JENSEN HUGHES

Advancing the Science of Safety

APPLICATIONS OF RISK INFORMED FIRE PROTECTION

FRANCISCO JOGLAR | **January 2021**

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Introduction

Agenda

+ A brief technical overview of risk and fire risk (10 min)
+ Recent advances in Fire Risk Technology (5 min)
+ Ongoing SFPE activities on Fire Risk Assessment (5 min)
+ Examples of Risk Informed Applications (30 min)

Introduction

What is Fire Risk

Quantitative or qualitative measure of fire incident loss potential in terms of both the event likelihood and aggregate consequences.

Fire Hazards Analysis → Scenario Development →

Scenario	Frequency	Consequences	Risk
Scenario 1	λ_1	C_1	$= \lambda_1 \cdot C_1$
Scenario 2	λ_2	C_2	$= \lambda_2 \cdot C_2$
Scenario 3	λ_3	C_3	$= \lambda_3 \cdot C_3$
Scenario 4	λ_4	C_4	$= \lambda_4 \cdot C_4$
The total risk is the summation of the product of λ and C			$= \sum \lambda_i \cdot C_i$

About fire scenarios:

1. Fire scenarios are the building blocks of a fire risk model. How many scenarios? Which scenarios?
2. Is a set of elements characterizing a fire event***: Ignition Source, Intervening combustibles, Detection and suppression, Consequences***

Introduction: Fire Risk Modeling

We are interested in modeling the key elements of a fire protection program

Fire Prevention (e.g., combustible controls, house keeping, hotwork procedures, etc.)

Detection and Suppression (e.g., fixed auto or manual systems, brigade, etc.)

Passive Fire Protection (e.g., fire walls, fire doors, etc.)

Life Safety (e.g., emergency procedures, egress)

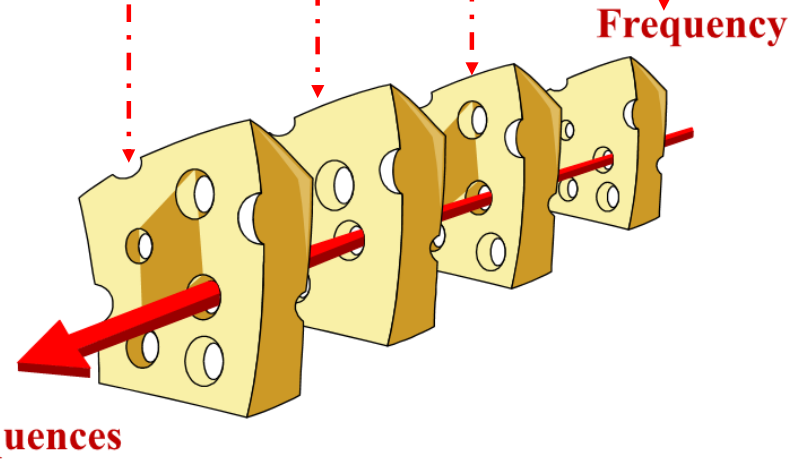
System Safety* (e.g., safe shutdown in a NPP)

$$R = \sum_{S} \lambda_i \cdot P_i \cdot C_i$$

Frequency

Mitigation Strategies

Consequences

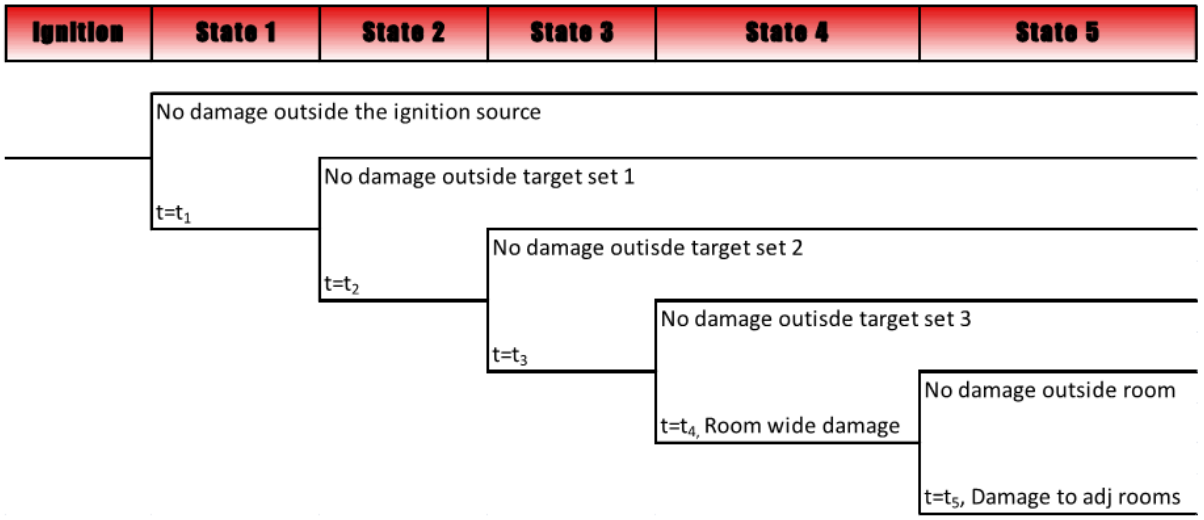


Introduction: Fire Risk Modeling

Often Used Modeling Tools

1. Event tree: Represents the “accident sequence” by modeling the chronology of the event
2. Fault tree: Used when modeling systems and subsystems

Event Tree Representing a Fire Scenario Progression



Introduction: Fire Risk Modeling

Often Used Modeling Tools

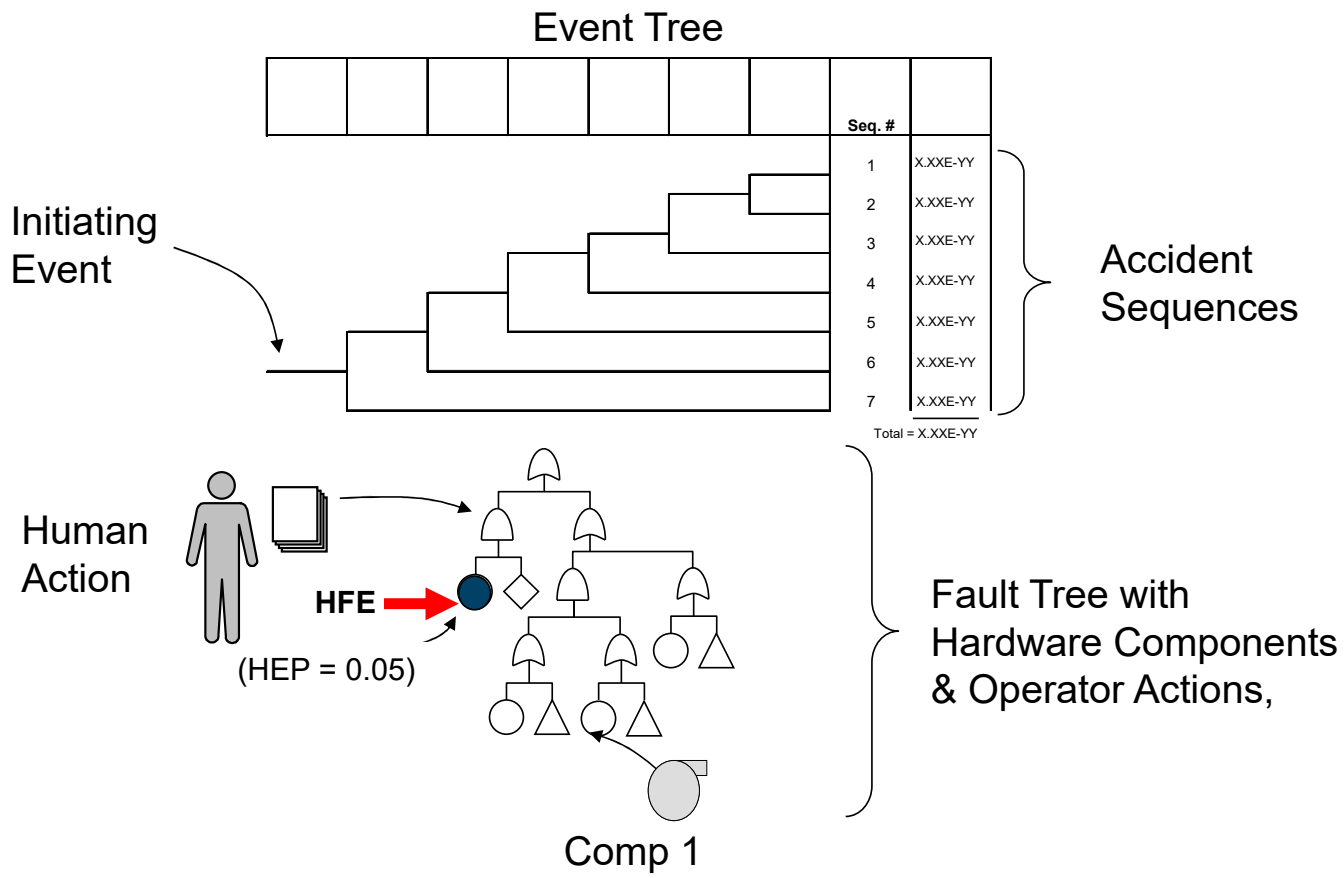
Event Tree Representing Detection/Suppression Strategy

	Prompt		Automatic		Manual				
Fire	Detection	Suppression	Detection	Suppression	Detection	Fire Brigade	Sequence	End State	Pr(non-suppression)
FI	PD	PS	AD	AS	MD	FB			
1	0	0					A	Not valid	
		1		0.98			B	Not valid	
				0.02		0.78	C	Not valid	
						0.22	D	Not valid	
	1		0.95	0.98			E	OK	
				0.02		0.76	F	OK	
						0.24	G	NS	4.6E-03
			0.05	0.98			H	OK	
				0.02		0	I	OK	
						1	J	NS	1.0E-03
								Total	**4.7E-03**

Introduction: Fire Risk Modeling

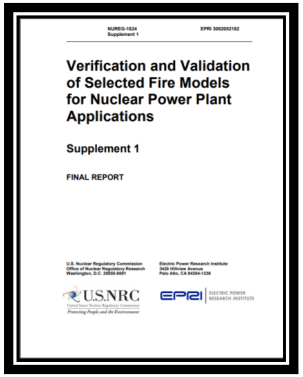
Often Used Modeling Tools

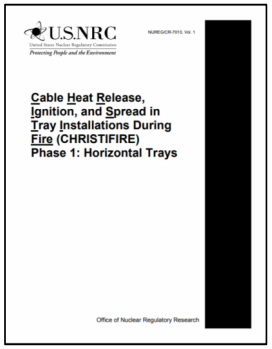
Event Tree & Fault Tree Combinations

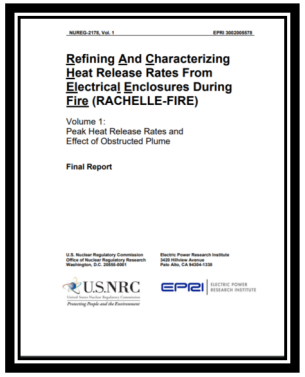


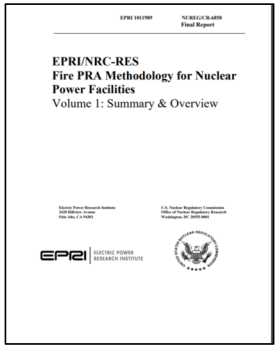
Fire Risk Assessment Research in the Nuclear Industry (2000-2020)

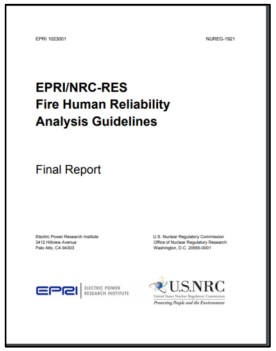
Research and Practical Information for Applications In and Out of the Nuclear Industry

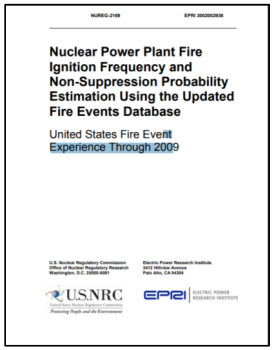












- NUREG/CR-6850 and Supp 1: Full Fire PRA methodology. Implemented in almost all NPP in US
- NUREG-1824, Supp 1: Verification and validation for fire models (FDS, CFAST and Eng Calcs)
- NUREG-2178, Vol 1 & 2: Heat release rates for electrical cabinets based on recent testing and additional modeling guidance
- NUREG-2233: Heat release rates for realistic transient combustibles based on recent testing

- NUREG/CR-7010: Guidance on modeling cable fires
- NUREG-2169: Fire ignition frequencies for typical ignition sources
- NUREG-1921: Fire human reliability analysis
- NUREG-7150: Electrical short circuit probabilities
- And there is more!

Ongoing SFPE Activities

- In Progress: SFPE Engineering Guide on Fire Risk Assessment (2nd Edition)
  - Major update from the 1st Edition
  - Currently resolving public comments
  - Quantitative & Qualitative examples consistent with NFPA 551 (Guide for the Evaluation of Fire Risk Assessments)
- In Progress: Next edition of the SFPE Handbook
  - Updated structure and information on fire risk assessment
  - Section on fundamentals and theory
  - Section on applications (e.g., transportation, nuclear power plants, etc.)

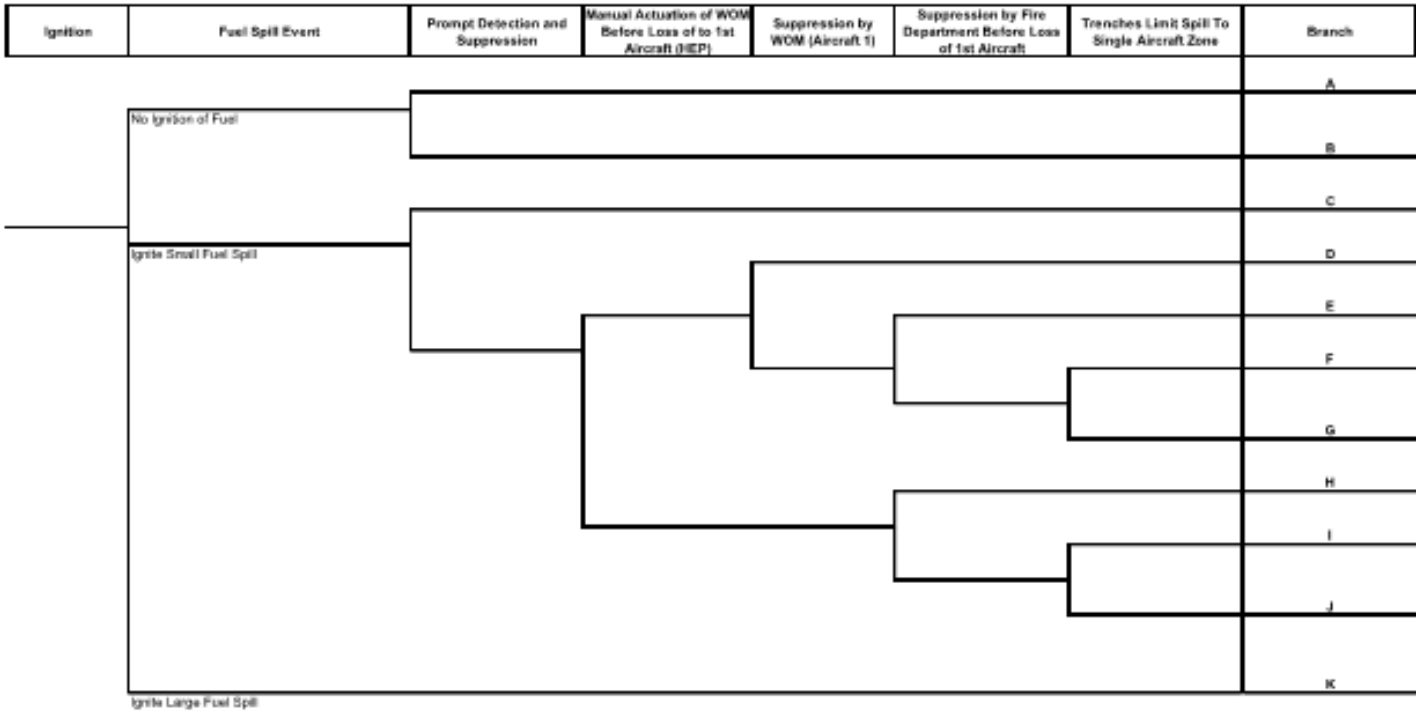
Applications: Nuclear Power Plants

- Almost all of the commercial nuclear power plants have completed Fire PRAs
- Resolved a number of non compliances in “older facilities” that were not designed for “new” regulations. It is noted that this was a very expensive effort.
- Fire PRAs are currently used in risk informed applications in efforts to reduce operating cost

$$CDF = \sum_i \lambda_i \cdot SF_i \cdot P_{NS-i} \cdot P_{BF} \cdot CCDP_i$$

- λ is the ignition source frequency
- SF is the severity factor
  - The probability of a fire severe enough to generate damage outside the ignition source
- P_{NS} is the non suppression probability
  - The probability that suppression activities limit the fire to a predefined damage state
- P_{BF} is the barrier failure probability
- CCDP is the conditional core damage probability

Applications: Aircraft Hangars



Applications: Batter Energy Storage Systems (BESS)

- On April 19, 2019, a BESS unit owned experienced a thermal runaway event. The facility was equipped with a clean agent suppression system similar to that found at several BESS sites.
- Venting, Water based, Clean Agents

Applications: NAVY

- Risk tools are useful to informed:
  - Operational facilities with limited possibilities on fire protection systems that can be installed an operated
  - Design of new facilities
  - Assist in highlighting importance of fire prevention and manual suppression strategies and training

Ignition	Prompt Detection	Prompt Supp	Team Detection	Team Supp	Fire Brigade	Sequence	Outcome
						1	Suppression successful
	Success					2	Suppression successful
						3	Suppression successful
						4	**Suppression failure**
						5	Suppression successful
	Failure					6	Suppression successful
						7	**Suppression failure**
					Probability of 0	8	Fire not detected
					Probability of 1.0	9	**Suppression failure**
						Prob:	Sum(Supp failure branches)

Some Concluding Remarks

- Hazard analysis VS Risk analysis
- Significant research that may be useful outside risk has been conducted over the last 20 years
- Design VS Built facilities
- The role of the AHJ and code compliance
- The importance of the accident sequence
- Updated SFPE Guide on Fire Risk Assessment coming up!