
27	34	0	1234	-	-	-	-	-	-	-	-	-	-	-	-	-
	87	0	778	-	-	-	-	-	-	1285	-	1019	-	-	-	-
	211	0	582	-	-	-	-	-	-	751	-	670	-	-	-	-
	702	0	473	-	-	-	-	-	-	549	-	501	-	-	-	860
	979	0	458	-	-	-	-	-	-	534	-	487	-	-	-	810
	1790	0	412	-	-	-	-	-	-	458	-	440	-	-	-	690

()*This column discriminates the instant the simulation presented instability. In this work the data were used only until this time.

Fire Detection and Suppression Analysis

Figure 3: Event tree for the firefighting systems

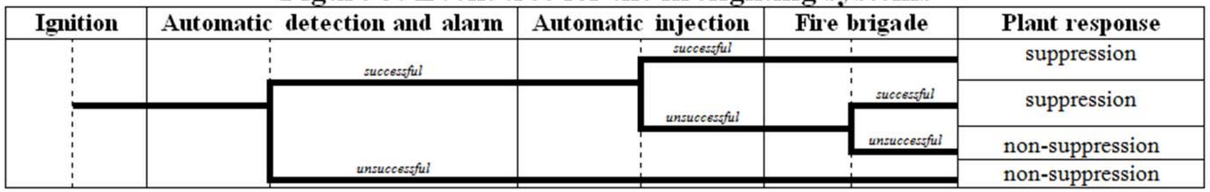


Table 8: Elapsed time for the suppression system performs the discharge

Fuel	Fixed						Transient					
Peak HRR [kW]	34	87	211	702	979	1790	47	85	142	317	404	650
$t_{detection}$ [s]	631	463	346	233	209	171	35	13	19	5	4	2
t_{sinal} [s]	5						5					
t_{delay} [s]	30						30					
$t_{discharge}$ [s]	10						10					
t_{total} [s]	676	508	391	278	254	216	80	58	64	50	49	47

Table 9: Elapsed time for the fire brigade response

Fuel	Fixed						Transient					
Peak HRR [kW]	34	87	211	702	979	1790	47	85	142	317	404	650
t_{alarm} [s]	636	468	351	238	214	176	40	18	24	10	9	7
$t_{communication}$ [s]	60						60					
$t_{raction}$ [s]	90						90					
t_{travel} [s]	140						140					
$t_{brigade}$ [s]	926	758	641	528	504	466	330	308	314	300	299	297

Suppression Probability and Scenario Frequency

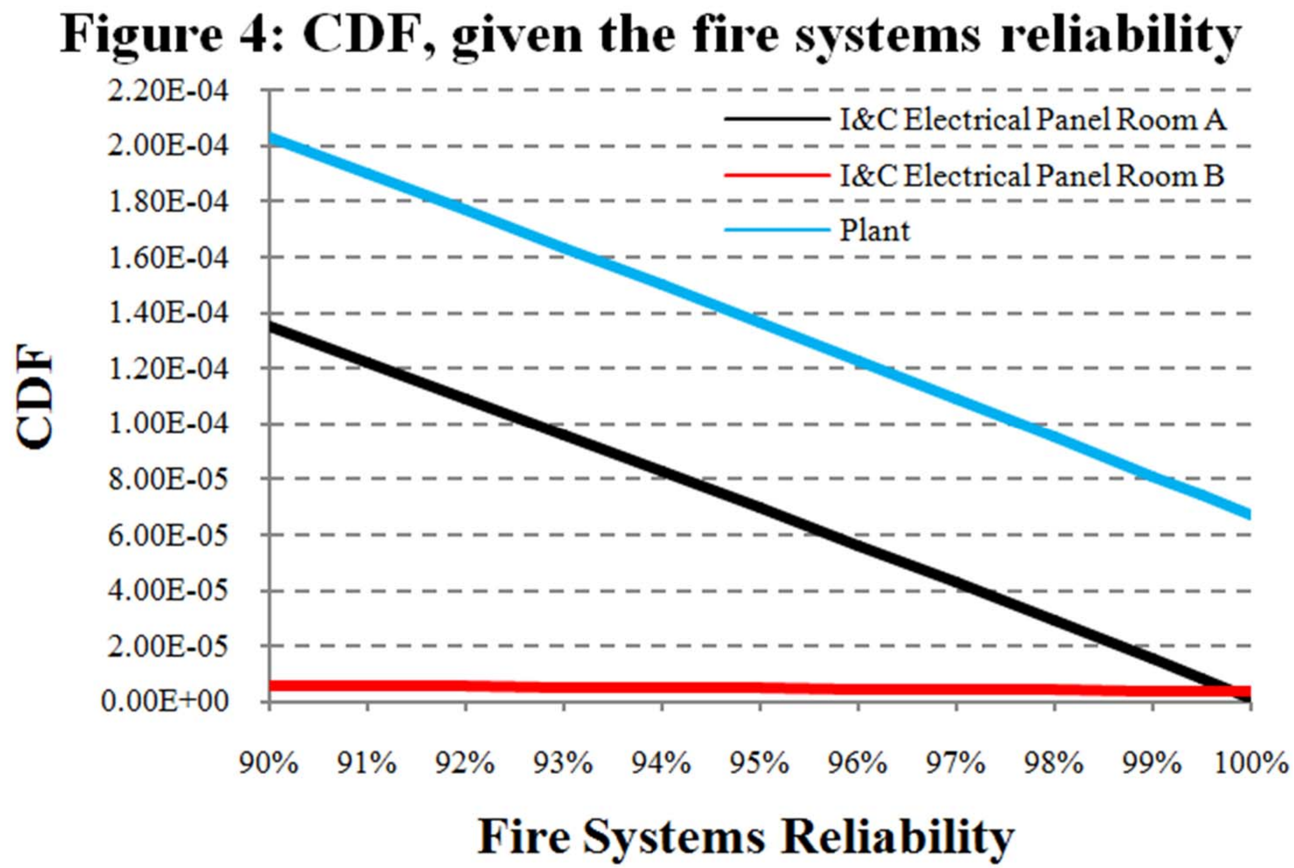
Table 10: CDF for the scenarios with ignition in Panel P27

Ignition Source	*Ignition Frequency (see Table 6)*	*Peak HRR [kW]*	*Peak HRR probability (see Table 5)*	*Affected equipment*	*Interval at which suppression occurs [s] (see Table 7)*		*Time for automatic combat, in [s] (see Table 8)*	*Time for the fire brigade response beginning, in [s] (see Table 9)*	*Probability of suppression in the interval*	*Frequency of damage to affected equipment*	*CCDP*	*CDF per scenario*
					begin	*end*						
27	6.16E-05	34	2.83E-01	27-32	0	N/A	676	926	1.00E+00	1.74E-05	7.33E-04	1.28E-08
27	6.16E-05	87	2.14E-01	27-32	0	1019	508	758	9.19E-01	1.21E-05	7.33E-04	8.87E-09
27	6.16E-05	87	2.14E-01	27-32 e 46-50	1019	1285	508	758	1.09E-02	1.44E-07	1.26E-03	1.81E-10
27	6.16E-05	87	2.14E-01	27-32, 46-50 e 41	>1285		508	758	7.01E-02	9.23E-07	1.71E-03	1.58E-09

Table 11: Probability of the suppression for panel P27 (Peak HRR: 87 kW)

Interval	Possible mutually exclusive events in the interval	P(*suppression in the interval*)
$[0s, 1019s[$	a) The success of detection (95%) and automatic injection (95%) occur, or; b) The success of detection (95%), failure of injection (5%), and success of the brigade (with time available for combat equal to 1019s minus 758s) occurs;	95%*95% + 95%*5%* $[1-e^{-0.098*(1019-758)}]$ = 9.19E-01
$[1019s, 1285s[$	c) Detection success (95%), injection failure (5%), and success of the brigade occurs between 1019s and 1295s;	95%*5%* $\{[1-e^{-0.098*(1285-758)}]-[1-e^{-0.098*(1019-758)}]\}$ = 1.09E-02
$[1285s, \infty[$	d) Detection failure (5%), or; e) Successful detection (95%), injection failure (5%), and brigade success occurs after 1295s.	5% + 95%*5%* $\{1-[1-e^{-0.098*(1285-758)}]\}$ = 7.01E-02

FIRE SYSTEMS RELIABILITY SPECIFICATION



Conclusions

- Based on the method for the detailed fire modeling presented by USNRC in NUREG/CR-6850, a probabilistic model was developed and fed with data from simulations performed in a CFD model, and the CCDP obtained from the PRM of the Fire PSA for the plant
- It was possible to develop a probabilistic model to assist in the specification of the fire fighting systems for the I&C rooms
- This probabilistic model also can be used to compose the Fire PSA of the plant

Thank you